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3D Concrete Printing Technology: Enhancing Productivity in the South African Construction Industry – Exploring the Benefits, Barriers, and Improvement Strategies

by
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Abstract

Provided its multitude of benefits, 3D Concrete Printing (3DCP) technology has the potential to transform the South African construction industry, with specific reference to the building sector, by revolutionizing the current traditional construction techniques. However, to fully realize the full potential of this innovative technology, it is of utmost importance to have a comprehensive awareness of its benefits, an understanding of the potential barriers associated with its adoption, and strategic measures tailored to smoothly integrate it into the construction industry. Therefore, this research study aims to comprehensively explore the benefits, barriers, and strategic measures associated with the adoption and implementation of 3DCP technology within the South African construction industry.

The research process began by conducting a comprehensive literature study, which delved deep into assessing the current state of 3DCP technology and its application in the construction industry. To fully comprehend the complex dynamics of this technology, a strong foundation was established through the literature study by synthesizing and consolidating information and conceptual frameworks. This assessment process provided insights into the unique potential opportunities and challenges that could be faced by the South African construction industry as it navigates its way into adopting and implementing 3DCP technology as one of the mainstream construction techniques. In addition to this, a survey questionnaire was distributed to various professionals working in the South African construction industry to collect detailed primary data. The survey questionnaire was well designed to probe their perceptions regarding this technology within the South African construction industry given its unique context. The collected data was subjected to a thorough and systematic analysis by applying both descriptive and inferential statistical techniques to determine how the industry perceives the benefits, barriers, and improvement strategies associated with the adoption of 3DCP technology. This systematic analysis yielded a wealth of information that highlighted common trends and main themes that shape the landscape of 3DCP technology adoption within the South African construction industry.

The findings of this research highlighted that the South African construction industry is fraught with substantial barriers despite being ripe and well-positioned to embrace the transformative potential of 3DCP technology. The high initial investment was consistently highlighted as the most prevalent barrier, followed by the absence of 3DCP technology experts and the lack of government incentives and support. However, the strategic measures formulated to mitigate these barriers were highly appraised by the professionals, further highlighting the readiness of the industry to leverage this innovative construction technology.

Ultimately, these research findings have implications that go beyond mere academic research as they are of significant value for stakeholders with a vested interest in the adoption and successful implementation of 3DCP technology in the South African construction industry. The research study promotes the application of sustainable and efficient innovative construction techniques, tailored to enhance productivity, and encourage environmentally friendly practices, thereby guiding the industry towards a future driven by innovation, competitiveness, and steady growth.

Opsomming

Met die vele voordele het 3D Concrete Printing (3DCP) tegnologie die potensiaal om die Suid-Afrikaanse konstruksiebedryf te transformeer, met spesifieke verwysing na die bousektor, deur 'n rewolusie van die huidige tradisionele konstruksietegnieke. Om die volle potensiaal van hierdie innoverende tegnologie ten volle te verwesenlik, is dit egter uiters belangrik om 'n omvattende bewustheid van die voordele daarvan te hê, 'n begrip van die moontlike hindernisse wat verband hou met die aanvaarding daarvan, en strategiese maatreëls wat aangepas is om dit vlot in die konstruksiebedryf te integreer. Daarom het hierdie navorsingstudie ten doel om die voordele, hindernisse en strategiese maatreëls wat verband hou met die aanvaarding en implementering van 3DCP-tegnologie binne die Suid-Afrikaanse konstruksiebedryf omvattend te ondersoek.

Die navorsingsproses het begin met die uitvoering van 'n omvattende literatuurstudie wat diep in die beoordeling van die huidige stand van 3DCP-tegnologie en die toepassing daarvan in die konstruksiebedryf verdiep het. Om die komplekse dinamika van hierdie tegnologie ten volle te begryp, is 'n sterk grondslag gevestig deur die literatuurstudie deur inligting en konseptuele raamwerke te sintetiseer en te konsolideer. Hierdie beoordelingsproses het insigte gegee oor die unieke moontlike geleenthede en uitdagings wat die Suid-Afrikaanse konstruksiebedryf in die gesig gestaar kon word, aangesien dit sy weg na die aanvaarding en implementering van 3DCP-tegnologie as een kon doen van die hoofstroom konstruksietegnieke. Daarbenewens is 'n vraelys oor die opname versprei aan verskillende professionele persone wat in die Suid-Afrikaanse konstruksiebedryf werk om gedetailleerde primêre data te versamel. Die opname-vraelys is goed ontwerp om hul persepsies rakende hierdie tegnologie binne die Suid-Afrikaanse konstruksiebedryf te ondersoek, gegewe die unieke konteks. Die versamelde data is aan 'n deeglike en stelselmatige ontleding onderwerp deur beide beskrywende en inferensier statistiese tegnieke toe te pas om te bepaal hoe die bedryf die voordele, hindernisse waarneem, en verbeteringstrategieë wat verband hou met die aanvaarding van 3DCP-tegnologie. Hierdie stelselmatige ontleding het 'n magdom inligting opgelewer wat algemene neigings en hooftemas beklemtoon wat die landskap van 3DCP-tegnologie-aanvaarding binne die Suid-Afrikaanse konstruksiebedryf vorm.

Die bevindinge van hierdie navorsing het benadruk dat die Suid-Afrikaanse konstruksiebedryf met aansienlike hindernisse belaai is, ondanks die feit dat dit ryp en goed geposisioneer is om die transformatiewe potensiaal van 3DCP-tegnologie te omhels. Die hoë aanvanklike belegging is deurgaans uitgelig as die algemeenste hindernis, gevolg deur die afwesigheid van 3DCP-tegnologie-kundiges en die gebrek aan regeringsaansporings en -ondersteuning. Die strategiese maatreëls wat geformuleer is om hierdie hindernisse te versag, is egter baie beoordeel deur die

professionele persone, wat die bereidwilligheid van die bedryf om hierdie innoverende konstruksietegnologie te benut, verder beklemtoon.

Uiteindelik, hierdie navorsingsbevindinge het implikasies wat bloot akademiese navorsing oorskry, aangesien dit van groot waarde is vir belanghebbendes met 'n gevestigde belang in die aanvaarding en suksesvolle implementering van 3DCP-tegnologie in die Suide Afrika-konstruksiebedryf. Die navorsingstudie bevorder die toepassing van volhoubare en doeltreffende innoverende konstruksietegnieke, wat aangepas is om produktiwiteit te bevorder en omgewingsvriendelike praktyke aan te moedig en sodoende die bedryf te lei na 'n toekoms wat gedryf word deur innovasie, mededingendheid, en bestendige groei.

Acknowledgement

I would like to dedicate this thesis to the living memory of my lovely late father, Mahlwaadibona, who has been supporting and encouraging me to pursue my academic journey as an Engineer. Even when I was doubting myself, he continued to push me to chase my dreams. I would also like to dedicate this research work to my loving mother and siblings, who continued to love and support me consistently through my academic journey. Their support has been instrumental in my success.

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Chapter 1: Introduction

1.1. Background

The construction industry is one of the most significant role players in driving the growth of the economy through infrastructural development and socio-economic development through creation of employment opportunities, more particularly in developing countries such as South Africa (Giang *et al.*, 2011). However, the current techniques applied in construction such as in-situ are often confronted with various challenges that contribute towards low levels of productivity, high construction material wastage, and minimal customization options (Delgado Camacho *et al.*, 2018). These challenges amongst others include construction projects running behind schedules, construction budgets being exceeded, leading to cost overruns, and multiple defects found in some construction projects. To overcome these challenges and promote sustainable construction practices, new innovative construction technologies need to be explored. 3DCP technology is one of the newly emerging construction techniques that has significantly gained global attention. As a potential game-changing technique, often referred to as additive manufacturing in construction, 3DCP technology involves the application of various concrete mixes specifically designed to fabricate three-dimensional structures layer-by-layer (Shakor *et al.*, 2017).

Given the inherent benefits associated with its application, the South African construction industry is well positioned to be revolutionized through the adoption and implementation of 3DCP technology in order address the challenges it is confronted with, thereby enhancing productivity. Furthermore, the integration of this innovative technology aligns with the South African goals to achieve sustainable development and economic transformation (Kolade *et al.*, 2022). While 3DCP technology has demonstrated its potential in various global context, there is a necessity to conduct a thorough investigation on its specific implications and suitability within the South African construction industry.

Numerous studies have investigated various aspects of 3DCP technology in construction. However, there has not yet been any research studies conducted specifically on the adoption and implementation of this innovative technology in the South African construction industry despite its promising potential. As a result, this research study aims to bridge this gap in the existing literature by exploring the benefits, potential barriers, and improvement strategies associated with the adoption of 3DCP technology within the construction industry, with specific reference to the building sector. By conducting an extensive investigation into the adoption of this technology, this research aims to contribute towards equipping the industry professionals, policymakers, and researchers with valuable insights to smoothly facilitated informed decision making and effective application of 3DCP technology. Moreover, this research process is not only focused on the identification of the inherent benefits associated with 3DCP technology, but also uncovers the barriers that could potentially hinder its adoption. Therefore, this makes it easier for the industry professionals to understand the technology's potential to enhance productivity, thereby aiding policymakers to develop targeted strategic measures and interventions aimed at addressing these challenges and facilitate the widespread adoption and implementation of 3DCP technology in the South African construction industry.

1.2. Problem Statement

Despite the inherent benefits associated with the application of 3DCP technology, it has not yet been widely adopted in the South African construction industry due to several existing factors that hinder the industry's ability to fully harness its potential. These factors include, but not limited to, the lack of awareness about this technology and its application in the construction industry. Therefore, it is of utmost importance to uncover and extensively understand these potential barriers and delve into the exploration of various strategic measures tailored to overcome these barriers, thereby paving the way for enhancing productivity in the construction industry.

1.3. Research Objectives

The primary aim and specific objectives of this research study are as follows:

- Identify the potential benefits of the application of 3DCP technology in the South African construction industry.
- Identify the key potential barriers to the adoption of 3DCP technology in the South African construction industry.
- Explore effective improvement strategies for promoting the widespread adoption of 3DCP technology in the South African construction industry.
- Evaluate the potential impact of 3DCP technology on productivity, sustainability, and innovation in the South African construction industry.

1.4. Scope and Limitations

The cope of this research study was limited to the adoption and implementation of 3DCP technology within the South African construction industry, with special reference to the building sector. The study primarily relied upon the data collected through a survey questionnaire sent out to various construction industry professionals such as project managers, consulting engineers, government officials, researchers/academics, amongst others. One of the critical limiting factors that must be acknowledged is that this research study was only limited to the South African context and does not cover the nuances and challenges faced in other countries. Furthermore, it must be acknowledged that this study was solely based on the perceptions, experiences, and opinions provided by the survey respondents and does not…due to the unavailability of data for comparison as there are no existing projects completed using 3DCP technology in South Africa.

1.5. Significance of the Study

The insightful information provided by the findings of this research study contributes to the existing body of knowledge about 3DCP technology in the construction industry, with specific reference to the South African context. Insights into the benefits, potential barriers, and improvement strategies linked to the adoption of 3DCP technology that could potentially serve as a guide for the stakeholders in the industry, policymakers, and researchers are provided in this study.

Through the identification of its benefits through conducting an extensive literature review, the proposition value of 3DCP technology is highlighted in this study. Furthermore, exploring barriers that could potentially hinder the adoption of this technology will shed light on the challenges that need to be addressed. In addition, the strategic measures tailored to facilitate the smooth integration of this technology into the South African construction industry will serve as recommended measures to the stakeholders and policy makers. This could lead to productivity improvement, sustainability, and innovation within the construction industry thereby supporting infrastructure development goals of the country.

1.6. Structure of the Thesis

The thesis is comprised of five chapters and the composition of each chapter is outlined as follows:

Chapter 1 provides the introduction to the research study, the statement of the research problem, research objectives, research scope and limitations as well as the significance of the research study.

Chapter 2 provides a comprehensive literature review carried out for this research study. The chapter begins by introducing 3DCP technology along with the definition and principles, evolution, and advancement as well as the global trends of this technology. The chapter goes further into identifying the potential benefits, barriers, and improvement strategies associated with the adoption of 3DCP technology in the South African construction industry. In addition, the chapter ends with a summary of the valuable insights gained through conducting a comprehensive literature study and acknowledges the existing gaps.

Chapter 3 outlines the methodology adopted to carry out the research study. The chapter provides a discussion of all the necessary key steps followed during the research process such as data collection, data analysis, ethical considerations, and validity of the research study.

Chapter 4 presents the data obtained from the survey questionnaire, analysis of the data and the discussion of the results considering the main objectives of the research study. The chapter begins by presenting the background, profiles of the respondents, the respondents' familiarity with 3DCP technology, and the mean ratings of the benefits, barriers, and improvement strategies associated with the adoption of this technology. The chapter goes further into making a comparison of the research findings with the existing literature and ends by discussing the implications of this research study for the South Africa construction industry.

Chapter 5 presents the conclusions derived from the research study and provides recommendations for future research studies.

Chapter 2: Literature Review

2.1. Overview

This chapter examines the existing literature to provide insight into 3DCP technology. The chapter begins by introducing 3DCP technology along with the definition and principles, evolution, and advancement as well as the global trends of this technology. The chapter goes further into identifying the potential benefits, barriers, and improvement strategies associated with the adoption of 3DCP technology in the South African construction industry. In addition, the chapter ends with a summary of the valuable insights gained through conducting a comprehensive literature study and acknowledges the existing gaps.

2.2. Introduction to 3DCP Technology

3DCP technology, sometimes referred to as additive manufacturing, is one of the newly emerging innovative technologies in the construction industry, tailored to fabricate building components one layer at a time (Ngo *et al.*, 2018). Figure 2.1 presents an image of a 3D concrete printer in the concrete laboratory at Stellenbosch University. This section presents a broad overview of the fundamental principles of this innovative technology as well as its advancements and current state in the industry.

Figure 2.1: 3D concrete printer at the Stellenbosch University concrete laboratory.

2.2.1. Definition and Principles

3DCP technology, sometimes referred to as additive manufacturing in construction, is one of the newly emerging innovative construction techniques tailored to fabricate three-dimensional concrete structures one layer at a time (Ngo *et al.*, 2018). This technology offers design engineers and architects the unprecedented freedom to design and construct complex geometries into physical structures (Classen et al., 2020).

The application of 3DCP technology, which includes the deposition of construction materials, one layer at a time, to fabricate desired concrete structures, is derived from the fundamental principles of additive manufacturing (Classen et al., 2020). This technology is heavily dependent upon advanced computer-aided design (CAD) software to generate precise digital models that can be further converted into readable instructions for the 3D printing machine to begin with the printing process (Khan, et al., 2020).

2.2.2. Evolution and Advancements

3DCP technology was derived directly from the prototype of additive manufacturing as one of the newly emerging innovative techniques in the construction industry (Classen et al., 2020). Over the years, this technology has, through in-depth research and development, rapidly evolved because of technological advancements as the construction industry moves closer to adopting new innovative ways of fabricating architectural structures.

2.2.2.1. Historical Development of Additive Manufacturing in Construction

In the 1980s, the concept of additive manufacturing, which includes several techniques of layer-by-layer material deposition, first emerged (Germaini *et al.*, 2022). However, in the early 2000s, its application in the construction industry began to gain traction (Germaini *et al.*, 2022). Initial experiments were centred around small-scale projects, such as the printing of building elements and prototypes(Tu *et al.*, 2023). Furthermore, researchers and industry leaders began to investigate various printing techniques and materials as the technology developed to address challenges unique to the construction industry. As a result, specialized 3DCP techniques such as extrusion-based printing, powder-based printing, and binder jetting, were developed(Tu *et al.*, 2023).

2.2.2.2. Techniques and Approaches in 3DCP

There are three techniques and approaches in the field of 3DCP technology namely, extrusion-based printing, powder-based printing, and binder jetting. To build a structure with extrusion-based printing, concrete must be carefully extruded through a nozzle or robotic arm and deposited one layer at a time (Nerella et al., 2019). This approach of 3DCP is the most applied and commonly accepted. The final form is determined by the movement of the printer during the continuous extrusion (Nerella et al., 2019). For powder-based printing, a binding agent is used to selectively solidify a powdered substance, such as cement or a cementitious mixture (Labonnote *et al.*, 2016). The powder is deposited one layer at a time by the printer, and then a binding solution is added selectively to harden specific areas (Labonnote *et al.*, 2016). This technique could produce greater resolution details and complex and intricate designs (Labonnote *et al.*, 2016).

Binder jetting is a technique that includes deposition on a liquid binder, one layer at a time, to a powdered substance such as sand or cement (Rodríguez-González *et al.*, 2022). The binder functions as an adhesive, joining the constituent parts to create a stable structure (Rodríguez-González *et al.*, 2022). This method is suitable for both large-scale building projects and small-scale prototypes as it offers flexibility in material choices (Rodríguez-González *et al.*, 2022).

Researchers and industry experts are investigating cutting-edge materials, such as fibre-reinforced concrete, lightweight aggregates, and sustainable substitutes, to improve the characteristics and functionality of printed structures as the technology progresses (Bazli *et al.*, 2023). Furthermore, advancements in robotics, automation, and digital design software continue to boost the effectiveness and scalability of 3DCP technology (Bazli *et al.*, 2023). Moreover, the advancement of 3DCP technology has greatly improved the construction industry. Despite this technology offering various benefits that have the potential to improve the construction industry for the better, there are several challenges that need to be addressed.

2.2.3. Current State of 3DCP Technology

The level of 3DCP technology currently shows significant advancements and applications with promising potential. With continued research and development work and technological advancements, 3DCP technology has become a practical construction technique that has the potential to completely change how infrastructure is designed and constructed. Figure 2.2 depicts the world's largest 3D-printed building, a two-storey office in Dubai, built by Apis Cor, effectively showcasing the current capabilities of 3DCP technology.

Figure 2.2 3D-printed two-storey office in Dubai built by Apis Cor.

2.2.3.1. Advancements in Materials

The development of specialized concrete materials and mixes made specifically for additive manufacturing is a major component of the current state of 3DCP technology. Different concrete compositions that offer greater printability, structural integrity, and durability have been investigated by researchers and industry specialists. Fibre-reinforced concrete, and environmentally friendly materials such as recycled aggregates and geopolymers are all examples of this (Uddin *et al.*, 2023). The material advancements have increased the potential of 3DCP technology, allowing the creation of intricate shapes, stronger materials, and better performance (Uddin *et al.*, 2023).

2.2.3.2. Progress in Printing Techniques

The status of 3DCP technology has witnessed significant advancements in printing techniques. Greater flexibility, accuracy, and speed in the printing process have been made possible by the advancement of robotic arm systems, gantry-based printers, and contour crafting techniques (Zhang *et al.*, 2018). The technological advancements make it possible to build larger structures, deposit materials with greater accuracy, and incorporate reinforcement elements during the printing process (Zhang *et al.*, 2018). Intricate architectural features and minute details may now be printed, thanks to advancements in nozzle designs and extrusion systems that have improved material flow control (Zhang *et al.*, 2018).

2.2.3.3. Automation and Digital Design Tools

The level of 3DCP technology today has been considerably impacted by the combination of automation and digital design tools. To fabricate complicated geometries and improve structural performance, computational methods, parametric design tools, and Building Information Modelling (BIM) software are being applied (He *et al.*, 2021). Through the application of these tools, actual structures may be created from digital models with little to no error, increasing printing efficiency (He *et al.*, 2021). Real-time monitoring and feedback systems are also included, which guarantees quality control and permits adjustments during the printing process, improving accuracy and reducing waste (He *et al.*, 2021).

2.2.3.4. Applications and Demonstrations

Numerous 3DCP applications and demonstrations have been accomplished in recent years. These encompass everything from small-scale prototypes and pavilions to full-scale buildings and structural elements (Lowke *et al.*, 2018). The building of homes, bridges, and even the potential for extraterrestrial colonies are notable initiatives (Lowke *et al.*, 2018). These practical applications have demonstrated the viability and potential of 3DCP technology in resolving building-related challenges, lowering costs, and shortening project lead times. Figure 2.3 illustrates the construction of a two-storey office in Dubai, utilizing 3D printing technology. This remarkable structure, built by Apis Cor, vividly demonstrates the current applications of 3DCP technology.

Figure 2.3: Construction of a Two-Storey Office in Dubai Using 3D Printing Technology by Apis Cor.

2.3. Benefits of 3DCP Technology in Construction

3DCP technology offers numerous benefits that have the potential to revolutionize the construction industry (Buchanan *et al*., 2019). These benefits cover a range of construction-related aspects, including faster construction speed, cost-effectiveness, reduced construction material wastage, reduced health and safety hazards, improved customization, improved precision and accuracy, improved quality control, and improved performance in housing delivery. 3DCP technology has brought about significant improvements through leveraging the unique capabilities of additive manufacturing in these areas (Buchanan et al, 2019).

2.3.1. Faster Construction Speed

The potential of 3DCP technology to significantly increase the speed of construction, revolutionizing traditional methods of construction, is one of the primary benefits of the technology in the construction industry (Alami *et al.*, 2023). By taking full advantage of the principles of additive manufacturing, 3DCP technology makes it possible to fabricate structures quickly and automatically, outpacing the speed restrictions associated with traditional construction techniques (Alami *et al.*, 2023). The application of this technology eliminates the need to labour-intensive processes like formwork installation and manual placement of concrete, which saves a significant amount of time (Tay *et al*., 2019). Furthermore, 3DCP technology accelerates construction speed by eliminating formwork (Tay *et al*., 2019). Traditional construction methods often call for the labour- and time-intensive fabrication of temporary moulds (Buchanan *et al*., 2019). By directly fabricating structures one layer at a time, 3DCP technology eliminates the requirement for extensive formwork setup. Buildings and infrastructure may be constructed in a fraction of the time it would take the application of traditional methods due to the precise deposition of concrete, guided by robotic arms or gantry systems (Tay et al., 2019).

Additionally, the automated nature of 3DCP technology eliminates the need for manual labour, hastening the construction process (Bazli *et al.*, 2023). Concrete deposition may be accurately controlled by robotic systems, ensuring quick and reliable material placement (Bazli *et al.*, 2023). It is possible to construct optimised structures with intricate architectural characteristics and complex geometries by combining digital design tools with parametric modelling (Nguyen-Van *et al.*, 2023). 3DCP technology contributes to accelerated construction speed, by optimising the design, thereby making it an appealing option for projects with constrained schedules or pressing housing demands (Leschok *et al.*, 2023). Therefore, it is crucial to keep in mind that the speed at which 3DCP technology may speed up construction might vary depending on several variables, including the size of the project, the complexity of the building, the chosen printing technique, and the characteristics of the printing materials. To fully benefit from rapid construction speed, the printing process must be carefully planned, coordinated, and optimised. Future improvements in construction time will be made possible by even larger advances in printing speed, thanks to continuous research and development in 3DCP technology.

2.3.2. Cost-effectiveness

A major benefit of 3DCP technology in the construction industry is cost-effectiveness (Muhammad Salman *et al.*, 2021). The construction technique provides potential cost reductions throughout the construction process by utilising the capabilities of additive manufacturing (Muhammad Salman *et al.*, 2021). The reduction of construction material waste is one of the main ways that 3DCP technology improves cost-effectiveness. Due to issues including inaccurate measurements, incorrect formwork assembly, and inefficient material consumption, traditional construction methods frequently result in considerable construction material waste (Muhammad Salman *et al.*, 2021). Contrarily, 3DCP technology allows for accurate and controlled material deposition, minimising waste, and maximising resource utilisation (Shakor *et al.*, 2017). This construction technique decreases the consumption of construction materials, resulting in cost savings and increased resource efficiency by only placing concrete where it is required to create the desired structure.

Additionally, the application of 3DCP technology may result in lower labour costs (Gebler et al., 2014) per constructed unit. Manual labour is frequently used in conventional construction techniques for activities including assembling formwork, placing materials, and finishing. These labour-intensive tasks might account for a sizable chunk of the cost of construction (Gebler et al., 2014). The automated aspect of the 3DCP process lessens the need for manual labour. Concrete may be deposited autonomously using robotic systems or gantry-based printers, which eliminates the requirement for a large workforce (Gebler et al., 2014). This automation improves overall cost-effectiveness by lowering labour expenses and the possibility of human error.

Although 3DCP technology has the potential to be cost-effective, it is crucial to consider several aspects that may affect how economically viable its adoption will be overall. These aspects include the price of the original investment, ongoing expenses, material choice, project size, and regional market circumstances. To establish the cost-effectiveness of implementing 3DCP technology in a particular building project, a thorough cost analysis and evaluation of the individual project needs are required.

2.3.3. Reduced Construction Material Wastage

The application of 3DCP technology has the potential to significantly reduce construction material waste (Khan et al., 2021). Due to inaccurate measurements, incorrect formwork assembly, and inefficient material consumption, traditional building methods sometimes result in significant material waste (Khan et al., 2021). This waste has detrimental effects on the environment in addition to raising project expenses. Contrarily, 3DCP technology overcomes these challenges by allowing for accurate and controlled material deposition (Khan et al., 2021). This construction technique applies concrete one layer at a time, in accordance with a specified design, using computer-controlled robotic arms or gantry-based printers (Germaini *et al.*, 2022). Only the necessary amount of concrete is used for the construction project, thanks to this degree of accuracy, which also prevents the need for extra material. Construction projects may save a lot of money by using 3DCP to reduce material waste and the expenses associated with material procurement and disposal.

Furthermore, the capacity to recycle and reuse construction materials on-site is another benefit of 3DCP technology (Nerella et al., 2019). Better material management is made possible by the capacity to construct structures one layer at a time. When alterations or adjustments are required, 3DCP technology enables effective adaptation without producing a lot of waste (Nerella et al., 2019). Recycling and reusing materials that are left over from one building project can be utilised in subsequent prints, which saves on raw resources. This closed-loop method helps the building sector use resources sustainably and has a lower total environmental effect. Moreover, the accuracy of 3DCP technology implies that complex geometries and detailed patterns may be realised without producing a lot of waste (Nerella et al., 2019). Material loss results from the frequent need to cut and shape materials to suit design requirements in traditional building methods. The actual structure is created immediately from the computer design file via 3DCP technology, negating the need for further material processing. This simplified procedure reduces material waste and raises total resource productivity (Delgado Camacho *et al.*, 2018).

Therefore, it is crucial to keep in mind that the degree of material waste reduction brought about by 3DCP technology might vary based on several variables, such as project complexity, design optimisation, material choice, and building methods. When evaluating the possible advantages of decreased material wastage, it is also important to consider financial factors, technological viability, and material availability. A thorough investigation and consideration of the project needs will yield insightful information on the financial and environmental benefits of implementing 3DCP technology in the construction industry.

2.3.4. Reduced Health and Safety Hazards

The adoption and implementation of 3DCP technology in construction has the potential to bring about significant reduction of health and safety hazards. The hard labour, heavy lifting of construction equipment, and exposure to hazardous conditions that are commonly associated with traditional construction methods can put construction workers at risk of accidents, injuries, and long-term health issues (Filip et al., 2023). However, the advantages offered by 3DCP technology aid in lessens health and safety hazards. Construction workers' risk of musculoskeletal injuries is minimized automated systems applied in 3DCP technology that reduce physically demanding activities like heavy lifting and repetitive motions (Filip et al., 2023). Furthermore, this technology lessens the need for extensive formwork and scaffolding, which decreases the risk of falls, injuries and even loss of life during installation and removal.

3DCP processes are regulated and automated, which minimize construction workers' exposure to hazardous materials and gases (Filip et al., 2023). Exposure to risk is reduced by careful management of the concrete mixtures and deposition, thereby making construction sites to have better health and safety conditions. While following safety procedures, performing routine maintenance, and comprehensive training are necessary for safe operation, it is crucial to control any risks related to equipment failure, software errors, and operator training requirements (Filip et al., 2023). Applying 3DCP technology is safe and effective when the construction industry stakeholders are engaged, risk assessments are carried out, and industry norms and regulations are followed.

2.3.5. Improved Customization

One of the main benefits of 3DCP technology in the construction industry is improved customization. Complex design and customized building components may often only be realised to a limited extent with the application of traditional construction methods (Wu et al., 2016). However, the capacity to design and construct intricate and customized structures is greatly improved by 3DCP technology. Designers may produce complex and distinctive shapes that can be instantly turned into 3D-printed concrete structures through the application of computer-aided design (CAD) software (Wu et al., 2016). Complex and intricate geometries and patterns, and architectural details that would be difficult or time-consuming to build using traditional construction methods can be easily created as 3DCP technology has precise control over the concrete deposition process.

Additionally, on-site customisation using 3DCP technology permits for real-time alterations and tweaks to the design during the construction process (Wu et al., 2016). The flexibility is useful, especially for projects such as architectural facades, structures, and ornamental parts where customization is a priority. Architects, design engineers, and construction professionals now have new opportunities to experiment with inventive and distinctive designs, pushing the limits of what is feasible in construction, thanks to the expanded customisation capacity of 3DCP technology (Wu et al., 2016). To ensure the effective implementation of customised features utilising 3DCP technology, it is crucial to consider variables such as material compatibility, structural integrity, and design optimization.

2.3.6. Improved Precision and Accuracy

One of the significant benefits of 3DCP technology in the construction industry is improved precision and accuracy. The application of 3DCP technology enables a highly regulated and automated process that assures precise and accurate outcomes, in contrast to conventional construction techniques that rely upon manual labour and human intervention (Henneh et al., 2021). Furthermore, 3DCP technology can perfectly deposit the concrete material one layer at a time, adhering to the exact parameters set in the digital design, thanks to the application of advanced robotics and computer-controlled systems (Bazli *et al.*, 2023). The fluctuations and mistakes that might occur during manual construction processes are eliminated at this degree of precision, which increases the dimensional correctness and consistency of the end product.

In projects requiring close tolerances, intricate details, and complex structural components, the capacity to produce precise geometries and accurate measurements is beneficial (Bazli *et al.*, 2023). It increases the overall quality of construction, reduces waste and rework, and promotes the structural reliability and functionality of the printed components. Additionally, the accuracy of 3DCP technology enables effective material use, minimising waste and maximizing resource utilisation. Reducing the environmental effect associated with excessive material usage, helps to encourage sustainable construction practices in addition to economic savings.

2.3.7. Improved Quality Control

One of the significant benefits of 3DCP technology in the construction industry is improved quality control. A better level of quality assurance is possible due to the sophisticated capabilities of 3DCP technology, which provide increased monitoring and control throughout the whole construction process (Buswell *et al.*, 2022). Traditional construction techniques frequently rely upon manual inspections and quality control processes, which are prone to human error as they can be subjective. However, 3DCP technology makes use of automated systems and sensors that enable real-time monitoring and feedback (Buswell *et al.*, 2022). By doing this, it is ensured that the printed structure adheres to the specified standards and requirements.

Furthermore, sensors monitor variables during the printing process, including material flow, temperature, and layer thickness, giving constant data about the accuracy and uniformity of the printed components (Bazli *et al.*, 2023). Any variations or irregularities can be quickly detected, enabling quick corrections to guarantee the intended quality. Moreover, the ability to immediately include quality control measures in the digital design and printing is another benefit of 3DCP technology (Labonnote *et al.*, 2016). This includes having the option to insert reinforcement elements or embedded sensors, such as fibre-optic sensors or structural monitoring devices, which can continuously monitor the performance and integrity of the structure.

Overall, enhanced quality control in 3DCP technology guarantees that the printed structures comply with the necessary requirements, minimising flaws, rework, and costly mistakes. It improves the reliability and durability of the construction components, which helps construction projects succeed.

2.3.8. Improved Performance in Housing Delivery

One of the major benefits of 3DCP technology is improved performance in housing delivery. The construction industry can overcome numerous obstacles and improve the effectiveness of housing projects by adopting this cutting-edge technology (Bazli *et al.*, 2023). Often, traditional construction techniques run into problems including time limitations, high costs of labour, and construction material waste, which can delay the timely delivery of housing units (Bazli *et al.*, 2023). However, a potential solution to these challenges is offered by 3DCP technology.

Rapid construction is made possible by the application of 3DCP technology as labour-intensive processes such as setting up formwork and pouring concrete by hand are no longer necessary (Bazli *et al.*, 2023). Due to the significant reduction in construction time, housing projects can now be completed more quickly. Furthermore, the exacting and automated features of 3DCP technology guarantee consistency in quality and accuracy in the process of building housing units. In addition, 3DCP technology enables optimization of construction material usage thereby reducing waste and enhancing resource efficiency. The versatility and adaptability of housing construction can be further improved by the capacity of this technology to print complicated geometries and customized designs (Lowke *et al.*, 2018). This creates opportunities for architectural designs and more customization options that can accommodate different homeowner needs and preferences.

Overall, the application of 3DCP technology has enhanced the performance of the housing delivery process, resulting in quicker construction, cost savings, less material waste, and greater design flexibility. These benefits help to meet the urgent need for affordable and sustainable housing solutions by facilitating the timely and effective delivery of housing units.

2.4. Barriers to the Adoption of 3D Concrete Printing Technology

The adoption and implementation of 3DCP technology within the construction industry does not only come with potential benefits but it is accompanied by various barriers that hinder its widespread application. It is therefore of utmost importance to understand these barriers to address them to facilitate the successful integration of this innovative technology.

2.4.1. High Initial Investment

One of the major barriers to the broader application of 3DCP technology is the expensive initial expenditure requirement. Investing in this cutting-edge printing technology, setting up the appropriate infrastructure, and employing and training the workforce could be expensive (Adaloudis et al., 2021). Construction companies, especially the smaller ones, may be discouraged from investing in this technology due to the associated cost load. There are several strategies that could be explored to get beyond this barrier. First, looking into joint ventures and partnerships with technology experts and providers can assist in sharing the expenses and resources, making the initial expenditure more reasonable and manageable. The government can play a significant role in encouraging the adoption of 3DCP technology by providing financial incentives, grants, or subsidies. Furthermore, to lower the total cost associated with this technology, there is a necessity for research and development activities to concentrate on developing affordable printing materials and techniques. The application of 3DCP technology can be promoted thereby increasing its use and benefits in the construction industry by minimizing the large initial investment barrier.

In addition, it is of paramount importance to emphasise the potential long-term financial benefits that 3DCP technology can offer. This technology has the potential to result in cost savings throughout the course of the project, even if the initial expenditure may be larger in comparison with the traditional construction methods. Furthermore, 3DCP technology has the potential to increase the efficiency and cost-effectiveness of a project by allowing for quicker construction, less material waste, and better-quality control. The necessity of educating stakeholders in the construction industry about the long-term benefits and the potential return on investment from the use of this technology cannot be overstated. To get over the alleged financial barriers and persuade the construction companies to adopt and embrace it as a viable and affordable construction technique, it could be helpful to provide successful case studies of real-world applications.

2.4.2. Lack of Government Incentives and Support

One of the fundamental potential barriers to the widespread adoption of 3DCP technology in the construction industry is the absence of government incentives and support (Opawole et al., 2022). The growth of technological innovations in the construction industry is greatly influenced by government initiatives and legislation. Construction companies could be reluctant to make the necessary investments in the infrastructure and equipment for putting 3DCP technology into practice without sufficient assistance, such as financial incentives, subsidies, tax benefits, and regulatory frameworks. Furthermore, the government must understand the potential of 3DCP technology and its inherent benefits for the construction industry to address this barrier. The government ought to create, through comprehensive plans and regulations, a way to encourage the adoption of this technology. Offering financial incentives, such as grants or subsidies, can help defray the upfront expenses of purchasing and putting 3DCP technology into use (Opawole et al., 2022). Governments can set regulations, standards, and certification procedures for 3DCP technology in conjunction with academic institutions, business professionals, and construction firms. Governments may encourage construction companies to adopt this cutting-edge technology and get beyond the lack of incentives and assistance by creating a welcoming atmosphere.

The government may also promote stakeholder engagement and information sharing by setting up conferences, workshops, and training sessions centred on 3DCP technology. These programmes may contribute to increasing public knowledge of the advantages, potential, and recommended uses of the technology. Governments may play a key role in overcoming the lack of incentives and support, boosting the use and integration of 3DCP technology in building projects, by actively engaging with the construction sector and establishing a supportive environment.

2.4.3. Lack of Design Codes and Standards

A fundamental barrier to the widespread application of 3DCP technology in the construction is the absence of design codes and standards (Alabbasi *et al.*, 2023). Design codes and standards offer guidelines and specifications that guarantee safety, durability, and quality of constructed structures. The current design standards codes and standards, however, may not sufficiently handle the special concerns and requirements of this cutting-edge construction technique in the context of 3DCP technology. It is essential to create certain design codes and standards that consider the nuances of 3DCP technology to overcome this barrier. To create thorough regulations that cover the whole 3D printing process, from material selection and structural design to printing settings and post-processing techniques, industry players, it is essential for research institutions, and regulatory agencies to work together (Alabbasi *et al.*, 2023). To ensure the effective and secure implementation of 3DCP technology, these coded and standards should take into consideration elements such as material qualities, layering procedures, structural integrity, and quality control measures (Alabbasi *et al.*, 2023).

Furthermore, there is a necessity to conduct further research and development to improve the understanding of the behaviour as well as the performance of the printed structures. This involves researching the structural integrity, fire resistance, and long-term durability of printed components. It is feasible to develop robust design codes and standards that offer clear guidelines for architects, engineers, and construction professionals working with 3DCP technology by investing in research and engaging with industry specialists (Alabbasi *et al.*, 2023). In the end, the creation of thorough design codes and standards will inspire industry trust and encourage the widespread implementation of this revolutionary construction technique.

2.4.4. Risk Aversion

The implementation of 3DCP technology in the construction sector is significantly hampered by risk aversion (Martens *et al.*, 2020). Due to perceived dangers and uncertainties surrounding its implementation, many stakeholders, including project owners, developers, and contractors, may be reluctant to use this novel technology(Alami *et al.*, 2023). Risk aversion among business professionals is a result of the novelty and unfamiliarity of 3DCP technology as well as possible concerns about project delays, cost overruns, and quality problems (Martens *et al.*, 2020). It is essential to address the perceived dangers through proactive risk management methods and good communication to get over this barrier. For each project requiring 3DCP technology, detailed risk analyses and feasibility studies must be conducted. Stakeholders may reduce the perceived risks connected with this new building approach by identifying possible risks and creating measures for mitigating them.

Additionally, reducing risk aversion may be accomplished through spreading the word and fostering information exchange about successful case studies and best practises in 3DCP technology. Building confidence and trust in the technology may be accomplished by emphasising good experiences by early adopters, sharing success stories, and highlighting the advantages.

Platforms for cross-industry collaboration and information exchange, such as conferences, seminars, and forums, can make it easier to share experiences, lessons learned, and risk management techniques, building an atmosphere that is conducive to the adoption of 3DCP technology.

2.4.5. Limited Awareness of Benefits

One of the fundamental barriers to the broad adoption of 3DCP technology in the construction industry is the lack of public understanding of its benefits (Pessoa *et al.*, 2020). The potential benefits and positive impacts that this technology can offer to construction projects may not be fully understood by many parties, including project owners, architects, engineers, and contractors. This lack of knowledge may be caused by several things, including a lack of exposure to case studies that have been effective, a lack of information being widely disseminated, and a lack of training and educational opportunities. (Pessoa *et al.*, 2020) It is important to concentrate on raising awareness and disseminating information about the benefits of 3DCP technology to overcome this barrier. This might be accomplished through focused marketing initiatives, business gatherings, workshops, and seminars with a focus on presenting noteworthy projects and emphasising the practical advantages of this technology. By planning knowledge-sharing events and creating instructional resources, cooperation between academic institutions, industry groups, and technology suppliers may raise awareness.

In addition, a further way to close the knowledge gap and raise awareness among aspiring construction professionals is to incorporate 3DCP technology into academic curricula and professional training programmes. The construction industry can apply 3DCP technology more widely by expanding stakeholder awareness of its benefits, potentials, and best practises through extensive education and training opportunities.

2.4.6. Lack of 3D Concrete Printing Technology Experts

The shortage of professionals with specialised knowledge and abilities in the construction industry is a significant barrier to the adoption of 3DCP technology in the construction industry (Maqbool *et al.*, 2023). Since this technology is still in its infancy and evolving stage, there is a limited number of experts who have the skills necessary to successfully implement and apply 3DCP technology in construction projects. The effective adoption and integration of the technology may be hampered by this scarcity of experienced specialists since it calls for a certain set of skills and knowledge (Maqbool *et al.*, 2023).

To address this problem, efforts should be undertaken to create a work that is knowledgeable about and skilled in the application of 3DCP technology. This can be accomplished by creating training programmes, certification courses, and educational initiatives that concentrate on disseminating expertise in this field (Maqbool *et al.*, 2023). The development and delivery of thorough training programmes that cover a variety of aspects of 3DCP technology, such as design principles, material selection, equipment operation, quality control, and troubleshooting, can be aided by collaborations between academic institutions, industry organisations, and technology providers.

Furthermore, fostering research and development initiatives in the field of 3DCP technology can also help to increase the level of competence in the construction industry. Collaborations between academic institutions, industrial stakeholders, and technology developers may foster innovation, information sharing, and the creation of fresh perspectives and best practises. The construction industry can overcome the obstacle of a shortage of specialists in 3DCP technology and realise the full potential of this cutting-edge construction technique by making investments in the development of a skilled workforce and fostering a culture of continuous learning and information sharing.

2.4.7. Fragmentation of Supply Chain and Procurement Systems

Fragmentation of the supply chain and procurement system is one of the major barriers to the widespread use of 3DCP technology in the construction industry (Beltagui *et al.*, 2020). The intricate network of suppliers, subcontractors, and procurement processes that traditional construction practises can entail may not be well adapted to meet the needs of 3DCP technology (Beltagui *et al.*, 2020). The necessity for specialised materials, tools, and processes might make it difficult to integrate this technology into the current supply chains.

Streamlining and optimising the supply chain and procurement procedures specifically designed for 3DCP technology is to get over this barrier (Beltagui *et al.*, 2020). To guarantee the quality and availability of the materials and components required for 3D concrete printing, this may include locating and collaborating with suppliers that specialise in doing so. Additionally, developing direct connections with 3DCP equipment suppliers may facilitate the procurement process and guarantee the timely purchase of the necessary equipment.

The effective application of 3DCP technology also depends on cooperation and coordination amongst supply chain players (Beltagui *et al.*, 2020). To promote communication and knowledge exchange, this involves working with architects, engineers, contractors, material suppliers, and equipment makers. The procurement process may be streamlined and flawless coordination between project participants can be achieved by implementing digital platforms or technologies that enable real-time cooperation and information exchange. The construction sector may fully utilise 3DCP technology and reap its benefits in terms of efficiency, cost-effectiveness, and quality by addressing the fragmentation of the supply chain and procurement procedures.

2.4.8. Concerns about Job Loss for Unskilled Workers

One of the barriers to the adoption of 3DCP technology in the construction industry is concerns about the loss of jobs for unskilled workers (Tabassum *et al.*, 2023). There are concerns that when technologies automate some construction processes, they may result in a decline in the demand for manual labour and adversely affect job opportunities for unskilled workers (Tabassum *et al.*, 2023). This challenge is especially significant in areas where the construction industry serves as a major source of employment for a larger segment of the local workforce.

A multifaceted strategy that emphasises the need for worker retraining and upskilling is needed to address these issues (Tabassum *et al.*, 2023). Unskilled people can acquire the skills needed to cooperate with and supplement 3DCP technology by being given access to training programmes and educational initiatives. This may entail receiving instruction on how to use and maintain printing machinery, quality control procedures, and other pertinent duties. A smooth transition for workers whose responsibilities may be impacted using 3DCP technology may also be achieved by putting in place measures to facilitate job transition and career development, such as job placement programmes, apprenticeships, or vocational training.

It is imperative that industry stakeholders, such as construction companies, governments, and labour unions, actively address and mitigate the concerns about job loss. The industry may provide alternative employment prospects by highlighting the possibility for new job development in fields like operating and maintaining 3DCP equipment or working in connected industries like material manufacturing or digital design. Additionally, creating a welcoming workplace that encourages lifetime learning and ongoing skill development may provide employees the confidence they need to adapt to new technology and embrace new possibilities in the developing construction industry.

2.4.9. Unpredictable Weather Conditions

The unpredictable weather conditions are considered one of the obstacles to the adoption of 3DCP technology (Ambily *et al.*, 2023). As with many other countries, South Africa is faced with climate inconsistencies such as intense rainfalls, storms, sweltering heat waves, and fluctuating humidity levels. The quality and durability of structures constructed with 3DCP technology could potentially be affected by these weather variables, which have a significant on construction operations (Sun *et al.*, 2017).

The unforeseen unpleasant weather events frequently cause delays in construction project delivery, which could consequently lead to compromising the integrity of the structure as well as project cost escalation (James *et al.*, 2014). Furthermore, it is of paramount importance to address these weather-related concerns since some 3DCP technology processes are vulnerable to the humidity and temperature of the surrounding air conditions (Han *et al.*, 2022). As a result, the construction industry stakeholders should embark on a journey to tailor strategic measures such as having weather-monitoring processes to predict unfavourable weather conditions, thereby making it easier for project managers to plan printing operations for times when the conditions are more favourable. In addition, developing weather-resistant printing materials and tools can improve the adaptability of the technology to various weather conditions.

2.4.10. Limited Production Size

3DCP technology has restrictions in terms of the sizes of products it can produce, and this presents a potential barrier that requires consideration by the South African construction industry in the journey of adopting this technology (Sun *et al.*, 2017). Despite the technology's capability to produce customized designs, the physical obstacles of the printing equipment restrict the sizes and scope of printable concrete structures, notwithstanding the benefits of design flexibility and custom creations brought forth by 3DCP technology (Sun *et al.*, 2017). Furthermore, this barrier could potentially make the adoption of 3DCP technology uneasy for large-scale construction projects. This barrier calls for the exploration of advancing this technology further to achieve project objectives. To overcome this barrier, manufacturers should focus on advancing 3D printers such that they are able to print more substantial structures. Construction project managers, design engineers, and architects must simultaneously evaluate the suitability of 3DCP technology for projects considering their scope and complexity.

2.5. Improvement Strategies for Implementing 3D Concrete Printing Technology

To address the barriers mentioned in section 2.3 and maximize the potential benefits, the implantation of 3DCP technology in the construction industry requires the adoption of effective improvement strategies to address the identified barriers and maximize the potential benefits.

The successful adoption and implementation of this cutting-edge technology can be facilitated by the following improvement techniques.

2.5.1. Providing Subsidies or Financial Incentives for Adoption

The provision of subsidies or financial incentives is one of the key improvement strategies for implementing 3DCP technology in the construction industry. By encouraging construction companies to embrace the potential benefits of 3DCP technology, this strategy aims to lessen the financial burden that comes with its adoption. The government together with the industry stakeholders can encourage the widespread adoption and implementation of this innovative technology and hasten its integration into construction practices by providing financial support. Furthermore, direct financial aid or tax incentives are only two examples of the many ways subsidies or financial incentives can be presented (Sepasgozar *et al.*, 2023). Grants or subsidies offered to construction companies for the procurement of 3DCP equipment or the implantation of the necessary infrastructure are examples of financial aid. These financial subsidies assist in offsetting the high initial investment costs related to procuring 3DCP equipment, specialised software, and materials by lowering the upfront expenditures. This increases the likelihood that construction companies will think about and invest in this cutting-edge technology.

Contrarily, tax incentives can include tax deductions or credits for costs associated with the acquisition and operations of 3DCP equipment, research and development initiatives, or training programmes for the workforce (Sepasgozar *et al.*, 2023). Construction companies are encouraged to explore and invest in 3DCP technology as an instrument to enhance their competitiveness and efficiency by lowering the tax burden. Such financial incentives encourage construction companies to take the risk and deploy 3DCP technology by not only assisting with the financial barrier but also sending a message of support and commitment from the government and industry stakeholders.

In addition, the provision of subsidies or financial incentives for adopting 3DCP technology creates an enabling environment that encourages its adoption in the construction industry. This tactic encourages construction companies to participate in this cutting-edge technology by lessening the financial burden and demonstrating support, which boosts adoption rates and hastens industry transformation. In the end, this aids in the growth of a construction industry that is more efficient, technologically sophisticated, and sustainable.

2.5.2. Offering Training and Educational Programmes

Offering training and educational programmes is another vital improvement strategy for implementing 3DCP technology in the construction industry (Won *et al.*, 2022). For construction industry professionals, such as engineers, architects, technicians, and operators, to effectively utilize and leverage the potential of this technology as new processes and methodologies are being introduced, it is crucial to provide them with the necessary knowledge and skills they require (Won *et al.*, 2022). Different aspects of 3DCP technology, such as machine operation, software application, material handling, and quality control, can be covered in training programmes. The industry associations, technical institutions, universities, or even equipment manufactures may provide these programmes. Participants may build practical skills and get a thorough grasp of the complexities of the technology by engaging in hands-on training, workshops, and simulation exercises. The ability to implement and manage such projects is improved by providing construction experts with the knowledge and skill in 3DCP technology, guaranteeing their effective integration into the construction industry.

Educational programmes are essential in fostering awareness and understanding of 3DCP technology in addition to training (Won *et al.*, 2022). Academic institutions can provide specialised courses, workshops, or even degree programmes in digital fabrication, additive manufacturing, and building automation. These courses give students the academic understanding, research experiences, and hands-on training they need to go on to become future leaders in their profession. Educational institutions help to build a trained workforce that can lead the acceptance and development of this technology in the construction industry by integrating 3DCP technology into the curriculum (Won *et al.*, 2022). By providing thorough training and educational opportunities, we can make sure that the workforce in the construction sector is capable of accepting and utilising 3DCP technology. The ability to fully use the potential of this technology is given to construction experts and upcoming graduates by offering the essential skills, information, and resources, resulting in its successful adoption and integration into construction practices.

2.5.3. Collaborating with Research Institutions and Industry Experts

Collaboration with research institutions and industry experts is one of the significant improvement strategies for implementing 3DCP technology in the construction industry (Won *et al.*, 2022). The effective application of this technology can be ensured by encouraging collaborations and knowledge sharing between academic institutions, research organisations, and industry players. This will help to overcome technical barriers, spur innovation, and make the most of available resources. Research institutions are essential to expanding our understanding of 3DCP technology. They carry out cutting-edge research, create unique techniques, and investigate creative applications that test the limits of this technology. Players in the construction business can obtain the most recent research results, receive access to cutting-edge facilities, and gain from the knowledge of researchers and scientists by working with such organisations. Together, research institutes and industry stakeholders can create novel materials or additives that are specifically suited to the needs of the construction industry, evaluate the performance of 3DCP techniques, and optimise printing processes (Won *et al.*, 2022).

Collaboration with specialists in the field, such as architects, engineers, and construction workers with first-hand knowledge of 3DCP technology, also highlights useful insights and best practises. On design issues, structural integrity, project management, and implementation techniques, industry professionals can offer helpful advice (Won *et al.*, 2022). Their first-hand experience with the difficulties and accomplishments of applying 3DCP technology in the real world greatly benefits the implementation process. Collaboration with professionals in the field may also promote information exchange, mentoring, and the creation of standards and best practises that will advance the acceptance and integration of this technology into building procedures. The construction sector can address technical challenges, stimulate innovation, and advance the effective deployment of 3DCP technology by encouraging collaboration with research institutes and industry professionals (Won *et al.*, 2022). The sharing of concepts, academic discoveries, and real-world knowledge expedites the creation and implementation of best practises, allowing the sector to fully realise the promise of this game-changing technology.

2.5.4. Developing Design Codes and Standards

The development of design codes and standards specifically for 3DCP technology is one of the key strategies for the effective implementation of this technology in the construction industry. The framework of guidelines, regulations, and specifications provided by design codes and standards ensures the secure, effective, and dependable application of 3DCP technology in construction projects (Ter Haar *et al.*, 2023). Design codes and standards for 3DCP technology include a wide range of topics, such as structural planning, material selection, printing procedures, quality assurance, and post-processing needs. On issues like printer calibration, printing settings, layer thickness, material qualities, and structural integrity, they offer precise advice. Design codes and standards serve to assure uniformity, dependability, and conformity with industry best practises by establishing these requirements.

The construction industry can gain several benefits from having strong design codes and standards that are particular to 3DCP technology. By offering a clear road map for putting this technology into use in a secure and dependable way, they inspire trust among stakeholders, including designers, contractors, and regulatory agencies. Contractors may abide by established processes to assure consistent and high-quality printing, while designers can rely on standardised criteria to create efficient and structurally sound designs. In the end, the creation of design norms and standards promotes the advancement of 3DCP technology, improves industry acceptability, and makes it easier for it to be included into customary construction methods.

2.5.5. Increasing Awareness of Benefits and Capabilities

One of the key improvement strategies for the successful implementation of 3DCP technology in the construction industry is raising awareness of its benefits and capabilities (Ma *et al.*, 2022). Despite the enormous potential of the technology, there is still a lack of awareness amongst the construction industry stakeholders regarding its benefits and the radical changes it may bring about in the way construction is carried out (Ma *et al.*, 2022). To address this, it is crucial to launch focused campaigns aimed at teaching and educating key industry participants, such as architects, engineers, contractors, and clients, regarding the benefits and capabilities of 3DCP technology. Various methods, including workshops, seminars, conferences, industry events, and digital platforms, can be used to accomplish this. These initiatives should focus on highlighting the benefits of 3DCP technology.

Furthermore, stakeholders can better understand and appreciate the potential of 3DCP technology and its positive impacts on project timelines, costs, and sustainability by raising awareness (Ma *et al.*, 2022). For the industry stakeholders to make informed decisions when considering adopting this innovative technology, they can also gain a greater understanding of its unique applications and the limitations thereof. Moreover, increased awareness can also encourage industry professionals to work together and share information, which can result in the development of best practices and the exploration of new possibilities in construction. Therefore, it is crucial to target certain groups within the construction industry with awareness-building initiatives. For instance, contractors can be made aware of the design flexibility and customization options provided by 3DCP technology. The long-term benefits of this technology, such as reduced maintenance costs and enhanced sustainability, can be explained to clients. The benefits and capabilities of 3DCP technology can be effectively communicated to various stakeholders by tailoring the messaging and approach, creating a welcoming atmosphere for its adoption and implementation.

2.5.6. Developing a Skilled Workforce in 3D Concrete Printing

One of the key aspects of successfully implementing 3DCP technology in the construction industry is developing a skilled workforce. Since this technology is relatively new in the industry and differs from the conventional methods of construction, it requires specialised knowledge and expertise (Won *et al.*, 2022). To ensure that construction professionals can efficiently run and maintain 3DCP equipment, it is crucial to engage in training programmes and educational activities. There are several strategies that can be employed to develop a skilled workforce. One strategy is to work together with academic institutions, career centres, and industry professionals to create specialised training programmes and courses centred on 3DCP technology (Won *et al.*, 2022). These courses may address 3D printing-specific subjects in digital design, material science, machine operation, troubleshooting, and quality control. People may learn the technical abilities and practical understanding necessary to use this cutting-edge technology by receiving thorough training.

Another strategy is to provide internship and apprenticeship opportunities where prospective professionals may obtain practical experience while being supervised by experienced practitioners. These programmes can offer a structured learning environment and aid in the transfer of information from seasoned professionals to the next workforce. Industry cooperation may also help mentorship initiatives and knowledge-sharing forums where experts can share their experience, best practises, and insights in the field of 3DCP technology. The construction industry can assure a seamless transition to 3DCP technology by investing in the training of a qualified and skilled workforce. Professionals with the necessary skills will be able to operate the machinery as well as comprehend the subtleties of material behaviour, project planning, and coordination needed for effective execution. A knowledgeable workforce can also help the technology grow by giving insightful input, pointing out potential improvements, and pushing the limits of what is feasible with 3DCP technology. Overall, maximising the benefits and possibilities of 3DCP technology in the construction industry depends on the development of a skilled workforce.

2.5.7. Streamlining the Supply Chain and Procurement Processes

Implementing 3DCP technology in the construction industry requires a crucial improvement strategy such as streamlining the supply chain and procurement procedures (Proverbs *et al.*, 2000). Traditional construction methods often entail labour-intensive procurement processes, such as locating supplies, controlling vendors, and scheduling delivery (Proverbs *et al.*, 2000). The application of 3DCP technology can be hampered by these inefficiencies. The effective implementation of this technology into building projects can thus be facilitated by optimising the supply chain and procurement processes. One of the strategies for simplifying the supply chain is to form strategic alliances with equipment and material suppliers (Proverbs *et al.*, 2000). Working together with reputable and trustworthy suppliers helps provide a quick and constant supply of high-quality materials created especially for 3DCP technology. These collaborations can also make it easier to design specialised materials that are specifically suited to printing needs, such as additives and concrete mixtures that can be printed.

Furthermore, digital technological integration can improve the effectiveness of the supply chain and procurement processes. The whole procurement cycle, from initial material selection to final delivery on-site, can be streamlined by implementing digital platforms and tools for material purchasing, inventory management, and logistics (Proverbs *et al.*, 2000). Through process automation, decreased paperwork, and real-time material tracking, these digital solutions may increase coordination and shorten lead times. Additionally, it is essential to take a collaborative stance inside the supply chain. It can be useful to detect possible bottlenecks and simplify decision-making processes by encouraging open communication and cooperation among project stakeholders, including designers, contractors, material suppliers, and equipment manufacturers. Potential disputes or delays can be avoided, and the supply chain can be improved to successfully support the application of 3DCP technology by including all parties early in the project design phase.

2.5.8. Addressing Concerns about Job Loss

One of the key aspects of implementing 3DCP technology in the construction industry is addressing concerns about job loss. The introduction of automation and innovative technologies such as 3DCP technology in the construction industry have raised concerns amongst the people about the potential loss of jobs that were traditionally carried out by skilled and unskilled workforce (Pessoa *et al.*, 2021). It is crucial to create plans that address these issues and offer alternative employment prospects to ensure the successful adoption and implementation of 3DCP technology. Focusing on reskilling and upskilling the workforce is one strategy for resolving concerns about job loss (Pessoa *et al.*, 2021). The construction industry employees can obtain the skills and information they need to adapt to the shifting industry landscape by investing in training programmes and educational initiatives. In addition to training in complementing skills like digital design and engineering, these programmes may also involve specialised instruction in 3DCP technology, such as running and maintaining the printing equipment (Pessoa *et al.*, 2021). Job displacement can be reduced, and new employment possibilities can be established by providing individuals with the skills required to work alongside the technology.

Additionally, encouraging cooperation among technology developers, construction companies, and labour unions might assist in addressing concerns about job loss. Concerns can be addressed proactively and mitigation strategies to lessen the impact on employees can be established by including stakeholders in talks and decision-making processes. To ensure a seamless transition and employment retention, this partnership can entail investigating job rotation programmes where employees are educated to execute numerous positions within the 3DCP workflow. Lastly, promoting fair and ethical employment practises through policy implementation and discourse will assist safeguard employees' rights and wellbeing when 3DCP technology is used.

In general, resolving concerns about job loss is essential for the effective implementation of 3DCP technology in the construction industry. The construction industry can navigate the transition to this innovative technology while maintaining the wellbeing and livelihoods of its personnel by concentrating on upskilling and reskilling programmes and encouraging collaboration among stakeholders. The industry can embrace the benefits of 3DCP technology while minimising any possible negative effects on jobs by using a complete approach that prioritises worker training, job retention, and ethical employment practises.

2.5.9. Mitigating the Impact of Unpredictable Weather Conditions

The impact of unpredictable weather conditions is one of the major challenges the construction industry, particularly in South Africa, must deal with (Ntuli *et al.*, 2014). Strong winds, extreme heat, and heavy rain can cause delays in construction projects, throwing off building schedules, and waste more materials. It is crucial to consider techniques to lessen the negative impacts of weather on the printing process and maintain continuous operations when deploying 3DCP technology. Construction companies can use a variety of mitigation strategies to mitigate the effects of unpredictable weather (Ntuli *et al.*, 2014). Investing in the development of 3DCP materials resistant to the unpredictable weather conditions is one best strategy. The printing process may continue even during bad weather events by employing materials that can survive varied weather conditions, such as rain-resistant concrete mixes or UV-resistant polymers, which reduces delays and boosts productivity.

Furthermore, implementing suitable scheduling and emergency preparations is another mitigating strategy. To schedule printing operations during favourable weather conditions, construction projects might include weather forecasting technologies and historical weather data. Companies may reduce the chance of weather-related delays and maximise the usage of 3DCP technology by coordinating the building schedule with anticipated weather patterns. Moreover, Construction companies can contribute to the development of climate-controlled printing facilities. The printing process can be protected from the impacts of bad weather by designing covered or semi-enclosed printing facilities, which also offer a controlled atmosphere for the best printing conditions. This method lessens the possibility of weather-related disruptions while preserving the quality and integrity of printed structures.

In summary, minimising the effects of erratic weather is essential for the effective application of 3DCP technology in the South African construction industry. Construction companies can improve the resilience of the printing process and reduce weather-related delays by investing in weather-resistant materials, efficient scheduling, and weather-protected printing facilities. Due to South Africa's erratic and variable weather patterns, these techniques help to boost output, decrease project delays, and increase efficiency.

2.5.10. Promoting Research and Development for Large-Scale Production

Promoting research and development initiatives aimed at large-scale production is crucial if the South African construction industry is to fully harness the potential of 3DCP technology (Xiao *et al.*, 2021). Large-scale 3D printing gives the opportunity to build intricate and large buildings more effectively and affordably. However, this will only be possible with major improvements in printing methods, materials, and overall process design (Xiao *et al.*, 2021). Investing in the creation of improved printing materials is an important part of encouraging research and development for large-scale manufacturing. To improve the structural performance and durability of 3D printed materials, researchers can investigate new cementitious composites, fibre-reinforced concrete, and cutting-edge binders. In addition, research into eco-friendly and sustainable materials is necessary to support South Africa's expanding emphasis on green construction techniques.

Furthermore, the development of large-scale 3DCP technology depends on cooperation between academic, industrial, and governmental entities. Stakeholders can combine their knowledge, financing, and resources to speed up research and development efforts by developing partnerships and information-sharing platforms. These partnerships can also make it easier to establish research facilities and testing grounds for 3DCP technology, allowing scientists to carry out larger-scale tests, simulations, and prototypes.

To sum up, encouraging research and development for mass production is essential for realising the full potential of 3DCP technology in the South African construction industry. The industry can get over its existing obstacles and embrace the revolutionary advantages of large-scale 3D printing by using cutting-edge materials, collaborating with others, and investing in specialised research centres. R&D spending not only promotes technical development but also increases industry worldwide competitiveness, establishing South Africa as a pioneer in 3DCP technology adoption and innovation.

2.6. Summary

The literature review explored the state of 3DCP technology in the South African construction industry. Faster construction speed, cost-effectiveness, reduced material wastage, improved health and safety, enhanced customization, precision, quality control, and positive impact on housing delivery are all inherit benefits of this technology. There are, however, several barriers that prevent its widespread adoption, including high initial investment costs, a lack of government incentives, a lack of design codes and standards, risk aversion, a lack of awareness of the advantages, a shortage of experts, a fragmented supply chain, worries about job loss, and weather effects.

The development of standards and design codes, collaboration with research institutions and experts, raising awareness, supply chain streamlining, mitigating job loss, and research for large-scale production were among the improvement strategies suggested to address these issues.

As a result, knowing the advantages, challenges, and improvement plans will help decision-makers decide whether to embrace 3DCP technology, increasing efficiency and sustainability in the South African construction industry. The literature study serves as the basis for the next survey that will be used to collect first-hand information from construction industry professionals.

Chapter 3: Research Methodology

3.1. Background

In this chapter, an overview of the methodology adopted in conducting this research study is presented. The research method and strategy applied in designing, planning, and implementing the data collection process, ethical clearance considerations, and data analysis followed by a comprehensive interpretation of the data related to individual understandings and perceptions of the benefits, barriers, and improvement strategies associated with the adoption of 3DCP technology in the South African construction industry are discussed in this chapter.

3.2. Data Collection

This section provides the methodological procedure followed to gather the necessary data required to comprehensively conduct this research study, accompanied by the sampling strategy and development of the survey questionnaire.

3.2.1. Existing Data Collection

An extensive literature review was carried out to gain insightful information into the existing body of work related to the title of this research study, including various academic journals and scholarly databases, to gather the existing data. Throughout this process, gaps in the existing literature were uncovered and essential concepts were extracted. These concepts include the potential benefits, barriers, and improvement strategies related to the adoption and implementation of 3DCP technology in the South African construction as an instrument to enhance productive, which formed the basis of the investigations carried out in this research study.

3.2.2. Primary Data Collection

The primary data for this research study was collected through the nationwide survey questionnaire administered to the professionals working in the South African construction industry. The existing data collected from the literature study provided insightful information that guided the development of the survey questionnaire, ensuring that it did not deviate from the research objectives. The questionnaire was comprised of three sections. The first section was comprised of seven questions formulated to capture the survey respondents' demographic information, including their educational background, professional roles in the industry, affiliations with various professional bodies, working experience, organizational type and size, and the types of projects they have worked on. The information gathered from this section helped in interpreting the survey responses.

The second section of the survey questionnaire was designed to collect data regarding the respondents' familiarity, exposure, and hands-on experience with 3DCP technology. The last section of the survey questionnaire was the core of this research study as it sought to gather information regarding the respondents' perceptions of the benefits, barriers, and improvement strategies associated with the adoption of 3DCP technology in the South African construction industry. The respondents were asked to express their agreement or disagreement with several statements related to the benefits, barriers, and improvement strategies using a 5-point Likert scale, ranging from 1 to 5, with 1 representing "Highly insignificant" and 5 representing "Highly significant". To ensure that the respondents were fully concentrated on the survey questions and not just providing random responses, the rating scale for the last question of the last section was switched around, with 1 representing "Highly significant" and 5 representing "Highly insignificant".

3.2.3. Sampling Strategy

To ensure a comprehensive representation of the South African construction industry, a stratified random sample approach was employed, categorizing respondents based on organizational affiliations and industry roles. This method aimed to collect diverse perspectives while minimizing biases from self-selection.

Respondents were strategically selected through a combination of targeted and snowball sampling. The survey distribution primarily leveraged the Department of Civil Engineering at Stellenbosch University, focusing on industry professionals who participated in university short courses. This targeted approach ensured respondents possessed relevant expertise. Additionally, the survey was shared on LinkedIn, broadening the demographic reach within the construction industry. The snowball effect was facilitated as LinkedIn respondents disseminated the survey in their networks, capturing diverse perspectives. Encouraging further distribution within Stellenbosch University's database and beyond ensured a robust dataset, reflective of a wide spectrum of opinions and experiences in the South African construction industry.

3.2.4. Data Collection Procedures

The survey questionnaire was effortlessly distributed to the selected respondents through a carefully constructed email invitation. The objective of the study, the voluntary nature of participation, and the assurance of data protection and anonymity were all clearly stated on the cover letter of the email. The respondents were provided with a convenient link to access and complete the survey questionnaire. To increase the response rates, a specific deadline that was set for completion was extended, and polite reminders were sent out. The data collection method was closely monitored to guarantee its accuracy and integrity. This vigilance ensured the data accurately reflected the respondents' viewpoints, reducing the likelihood of bias.

3.3. Data Analysis

This section presents the statistical techniques, namely descriptive and inferential, applied to analyse the data collected from the survey questionnaire and extract meaningful insights.

3.3.1. Descriptive Statistics

Descriptive statistics were applied to present the overview demographic profiles of the respondents. This included the frequencies and percentages of educational backgrounds, professional roles, affiliations, years of experience, organizational sizes, organizational types, and the types of construction projects. Furthermore, descriptive statistics were also crucial in summarizing the percentage distribution of the respondents' level of awareness, knowledge, and firsthand experiences for the questions probing the respondents' knowledge of and experience with 3DCP technology. Moreover, this approach was carefully used to assess the Likert scale response in questions 11 through 14, which dealt with the perceived significance of benefits, potential barriers, and improvement strategies. To capture the respondents' sentiments and provide a comprehensive picture of their perspectives, measurements including means, and frequency distributions were computed.

3.3.2. Inferential Statistics

The inferential statistics were employed to go beyond just a simple summary and delved deep into analysis to draw meaningful conclusions about the relationship, significance, and correlations in the data.

Cronbach's Alpha Coefficient was applied to perform a reliability test to gauge the internal consistency of the survey questionnaire. The reliability of the items used to measure perceived benefits, potential barriers, and improvement strategies was evaluated by this test. The consistency and reliability of the survey questionnaire are confirmed by a high Cronbach's alpha value, which indicates that the questions within each construct are strongly related. The Cronbach's alpha value ranges from 0 to 1, with a higher value indicating stronger internal consistency (Taan *et al.*, 2018), demonstrated by the formula (1):

$$\alpha = \frac{n}{n-1}\left(1 - \frac{\sum_{i=1}^{k}\sigma_{yi}^{2}}{\sigma_{x}^{2}}\right) \tag{1}$$

Where:

- α = Cronbach's Alpha Coefficient
- n = Number of items (questions)
- k = Number of items in the set
- σ_{yi}^{2} = Variance of the scores on item i
- σ_{x}^{2} = Variance of the total scores on all items

Mean score calculations were carried out to determine the average score perceived significance of the benefits, potential barriers, and improvement strategies. The calculated mean scores provided a quantifiable measure of respondents' collective perceptions, aiding in formulating well-rounded conclusions. The mean score is defined as the arithmetic average of a set of values (Taan *et al.*, 2018) with the formula (2):

$$Mean = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2}$$

Where:

- $Mean$ = Mean score
- n = Number of responses
- x_i = Value of each individual response

3.4. Ethical Considerations

Ethical clearance was sought for this study to fulfil the research ethical requirements set by Stellenbosch University Faculty Ethics Screening Committee (FESC). As per requirements, the survey questionnaire along with the research proposal amongst other documents were submitted to the FESC for assessment by the Research Ethics Committee (REC) and the committee judged the study as a low-risk and permission was granted to go ahead with the process of collecting data. A copy of the approval letter from the FESC is presented in Appendix B. A disclaimer statement was included in the questionnaire along with a voluntary consent for the respondents to participate in the survey, guaranteeing their privacy and the freedom to opt out without any consequences.

3.5. Validity and Reliability

For the findings to be credible and reliable, the validity and reliability of the research study must be ensured (Taan *et al.*, 2018). While reliability is concerned with the consistency and stability of the study results across time and under various conditions, validity is concerned with the accuracy and truthfulness of the research outcomes. These factors are crucial in establishing the validity of the research study's conclusions.

A rigorous process was used to establish the content validity of the survey questionnaire. Following an extensive review of the literature and consultation with the study leaders, who are experts in the field of 3DCP technology, the survey questions were formulated. As a result, the survey questions were guaranteed to appropriately reflect the constructs being measured. Furthermore, a pilot test of the survey questionnaire's clarity and comprehensibility was carried out with a small group of construction industry professionals. The survey questions were further improved based on the respondents' feedback to increase their face validity. Moreover, the survey included both positively and negatively phrased questions to increase criterion-related validity, prevent response bias, and make sure that respondents were giving deliberate and sincere responses.

The Cronbach's Alpha Coefficient was applied to evaluate the internal consistency and reliability of the survey questionnaire (Taan *et al.*, 2018). Based on the responses to questions regarding the benefits, potential barriers, and improvement strategies associated with the adoption of 3DCP technology, the Cronbach's Alpha Coefficient was computed.

In conclusion, this research study ensures that the data collected and analysed accurately reflect the objectives of the research and contribute to the advancement of knowledge in the field of

3DCP technology by addressing validity and reliability concerns. While reliability ensures that outcomes are consistent, validity protects the research from measurement errors (Taan *et al.*, 2018). The thorough attention given to these factors strengthens the validity and significance of the research's findings and conclusions.

3.6. Limitations of the Study

It is a common trend for research studies to have inherent limitations that have the potential to influence the findings of the study, the interpretation thereof, and the research's generalizability. In this section, these limitations are critically explored to ensure that transparency is maintained throughout and provide context for understanding the scope and limitations of the research findings.

- **Sampling Limitations**

The survey questionnaire was sent out to a diverse group of professionals in the South African construction industry. The respondents who consensually agreed to take part in the survey hold various characteristics and perceptions of the barriers, benefits, and improvement strategies associated with the adoption of 3DCP technology that could potentially affect the research findings regardless of the efforts to obtain a sample that is representative. As a result, one should be cautious about taking a broad view of the research findings as representative of the general South African construction industry.

- **Self-Report Bias**

The survey questionnaire was designed such that it is solely reliant upon the information provided by the respondents. This approach opened a room for self-report bias, whereby the respondents could have potentially answered the survey questions based on their personal or professional characteristics regardless of the efforts made to assure anonymity and confidentiality.

- **Contextual Generalizability**

The findings of this research study offer insightful information for the South African context and are therefore not representative of other countries that may have various dynamics and characteristics that could potentially influence the adoption of 3DCP technology for productivity enhancement in their construction industry. Therefore, one should be cautious when directly applying these research findings to other contexts.

- **Scope Limitations**

This research study focused on determining the readiness of the South African construction industry to adopt and implement 3DCP technology as a tool to enhance productivity by exploring only the benefits, barriers, and improvement strategies associated with its integration. Therefore, it is worth noting that there is a probability of the existence of other critical factors that were not explored in this study that could affect the adoption and implementation of this innovative technology. Therefore, the findings of this study do not offer a full comprehension of the deeper complexities related to this research topic.

- **Time Constraints**

One of the limiting factors of this research study was time as it was carried out under a scheduled period, which could have possibly impacted the breadth and depth of the data collection process as a larger sample could have been used, as well as the investigation of other research possibilities. There is a probability that more complex and thorough research findings could have been obtained within a longer time frame.

Chapter 4: Results Presentation, Analysis, and Discussion

4.1. Background

This chapter presents the findings obtained from the survey conducted to investigate the perceptions of South African construction industry professionals towards the adoption and implementation of 3DCP technology. The main objective of the study was to gauge their familiarity with this innovative construction technology, learn about their perceptions of its benefits and potential barriers, as well as exploring improvement strategies for its successful adoption and implementation. A remarkable number of 136 responses, reflecting a robust 91% response rate, were received from the survey questionnaire that was distributed to 150 construction industry professionals. The respondents had varying backgrounds, roles, professional affiliations, and experiences, which offered a comprehensive understanding on how 3DCP technology is perceived in the construction industry. Therefore, this section provides the context for interpreting the results obtained from the survey as well as insights into the perceptions and attitudes of the construction industry professionals towards this technology.

4.2. Profile of Respondents

This section provides a summary of the respondents' profiles who took part in the survey. The collected data includes information about their educational backgrounds, roles in the construction industry, professional affiliations, years of working experience, organization size, type of organization, and the type of construction projects they are engaged in.

4.2.1. Educational background

The respondents' educational background shows a wide range of qualifications. As depicted in Figure 4.1 considerable 52% of the respondents are in possession of an honours/bachelor's degree, signifying a strong base of academic achievement within the construction industry. A significant 29% of the respondents are in possession of a Master's degree, indicating a substantial proportion of the industry professionals with advanced education. Furthermore, 11% of the respondents were in possession of a PhD/Doctorate, indicating a substantial proportion of the industry professionals with the highest academic qualification. Respondents in possession of a diploma account for 5%, while 2% are in possession of a high school/matric qualification. This distribution shows a wide range of educational backgrounds, which contributed to the diverse perspectives represented in the survey.

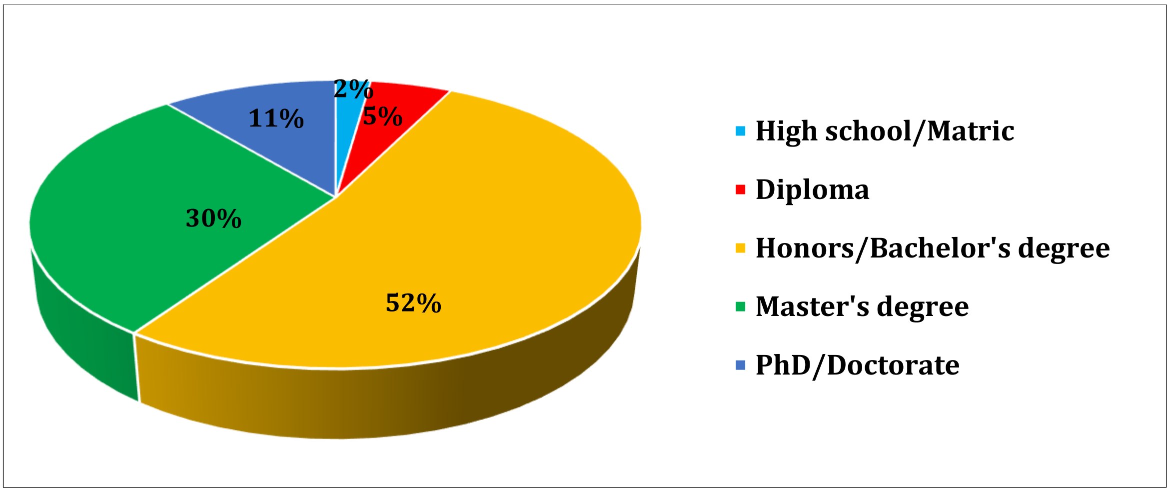

Figure 4.1: Respondents' educational background.

4.2.2. Roles in the construction industry

The roles of the survey respondents provided insights into their respective diverse areas of expertise in the construction industry. As depicted in Figure 4.2, consulting engineers formed the largest proportion of the respondents at 53%, highlighting the strong presence of professionals in various engineering and design-related fields. Construction project managers constituted 14% of the respondents. Government officials and researchers/academics highlighted the significance of regulatory and research-focused individuals, with each representing 8% of the respondents. Furthermore, 17% of the respondents fall under "Other" category, which included professionals such as quantity surveyors, architects, materials specialists, concrete technologists, material suppliers, and more. The combination of these roles provides a thorough perspective of the different stakeholders that took part in the survey, assisting in the development of a well-rounded understanding of perceptions and attitudes regarding 3D concrete printing technology.

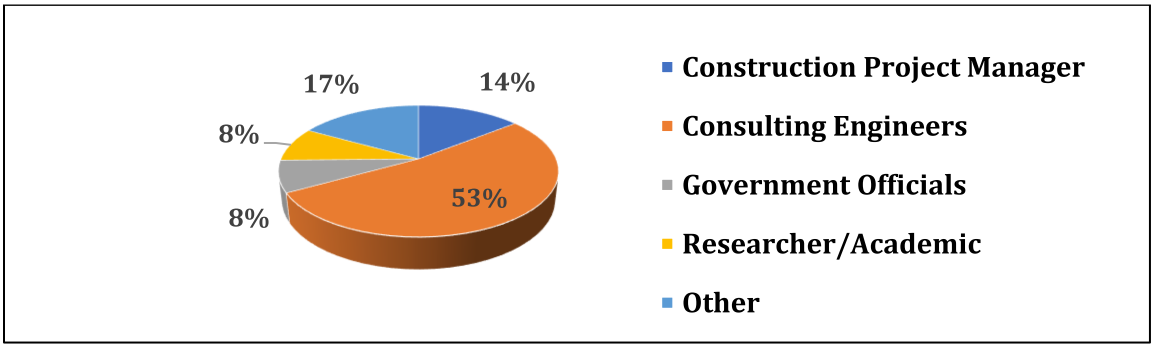

Figure 4.2: Respondents' roles in the construction industry.

4.2.3. Professional affiliation

The respondent's professional affiliations highlighted their ties to key construction industry bodies. As depicted in Figure 4.3, the Engineering Council of South Africa (ECSA) was highly represented, with a substantial proportion of 69% of the respondents, highlighting a strong representation of Professional Engineers. Furthermore, 8% of the respondents were affiliated with the South African Council for the Project and Construction Management Profession (SACPCMP), highlighting the presence of professionals in the field of project and construction management. Moreover, 23% of respondents fell under the "Other" category, which encompasses a wide range of additional networks such as the South African Council for the Architectural Profession (SACAPSA), the Association of Construction Project Managers (ACPM), and the South African Council for Quantity Surveyors (SACQSP), among others. Despite having modest representation, these affiliations collectively contribute to the diversity of professionals' perceptions regarding the adoption and successful implementation of 3DCP technology in the construction industry.

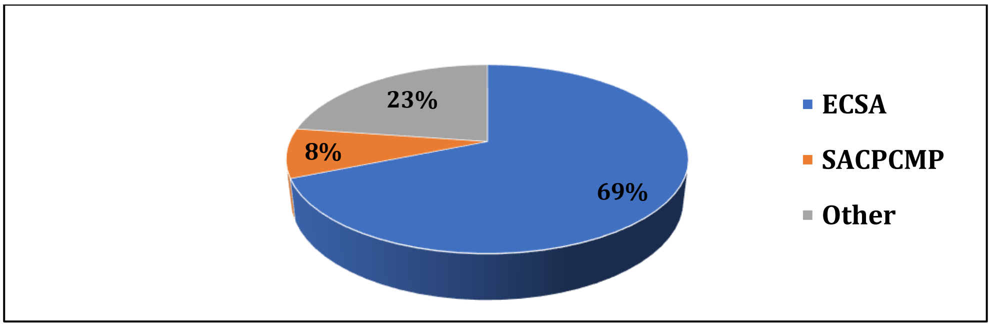

Figure 4.3: Respondents' professional affiliations.

4.2.4. Years of experience

The level of experience of the respondents highlighted their widespread participation within the South African construction industry. As depicted in Figure 4.4, 49% of the respondents indicated that they had more than 20 years of working experience, highlighting a significant portion of well-experienced professionals. Furthermore, 14% of the respondents indicated that they had between 11 and 20 years of experience, indicating a sizable intermediate level of experienced professionals. Moreover, 12% of the respondents indicated that they had between 6 and 10 years of experience, while 10% indicated that they had between 1 and 5 years of experience and 1% indicated that they had less than 1 year of experience, respectively.

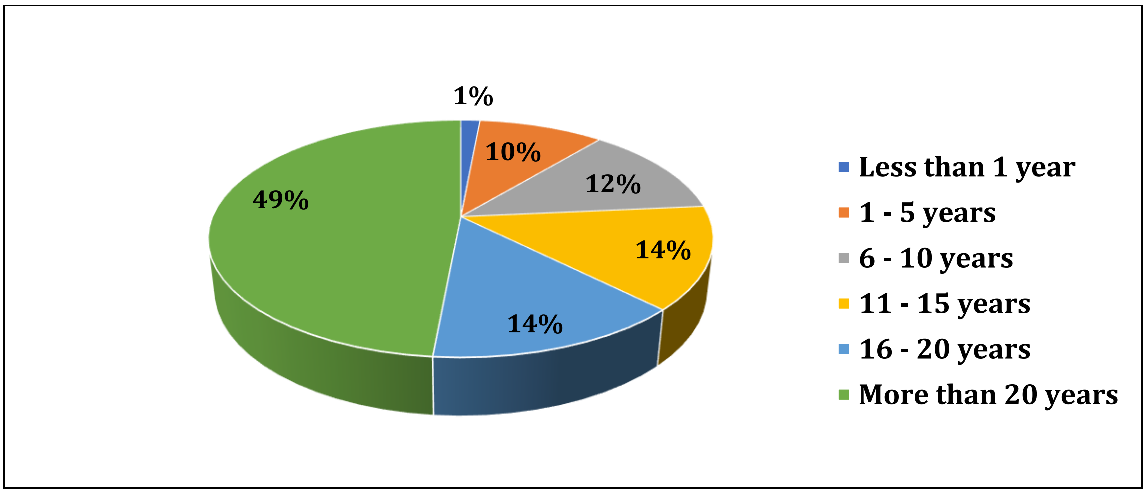

Figure 4.4: Respondents' working experiences.

4.2.5. Organization size

The sizes of the companies which the respondents worked for highlighted a diverse range of organizations in the construction market. As depicted in Figure 4.5, 28% of the respondents indicated that they belonged to companies with more than 500 employees, highlighting a significant portion of larger companies within the construction industry. Furthermore, 24% of the respondents indicated that they belonged to companies with between 1 and 10 employees, highlighting the representation of smaller companies. Additionally, 21% of the respondents indicated that they belonged to companies with between 101 and 500 employees, while 15% indicated that they belonged to companies with between 11 and 50 employees. Lastly, 12% of the respondents indicated that they belonged to companies with between 51 and 100 employees, respectively.

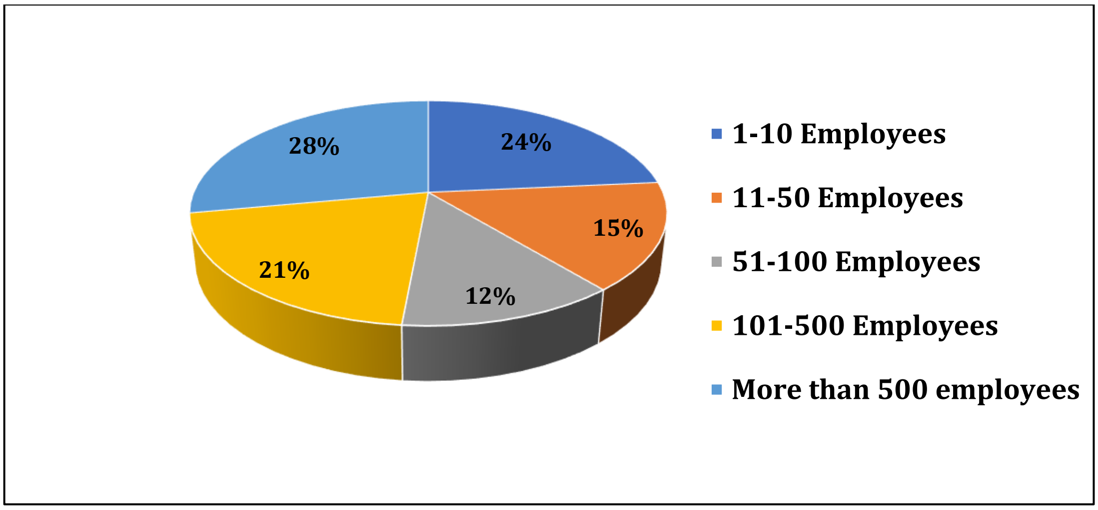

Figure 4.5: Respondents' organization size.

4.2.6. Type of Organization

The types of organizations to which the respondents belonged highlight their affiliations with two prominent sectors within the construction industry. As depicted in Figure 4.6, 76% of the respondents indicated that they work for companies falling under the private sector, while 24% of the respondents indicated that they work for companies falling under the government within the construction industry.

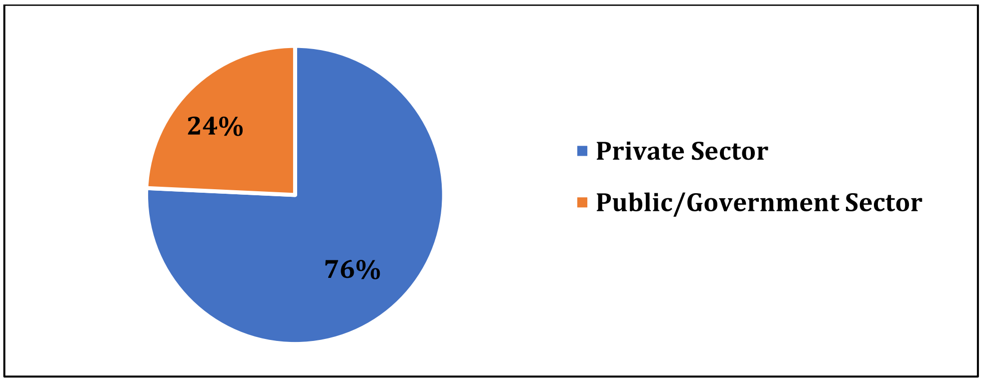

Figure 4.6: Respondents' organization type.

4.2.7. Type of construction projects

The types of construction projects in which the respondents were involved to highlight their versatility with various projects within the construction industry. As depicted in Figure 4.7, the respondents who were involved in infrastructural development projects accounted for

17% of the total responses, followed by those who were involved in industrial projects, accounting for 15% of the total responses, respectively. Furthermore, the respondents who were involved in commercial development projects accounted for 14% of the total responses, while the respondents who were involved in residential development projects accounted for 13% of the total responses. Additionally, the respondents who were involved in institutional development projects accounted for 12% of the total responses, while those who were involved in renovation and modelling projects accounted for 11% of the total responses. Lastly, respondents who were involved in other construction projects other than those mentioned accounted for 18% of the total responses.

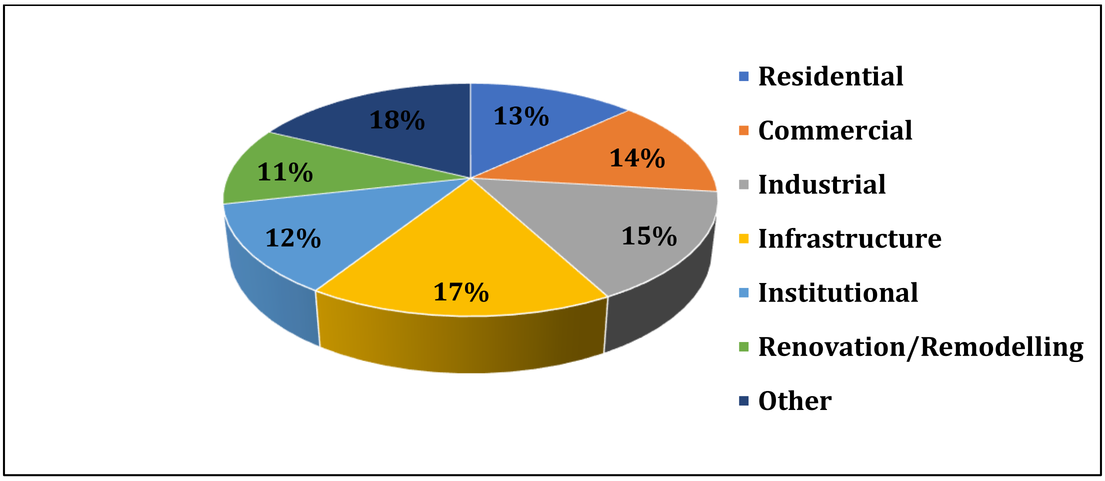

Figure 4.7: Respondents' construction project types.

4.2.8. Summary

The complete analysis of the respondents' profiles in this section provides a solid framework for comprehending their perceptions on the application of 3DCP technology in the South African construction industry. This profile analysis offers a comprehensive knowledge of the construction industry professionals taking part in the study, with a variety of backgrounds that included education, roles, affiliations, level of experience, organizational sizes, and involvement in various construction projects. The subsequent analysis is enriched by this variety of perspectives, resulting in a thorough understanding of the survey results.

The combination of educational achievements, ranging from high school/matric to PhD/Doctorate qualifications, along with a variety of roles they occupy such as consulting engineers, construction project managers, government officials, and researchers/academics, emphasizing the multifaceted nature of the construction industry. As a result, this complete examination of the respondents' profiles not only aids in the interpretation of their responses but also captures the intricate structure of the South African construction industry, laying out the groundwork for nuanced understanding of 3DCP technology within this dynamic environment.

4.3. Familiarity with 3DCP Technology

To determine whether the South African construction industry is ready to adopt and implement 3DCP technology as one of the mainstream construction methods, it is necessary to assess the respondents' familiarity with this innovative technology. The responses attained from the survey highlight that most of the respondents, accounting for 88% of the total responses, are familiar with the technology, indicating a higher degree of its awareness within the construction industry. The remaining 12% of the respondents indicated that they were not familiar with the technology as depicted in Figure 4.8, highlighting the need for awareness campaign.

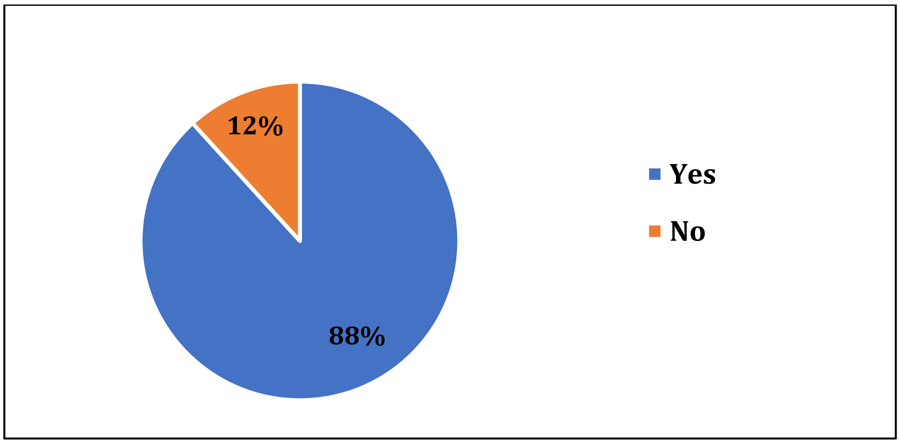

Figure 4.8: Respondents' familiarity with 3DCP technology.

Additionally, the respondents were asked to rate their level of knowledge regarding 3DCP technology. The response shows a range of knowledge, with 22% of the respondents indicating that they had "very low" knowledge, 41% reported a "low" level, 32% reported a "moderate" level, and 3% reported a "high" level of knowledge. Only 2% of respondents indicated to have "very high" levels of knowledge as depicted in Figure 4.9. Given that most respondents fell under the "low" to "moderate" familiarity range, this distribution emphasizes the opportunity for improving awareness and knowledge dissemination measures.

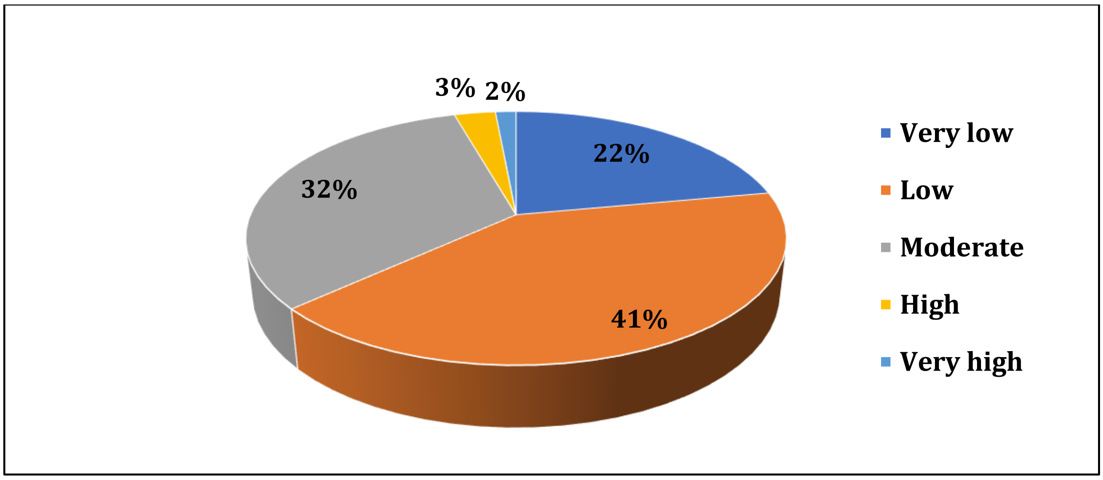

Figure 4.9: Respondents' level of knowledge of 3DCP technology.

Furthermore, the respondents were probed about their hands-on experience with 3DCP technology. The results revealed that 10% of the respondents have had direct experience with the technology, while 90% of the respondents have never experimented with it as depicted in Figure 4.10. This ratio implies that although knowledge and awareness of 3DCP technology is very high, its practical use in construction projects is still somewhat limited. This discovery emphasizes the potential for additional research and testing within the industry to fully grasp the potential advantages of the technology. Moreover, it is worth noting that most of the subset of respondents (10%) who reported to have experienced with 3DCP technology is primarily comprised of academics. These experts likely experimented with the technology in controlled laboratory environments as part of their academic research studies. This realization highlights the academic community's contribution to pushing the boundaries of innovation and experimentation while simultaneously highlighting the necessity for more extensive practical application within the broader construction industry.

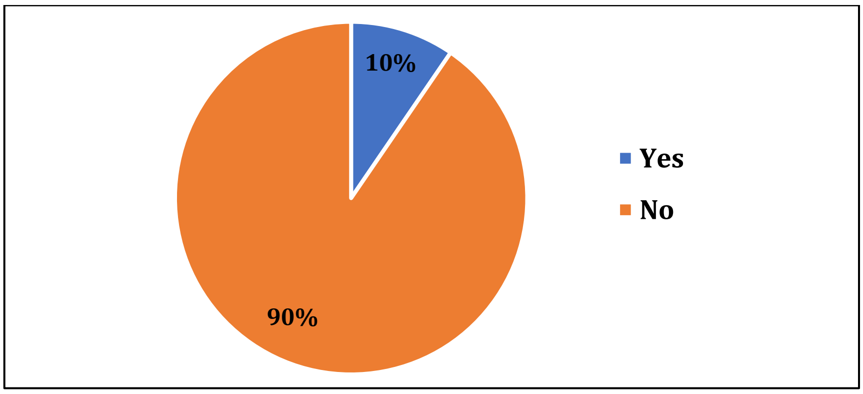

Figure 4.10: Respondents' experience with 3DCP technology.

4.4. Rating the Significance of Benefits

In this section, the potential benefits of the application of 3DCP technology in the construction industry are assessed based on the perceptions of the respondents. The respondents were instructed to rate the significance of all the benefits by assigning their mean rating scores using a five-point Likert scale. Each benefit was assigned a unique code as presented in Table 4.1.

Table 4.1: Codes for benefits of 3DCP technology

Code	**Benefits of 3DCP technology**
B1	Faster construction speed
B2	Cost-effective
B3	Reduced construction material wastage
B4	Reduced health and safety hazards
B5	Improved customization
B6	Improved precision and accuracy
B7	Improved quality control
B8	Improved performance in housing delivery

4.4.1. Cronbach's Alpha Coefficient Test for the Benefits

Before delving into the specific mean rating scores of the benefits tabulated, it is important to note that the reliability of the ratings of the benefits was evaluated using Cronbach's Alpha Coefficient. The coefficient value of 0.85 was obtained, indicating a high degree of internal consistency amongst the survey respondents' responses regarding the benefits.

4.4.2. Mean Rating Scores of the Benefits

This section provides insightful information into how the respondents, grouped in various categories, perceive the benefits offered by 3DCP technology. The mean rating scores of each category, based on the profiles of the respondents, were determined. Figure 4.11 presents the mean rating scores of two of the groupings, while the complete set is given in Appendix C.

- ***Educational Background***

In this section, the mean rating scores provided by the respondents regarding the significance of the benefits associated with 3DCP technology based on their educational backgrounds are analysed. The mean rating scores across all educational backgrounds are presented in Figure 4.11a.

(a)
(b)

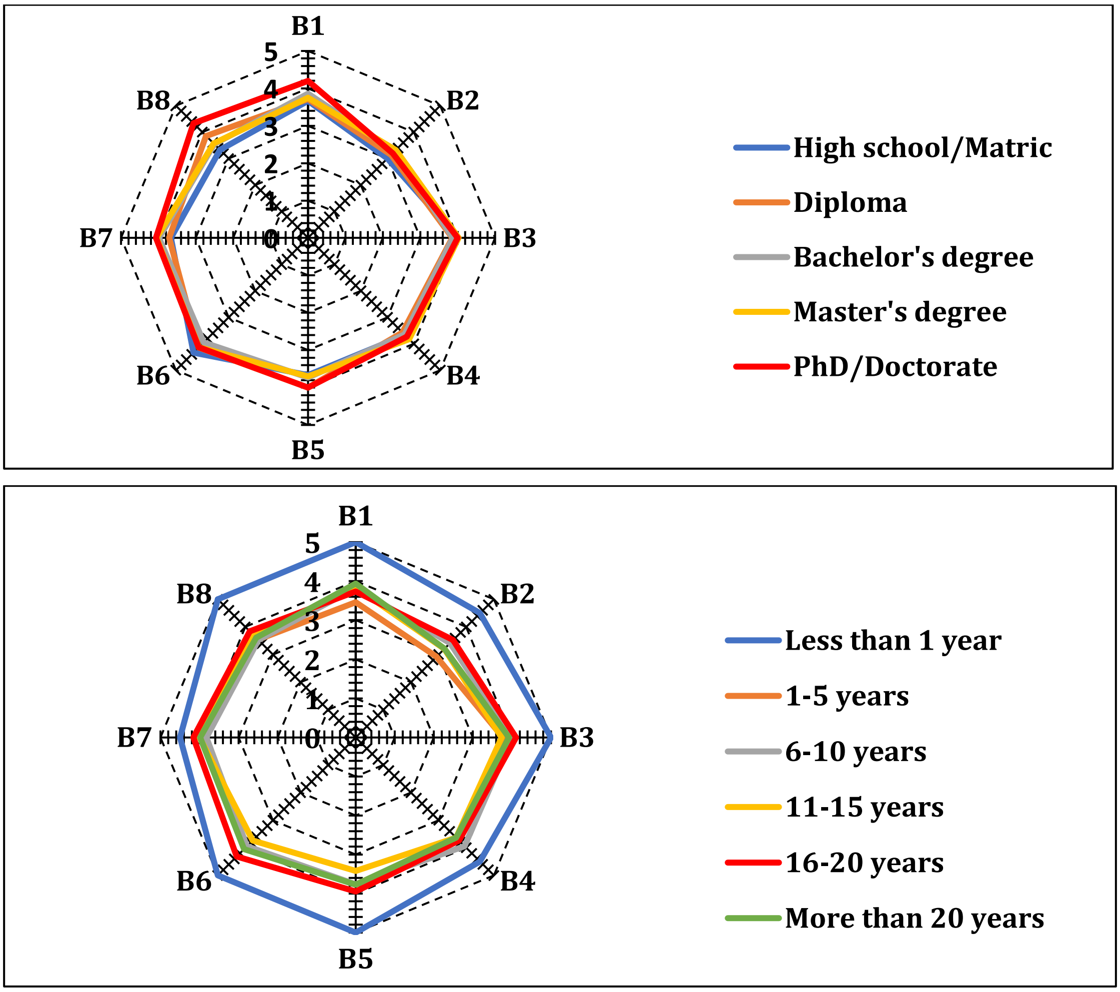

Figure 4.11: Mean rating scores of the benefits by (a) Educational Background, and (b) Experience

As depicted in Figure 4.11a, respondents who indicated holding a PhD/Doctorate qualification assigned the benefits higher mean rating scores, with consistency, in comparison to those with the respondents holding other qualifications. Respondents who hold a PhD/Doctorate qualification gave benefit B8 the highest mean rating score of 4.3. On the other hand, the mean rating scores assigned by the respondents holding a diploma and a bachelor's degree were marginally lower than those who hold a Master's degree and a PhD/Doctorate, even though they typically assigned significantly high mean rating scores for all the benefits. Overall, benefit B3 was assigned higher mean rating scores by all the respondents with various educational levels, indicating that they consider this benefit to be particularly significant.

When analysing the mean rating scores assigned by the respondents in Figure 4.11a, potential variations can be realized in how they perceive the benefits of 3DCP technology based on their level of education. Respondents holding higher levels of education, more especially those holding a PhD/Doctorate qualification, tend to perceive all the benefits as of high significance. This may be because of their deeper understanding of the implications and applications of 3DCP technology. Therefore, these findings provide insight into how the level of education of an individual may have an influence on the adoption of this innovative technology.

- ***Roles in the Construction Industry***

In this section, the professional roles of the respondents within the construction industry are examined to determine the influence they have on how they perceive the benefits of 3DCP technology. The radar cart presented in Appendix C with the title "Roles in the Industry" depicts the mean rating scores of the benefits assigned by the respondents across different professional roles. The radar chart titled "Roles in the Industry" in Appendix C was chosen to present the findings as it allows for a clearer comparison of the mean rating scores assigned by the respondents across various professional roles.

As depicted on the radar chart in Appendix C titled "Roles in the Industry", researchers/academics assigned most of the benefits the highest mean rating scores, with benefit B8 earning a mean rating of 4.2, followed by government officials and consulting engineers, respectively. These findings suggest that this group of professionals highly value the benefits associated with 3DCP technology. Despite generally assigning all the benefits substantially high mean rating scores, construction project managers and professionals falling under the category "Other" tended to assign mean rating scores that are slightly lower compared to those assigned by consulting engineers, government officials, and researchers/academics.

The analysis of the mean rating scores based on the respondents' role in the construction industry reveals variations in how various professional categories view the benefits of 3DCP technology. The benefits appear to be of greater significance to researchers/academics, who are well-known for their active involvement in the research and advancement of various construction techniques. Government officials and consulting engineers, who are crucial in implementing and regulating construction projects, also consider 3DCP technology to be of substantial value. This insightful data could aid in informing targeted strategies for promoting the adoption and successful implementation of 3DCP technology in the construction industry.

- ***Professional Affiliation***

This section examines how the respondents' professional affiliations influence their perceptions of the significance of the benefits of 3DCP technology. The radar chart in Appendix C titled "Professional Affiliation" presents the mean rating scores for each benefit across various professional affiliations. This radar chart in Appendix C titled "Professional Affiliation" allows for a clear comparison of each benefit's perceived significance across various professional affiliations within the construction industry.

It is clear from the radar chart in Appendix C titled "Professional Affiliation" that those respondents affiliated with ECSA assigned the highest mean rating scores for most of the benefits. They assigned benefit B6 the highest mean rating score of 4.1. Respondents affiliated with SACPCMP generally assigned lower mean rating scores compared to those who are affiliated with ECSA. However, they still assigned most of the benefits mean rating scores over the median value of 3.0, demonstrating that they consider these benefits to be significant. In addition, for benefits B5 and B6, professionals falling under the category "Other", which includes professionals affiliated with the South African Council for the Quantity Survey Profession (SACQSP) and South African Council for the Architectural Professions amongst many other professions, assigned mean rating scores that were relatively closer to those affiliated with ECSA.

The data analysis suggests that respondents affiliated with ECSA appear to give the benefits of 3DCP technology more weight than SACPCMP affiliates as well as "Other" affiliates. The fact that ECSA affiliated respondents value 3DCP technology more than others could also be associated with them being more familiar with the technology. Understanding the diverse viewpoints within the construction industry and developing strategies to promote the adoption and successful implementation of this technology amongst various professional affiliations are made possible by this valuable insight.

- ***Working Experience in the Construction***

This section examines how the respondents' working experience influence their perceptions of the significance of the benefits of 3DCP technology. Figure 4.11b presents the mean rating scores for each benefit across various levels of experience. Figure 4.11b allows for a clear comparison of each benefit's perceived significance across various levels of experiences within the construction industry.

Based on their years of working experience, the respondents' perceptions of the benefits of 3DCP technology highlights a noteworthy trend, as it can be seen in Figure 4.11b. All the benefits were assigned significantly higher mean rating scores from the respondents with less than a year of experience, indicating that they perceive these benefits to be more significant. On the other hand, the mean rating scores tend to generally decrease as the respondents' level of experience increases. Respondents with 1-5 years of experience, 6-10 years of experience, and 11-15 years of experience successively assigned lower mean rating scores for most of the benefits. However, it is crucial to note that even the respondents who are less experienced assigned these benefits the mean rating scores over the median of 3.0, indicating a perspective that is generally favourable. In addition, respondents with over 20 years of experience, as compared to those with 16-20 years of experience, exhibited a slight increase in their mean rating scores. This may suggest that professionals with extensive experience are beginning to recognize the value of 3DCP technology.

These results imply that professionals who are younger or less experienced tend to attribute higher to the benefits of this innovative technology. This insight can, therefore, be used to guide or inform strategies for promoting the adoption and successful implementation amongst professionals with various degrees of experience in the construction industry.

- **Organizational Size**

This section explores how the respondents' perceptions of the significance of the benefits of 3DCP technology are influenced by the size of the companies they work for. The mean rating scores, categorized by organizational size, are visually presented in the radar chart in Appendix C titled "Organizational Size". This chart provides a side-by-side comparison of how different organizational sizes influence their perceptions.

The radar chart in Appendix C titled "Organizational Size" highlights several significant findings on how the respondents' perceptions of the benefits of 3DCP technology are influenced by organizational size. Respondents from companies with 1-10 employees consistently assigned all benefits higher mean rating scores indicating that they perceive these benefits to be more significant. The mean rating scores are a little bit lower but still over the median of 3.0 for companies with 11-50 employees. This implies that respondents working under small- to medium-sized companies (SMEs) still regard these benefits to be significant. In comparison to smaller companies, the mean rating scores are relatively lower in comparison with 51-100 employees. However, the evaluations are still overwhelmingly favourable, showing that even medium-sized companies value these benefits. Furthermore, the mean rating scores of respondents with 101-500 employees exhibit similar mean rating scores to those that work under smaller companies. This indicates that these benefits are consistently valued across a range of company sizes. Moreover, it is interesting to note that respondents from companies with more than 500 workers assigned most of the benefits somewhat higher mean rating scores than the respondents who work under medium-sized companies. This suggests that larger companies perceive the benefits of 3DCP technology more favourable.

These results imply that organizational size have an influence the respondents' perception, although the benefits of the technology are typically acknowledged across a range of company sizes. This information can direct targeted strategies for promoting the adoption and successful implementation of 3DCP technology in various organizational contexts.

- **Organizational Type**

This section examines how the respondents' perceptions of the significance of the benefits associated with 3DCP technology are influenced by the sort of sectors they work under. The mean rating scores for each benefit, categorised by the organizational type, are visually presented on the radar chart in Appendix C titled "Organizational Type". This chart provides a comparative analysis of how various sectors influence the perceptions of the benefits of this innovative technology by highlighting several key insights.

Reading from the radar chart in Appendix C titled "Organizational Type" and comparing the respondents from the private to those from the government/public sector, the latter group assigned somewhat lower mean rating scores. However, these mean rating scores are still overwhelmingly favourable, indicating that the benefits associated with 3DCP technology are still deemed significant in the government/public sector. On the other hand, respondents from the private sector assigned most of the benefits somewhat higher mean rating scores. This suggests that those who work for private companies may have a more favourable perception of the benefits of 3DCP technology.

Overall, the results show that even though organizational type does have some influence on the respondents' perceptions, both respondents from the government/public and private sectors typically regard the benefits of 3DCP technology to be significant. This knowledge is quite useful for tailoring strategies to promote the adoption and successful implementation of this technology in various organizational contexts.

- **Types of Construction Projects**

This section explores how the survey respondents' involvement in various types of construction projects influence how they perceive the benefits of 3DCP technology. The radar chart in Appendix titled "Construction Project Type" visually represents the mean rating scores for each benefit, categorized according to the types of construction projects they were involvement.

The radar chard titled “Construction Project Type” highlights several noteworthy observations about how the respondents’ participation in different kinds of construction projects influence how they view the benefits of 3DCP technology. Respondents who were involved on residential and commercial construction projects consistently assigned all the benefits high mean rating scores. This indicates that these professionals believe that the application of 3DCP technology within these project categories offers significant benefits. The positive feedback from those respondents working in infrastructure and industrial projects suggests that 3DCP technology has a lot of potential in these fields. Furthermore, the mean rating scores from respondents who worked on institutional and renovation/remodelling construction projects were largely favourable, indicating that 3DCP technology may also be beneficial in the contexts.

Overall, the results confirm the respondents' broad belief that 3DCP technology has a significant positive impact on a range of construction projects. These insights can direct the focused application of this technology across various project types in the South African construction industry.

4.5. Rating the Significance of Potential Barriers

This section concentrates on assessing the significance of the potential barriers towards the adoption and successful implementation of 3DCP technology in the South African construction industry. The respondents, comprising various industry professionals and experts, were asked to rate these potential barriers on a scale from “Not Significant” (1) to “Highly Significant” (5). This methodical approach makes it possible to identify the challenges that the respondents believe are the most significant, providing insightful information into the areas that require immediate attention and intervention. This assessment helps in making decisions about policy and offers information for adoption strategies by quantifying concerns and nuances in perceptions. In the end, it lays a foundation for proactive measures meant to surmount obstacles and make it possible for the integration of 3DCP technology, fostering innovation within the South African construction industry.

4.5.1. Cronbach’s Alpha Coefficient Test for the Barriers

To evaluate the reliability of the responses about the perceived significance of the potential barriers to the adoption and implementation of 3D concrete printing technology in the construction industry, the study conducted a Cronbach’s Alpha Coefficient test in this section. The calculated coefficient value of 0.83 denotes a higher degree of internal consistency amongst the ratings assigned by the respondents. This high degree of consistency strengthens the reliability and dependability of the survey data in relation to the barriers, hence boosting the overall validity of the future study. Furthermore, it emphasizes that the survey questions on the significance of these barriers elicited reliable and consistent responses from the broad set of respondents, further bolstering the validity of the study's findings and insights.

4.5.2. Mean Rating Scores of Potential Barriers

This section examines the mean rating scores of the potential barriers. These mean rating scores provide valuable insights into how the respondents perceive the significance of each potential barrier concerning the adoption and successful implementation of 3D concrete printing technology in the South African construction industry. It is important to notice that the potential barriers are marked with reference codes to aid in clarity and understanding as shown in Table 4.2.

Table 4.2: Codes for potential barriers to the adoption of 3DCP technology

Code	**Potential barriers to the adoption of 3DCP technology**
BA1	High initial investment
BA2	Lack of government incentives and support
BA3	Lack of design codes and standards
BA4	Risk aversion
BA5	Limited awareness of the benefits
BA6	Lack of 3DCP experts
BA7	Fragmentation of supply chain and procurement
BA8	Concerns about job loss for unskilled workers
BA9	Unpredictable weather conditions
BA10	Limited production size

- ***Educational background***

Figure 4.12 presents a visual representation of the perceived potential barriers to the adoption of 3DCP technology amongst respondents with different educational backgrounds. The mean rating scores associated with each category, which provide an insightful perspective on the significance of these potential barriers, are presented in Figure 4.12.

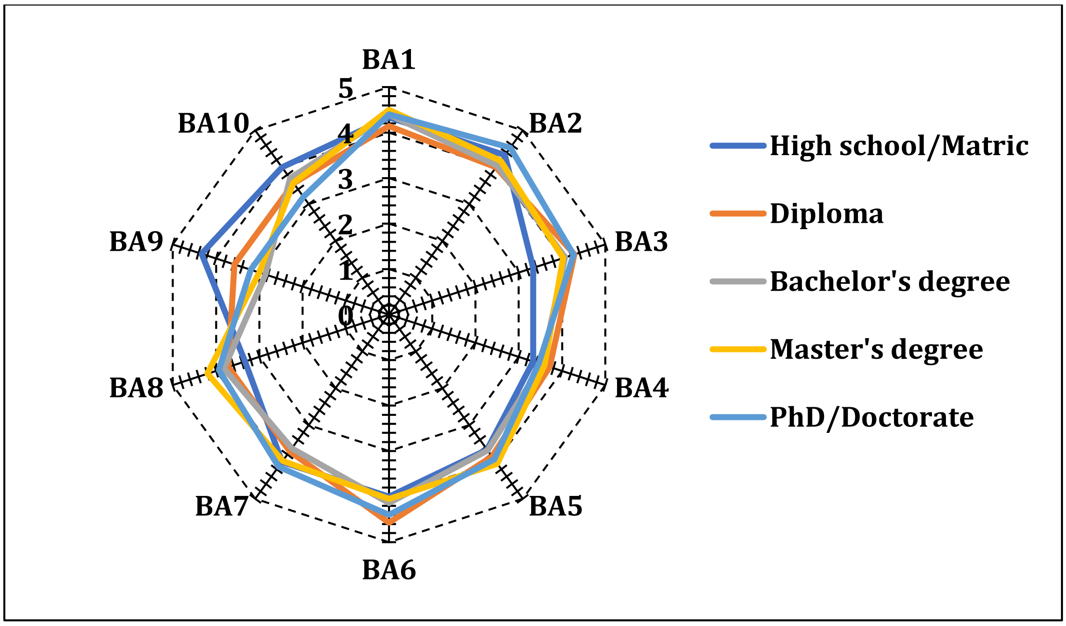

Figure 4.12: Mean rating scores of barriers based on respondents' educational background.

Respondents in possession of a high school/matric qualification rated barriers BA1 and BA9 as the most concerning, both with the highest mean rating score of 4.3. On the other hand, this group of respondents assigned relatively low mean ratings to barriers BA3, BA4, and BA8. According to them, the most significant barriers to the adoption of 3DCP technology are financial aspects and weather-related difficulties. Furthermore, respondents holding a diploma qualification expressed their concerns by rating barriers BA6, BA1, and BA3 as the most significant, with mean rating scores of 4.6, 4.3, and 4.1, respectively. Surprisingly, this group rated barriers BA9 and BA10 as the least concern, demonstrating that they are aware of the lack of skilled experts in the industry.

Respondents in possession of a bachelor's degree rated barriers BA1 as the most significant, with a mean rating score of 4.4, followed by barriers BA3 and BA6, with a similar mean rating score of 4.1. In contrast, this group perceives barriers BA10 and BA8 as the least significant, demonstrating more concern about the financial and skill-related aspects of adopting 3DCP technology. Moreover, respondents holding Master's degree rated barrier BA1 as the most significant, with a mean rating score of 4.5, followed by barrier BA2, with a mean rating score of 4.2. This group also assigned lower mean rating scores to barriers BA8 and BA10 as the least significant, demonstrating that they share the same financial concerns with those in possession of bachelor's degree. In addition, respondents holding PhD/Doctorate degree, rated barrier BA2 as the highest concerning, with a mean rating score of 4.5, followed by barriers BA2 and BA6, with a similar mean rating score of 4.2. In contract, this group rated barriers BA9 and BA10 as the least significant, demonstrating that their priorities are in line with regulatory and skill-related aspects of 3DCP technology adoption.

When taking a broader view, considering respondents from various educational backgrounds, barrier BA1 stands out to be the most substantial, with an overall mean rating score of 4.4. These results highlight the fact that, regardless of the respondent's educational background, financial factors are a recurring theme in the way the industry perceives the challenges associated with the adoption of 3DCP technology. In summary, while there are subtle variances in respondents' perceptions, the analysis of their educational backgrounds suggests that the most significant barrier to the adoption of 3DCP technology in the construction industry consistently emerges as the high initial investment. These results highlight the critical need for financial strategies and incentives that are suited to the various educational backgrounds in the industry to promote the widespread adoption of 3DCP technology.

- ***Roles in the construction industry***

The analysis of the mean rating scores given by the respondents based on their roles within the construction industry exhibits insightful information regarding the perceived significance of the barriers to the adoption and implementation of 3DCP technology. These findings are illustrated visually in Figure 4.13.

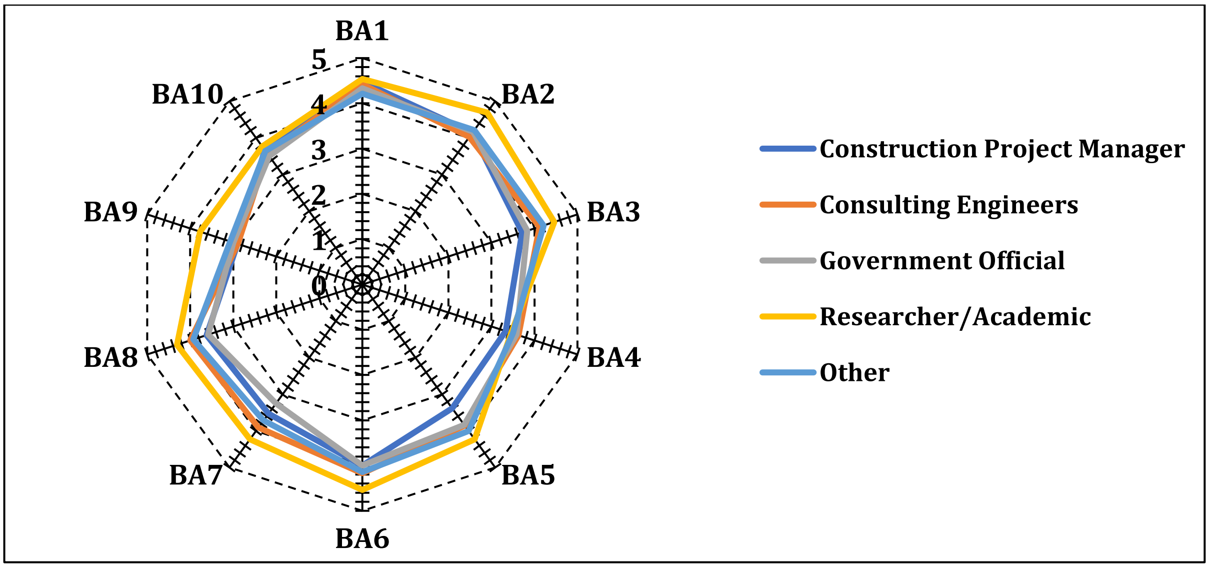

Figure 4.13: Mean rating scores of barriers based on the respondents' roles in the construction industry.

Construction project managers highlighted barrier BA1 as the most concerning, with a mean rating score of 4.5, indicating its substantial significance. They also highlighted barriers BA2 and BA3 as significant, with mean rating scores of 4.1 and 3.7, respectively. This group of professionals appear to be highly aware of the financial and regulatory barriers to the adoption and successful implementation of 3DCP technology. On the other hand, consulting engineers have similar concerns about barrier BA1, which they have assigned a high mean rating score of 4.4. They have also emphasized how significant barrier BA6 is, with a mean rating score of 4.2. These findings highlight their emphasis on financial considerations and the availability of qualified professionals in the field of 3DCP technology.

Government officials ranked barrier BA1 as the most significant, with a mean rating score of 4.3, followed by barrier BA3, with mean rating score of 3.8. These group of respondents emphasise the necessity for assistance and standards in the process of adopting 3DCP technology. Furthermore, researchers and academics rated barrier BA2 as highly significant, with an outstanding mean rating score of 4.7. Other barriers such as BA5 and BA3 were highly rated. This group of respondents appear to have a concrete understanding of the potential regulatory barriers and the necessity of providing incentives to promote the widespread adoption of this technology. In addition, the general category of "Other" rated barrier BA1 as the most significant, with a mean rating score of 4.2, followed by barrier BA6, with a mean rating score of 4.1. Their concerns are like those of consulting engineers and project managers.

A comprehensive analysis of all construction industry roles indicates a recurring pattern, with barrier BA1, which has an overall mean rating score of 4.4, continuing to be the biggest obstacle. This recurring theme highlights the widespread industry concern about the costs associated with the adoption of 3DCP technology. In conclusion, the analysis of various roles played by the respondents in the South African construction industry reveals a common concern about the high initial cost of implementing 3DCP technology. The importance of financial methods and incentives to promote the widespread adoption of this technology across the industry is highlighted by this concord.

- ***Professional affiliation***

This section analyses the respondents' ratings based on their professional affiliations in the construction industry and offers insightful information into how their affiliations influence their perceptions of the significance of the potential barriers to the uptake of 3DCP technology. These findings are illustrated visually in Figure 4.14.

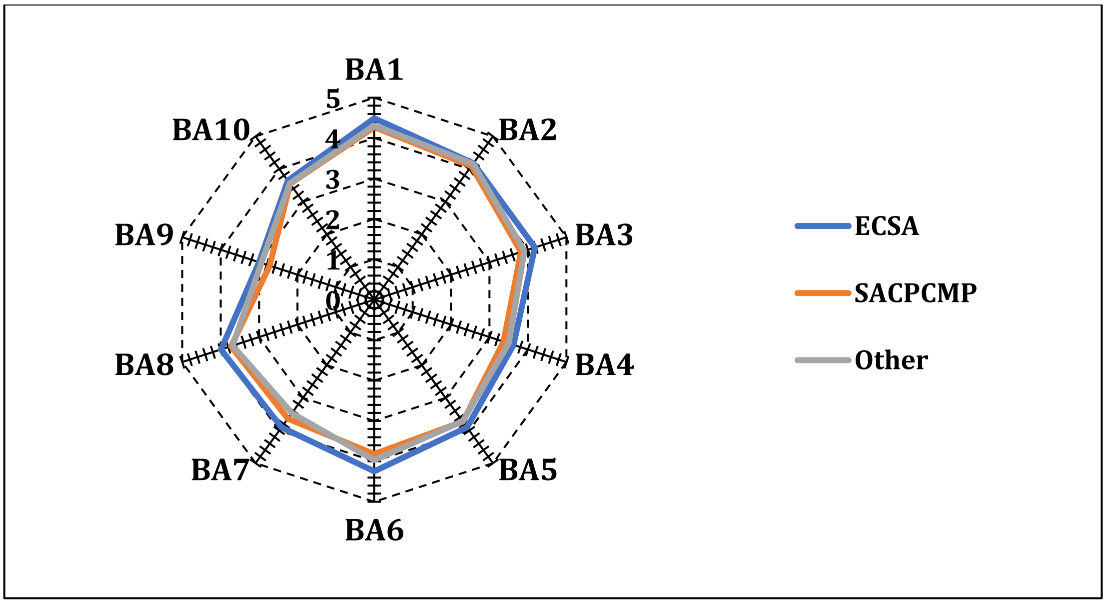

Figure 4.14: Mean rating scores based on respondents' professional affiliation.

Barrier BA1 was rated as the most prominent by respondents affiliated with ECSA, with the highest mean rating score of 4.5, closely followed by barrier BA6, with a mean rating score of 4.2. This group of professionals seem to be concerned highly concerned about the financial aspects associated with the adoption of 3DCP technology and the availability of experts in this field. On the other hand, respondents affiliated with SACPCMP rated barrier BA1 with the highest meaning rating score of 4.3, which is slightly lower than the mean rating score assigned by ECSA-affiliated respondents. Similarly, this group rated barriers BA8 and BA3 as significant, with mean rating scores of 3.7 and 3.8, respectively. This group considers the financial aspects and employment concerns as significant barriers to the adoption and successful implementation of 3DCP technology in the South African construction industry. Furthermore, professionals belonging to the “Other” category, rated barrier BA1 as the most significant, with a mean rating score of 4.3, followed by barrier BA6, with a mean rating score of 4.0. This group’s main concerns are quite like those of ECSA, with an emphasis on financial considerations and the availability of experts.

An overall analysis of all professional affiliations illustrates a common trend, with barrier BA1 being consistently rated as the most significant, with an overall mean rating score of 4.4. This highlights the general concern about the financial implications of adopting 3DCP technology in the South African construction industry. In conclusion, the analysis of the respondents’ professional affiliations suggests an agreement that financial barriers, particularly the high initial investment, represent a significant roadblock to the widespread adoption and implementation of 3DCP technology. These results highlight the necessity of resolving financial concerns and advocating cost-effective strategies to promote the adoption of this technology in the industry.

- ***Working experience in the construction industry***

The analysis of the respondents' mean rating scores according to their experience working in the construction industry provides insightful information about how their tenure influences their perceptions of the potential barriers to the adoption and implementation of 3DCP technology. These results highlight noteworthy trends and themes, which are presented in Figure 4.15.

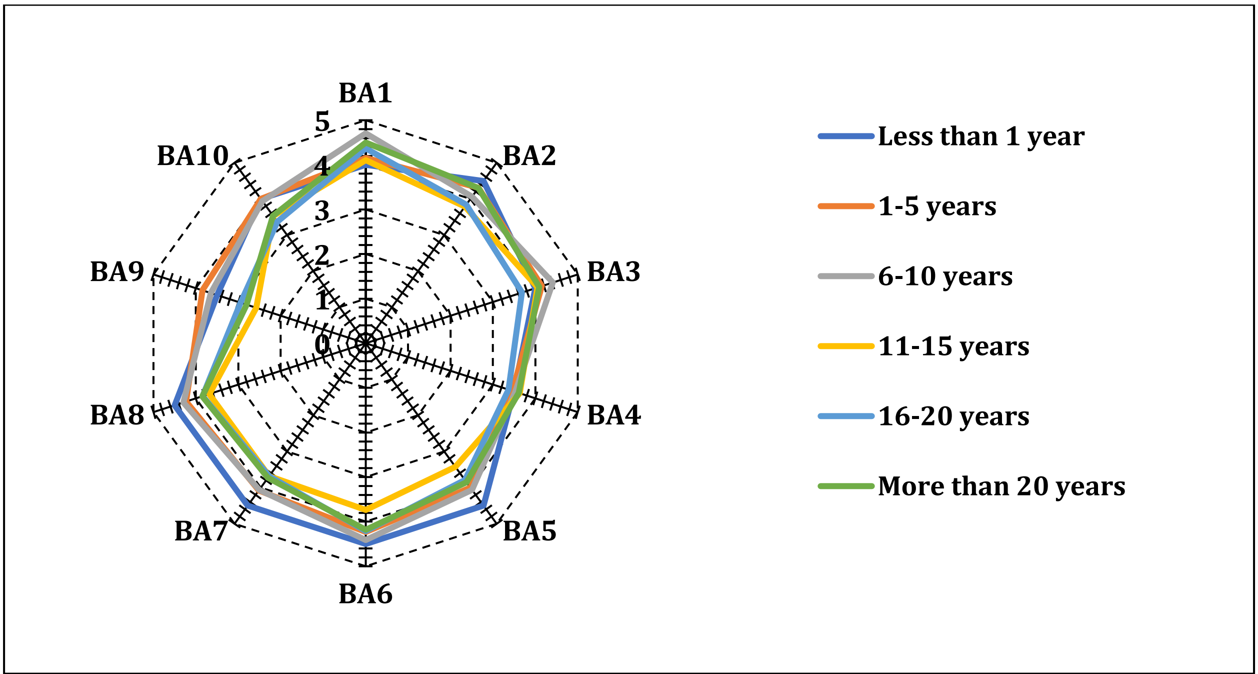

Figure 4.15: Mean rating scores of respondents based on their working experience.

Respondents with less than 1 year of working experience in the construction industry rated barriers BA2, BA5, BA6, BA7, and BA8 as highly significant, with a similar mean rating score of 4.5, followed by barriers BA1, BA3, and BA10, also with a similar mean rating score of 4.0. This group of respondents may perceive these barriers to be of great concern due to their limited exposure to the construction industry. On the other hand, respondents with 1-5 years of experience rated barrier BA2 as highly significant, with a mean rating score of 4.3, followed by barriers BA1, BA3, BA6, and BA8, with a similar mean rating score of 4.2, respectively. It is interesting to see that this group is more concerned about barriers related to financial and knowledge-based aspects. Furthermore, respondents with 6-10 years of experience rated barrier BA1 as the most significant, with the highest mean rating score of 4.7, followed by barrier BA6, with a mean rating score of 4.4. They also highlighted concerns about barrier BA8 and BA10. This group of respondents appears to strike a balance between its concerns about both labour and financial related issues.

Respondents with 11-15 years of experience, point out barriers BA1 and BA3 as the most significant, with a similar mean rating of 4.1, followed by barriers BA4 and BA8, with a similar mean rating score of 3.7. Barrier BA9 was rated as the least concerning, with a lower mean rating score of 2.6, indicating that this barrier would require less attention given their level of experience in managing such issues. Moreover, respondents with 16-20 years of experience rated barriers BA1 and BA6 as the most significant, with mean rating scores of 4.4 and 4.2, respectively. They also rated barriers BA8 and BA7 to be of concern. Barrier BA9 received the lowest mean rating score of 2.9 as the least significant, like respondents with 11-15 years of experience. In addition, respondents with more than 20 years of experience highly rated barriers BA1 and BA3, with mean rating scores of 4.5 and 4.1, respectively, followed by barrier BA8, demonstrating similar concerns with those with 16-20 years of experience. Barrier BA9 remains the least rated among all the barriers.

In summary, the analysis of these barriers across various levels of experience points out several recurring trends. A widespread industrial concern is reflected by the fact that barrier BA1 is highlighted as the most significant, followed by barriers BA6, BA2, BA5, and BA7. These results highlight how crucial it is to address financial concerns, the development of expertise, and regulatory support to encourage the adoption and successful implementation of 3DCP technology in the construction industry. This attempt may be more effective if strategies are tailored to address the unique challenges of industry professionals with various degrees of expertise.

- ***Organizational size***

Figure 4.16 visually depicts the results of the analysis of the respondents' ratings of potential barriers to the uptake of 3D concrete printing technology based on their organizational size within the construction industry, revealing noteworthy trends and insights.

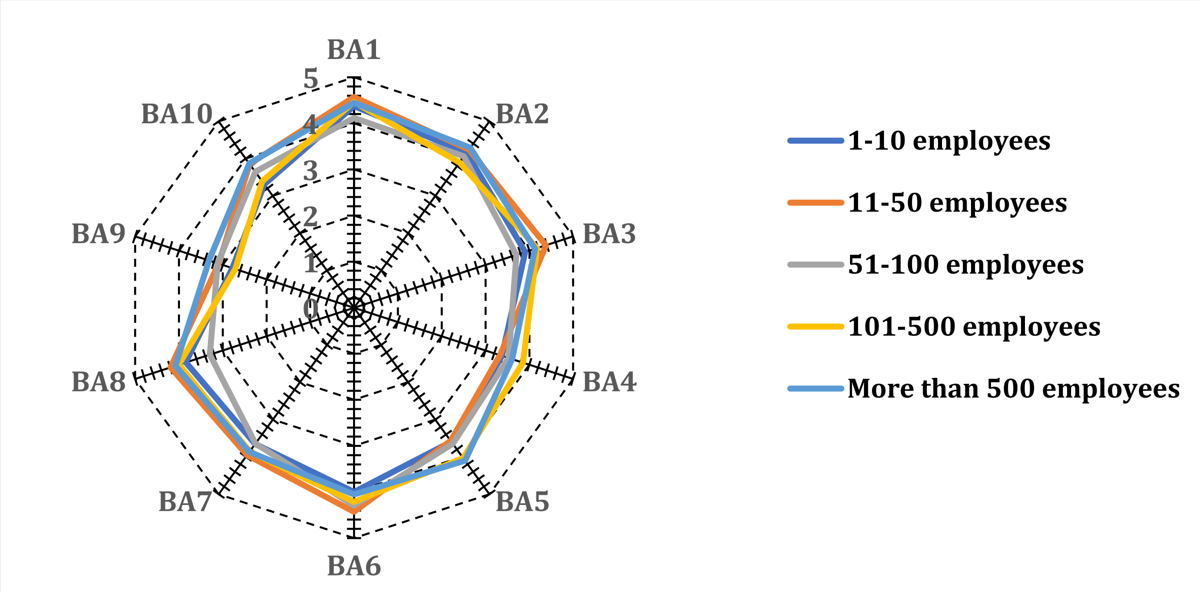

Figure 4.16: Mean rating scores of barriers based on respondents' organizational size.

Respondents from small companies with 1-10 employees rated barrier BA1 as the most concerning, with a mean rating score of 4.4, followed by barriers BA2 and barrier BA3, with mean rating scores of 4.2 and 3.9, respectively, indicating that they are attentive of the financial and awareness-related barriers. Barriers BA10 and BA4 were the least concerning, with mean rating scores of 3.3 and 3.4, respectively. On the other hand, respondents from companies with 11-50 employees highlighted barrier BA1 as highly significant, with a mean rating score of 4.6, in line with smaller companies, followed by barrier BA3 and BA6, with a similar mean rating score of 4.4, respectively. Furthermore, respondents from companies with 51-100 employees also rated barriers BA1 as the most significant, with a mean rating score of 4.1. They also assigned higher mean rating scores to barriers BA6 and BA7 of 4.3 and 4.0, respectively.

Respondents from companies with 101-500 employees perceive barriers BA1 and BA3 as the most significant, with mean rating scores of 4.5 and 4.2, followed by barriers BA6 and BA5, with mean rating scores of 4.2 and 4.0, respectively. It is worth noting that this group appears to be more concerned with the requirement for expertise and regulatory support. In addition, companies with over 500 employees rated barrier BA1 to be the most significant, with a mean rating score of 4.4. They have also rated barriers BA3 and BA6 as the most concerning, thereby emphasizing the value of expertise and regulatory support, as does the group with 101-500 employees.

In summary, the analysis of all the barriers to the adoption of 3DCP technology across various organizational sizes highlights several interesting trends. Barrier BA1 consistently appears as the most significant, showing a common financial concern shared by organizations of all sizes.

Additionally, recurring themes include the requirement for regulatory support and the development of 3DCP expertise. These results highlight the significance of addressing financial barriers, encouraging the development of expertise, and supporting regulatory frameworks to promote the adoption and successful implementation of 3DCP technology in the South African construction industry. To effectively overcome these barriers, there is a necessity to tailor strategies to the specific needs and goals of organizations of different sizes.

- ***Organizational type***

The accompanying radar chart, Figure 4.17, which illustrates the evaluation of potential barriers to the adoption of 3D concrete printing technology within the South African construction industry based on the respondents' affiliations with the government/public or public sectors, provides useful insights into the dynamics of these two segments.

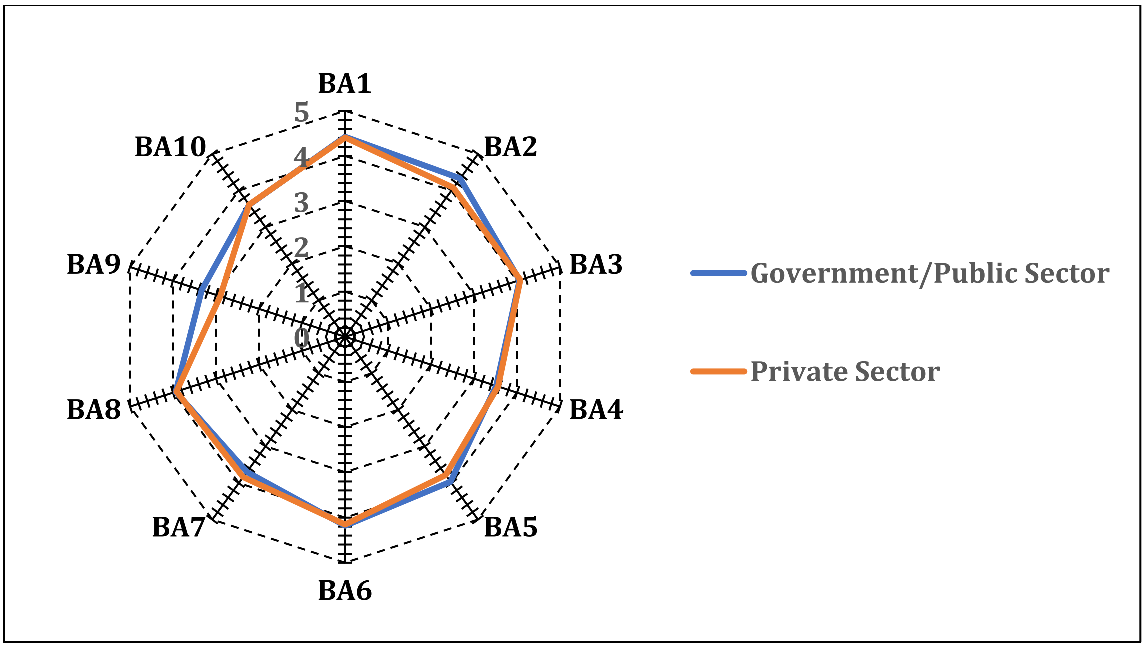

Figure 4.17: Mean rating scores of benefits based on respondents' organizational type.

Respondents affiliated with the government/public sector rated barrier BA1 as the most significant, with a mean rating score of 4.4, thereby highlighting the financial concerns confronting the government entities. This is followed by barriers BA2 and BA3, which were highly rated with mean rating scores of 4.3 and 4.1. However, barrier BA9 was the least rated, with a mean rating score of 3.3. On the other hand, respondents from the private sector share similar perceptions with the public sector as they rated barrier BA1 as the most significant, with a mean rating score of 4.4, thereby highlighting that financial concerns are universally shared across all sectors. This is followed by barriers BA2 and BA3, with mean rating scores of 4.3 and 4.1, respectively. Barrier BA9 was, once again, rated as the least concerning, with a mean rating score of 2.9.

Overall, barrier BA1 continues to be the most noticeable across both sectors, indicating the construction industry-wide financial challenges in South Africa. Barriers BA2 and BA3 highlight the necessity for government support and regulatory frameworks. To successfully facilitate the adoption and implementation of 3DCP technology in the construction industry, both the private and public sectors need to recognize these common goals and work towards resolving the financial barriers and cultivating regulatory support.

- ***Construction project type***

The analysis of the respondents' ratings according to the types of construction projects they were involved in provides insightful information about how their tenure influences their perceptions of the potential barriers to the uptake of 3DCP technology. These results highlight noteworthy trends and themes, which are presented in Figure 4.18.

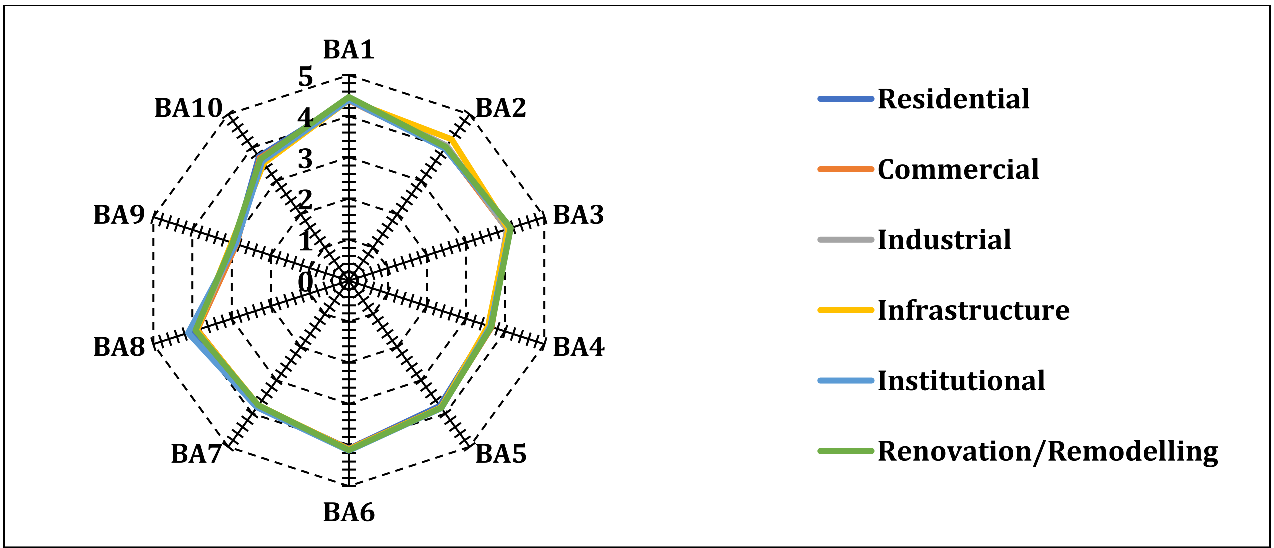

Figure 4.18: Mean rating scores of barriers based on respondents' types of projects they were involved in.

A comprehensive analysis of Figure 4.18 reveals several important trends of the barriers to the uptake of 3DCP technology across various construction project types. It is very interesting to note from Figure 4.18 that barrier BA1 was consistently rated as the most significant barrier across all project types, with an overall mean rating score of 4.4. This demonstrates how crucial it is to address financial barriers across the board. Although the overall mean rating scores indicate a high agreement in perceptions of barriers across various construction project types, it is important to note that the organizations participating in these projects face similar challenges in the adoption and implementation of 3DCP technology in the construction industry.

- ***Familiarity with 3D concrete printing technology***

The assessment of the respondents' knowledge of 3D concrete printing technology provides insight into their awareness of and familiarity with this innovative construction technology. Figure 4.19 visually depicts the perceived familiarity with 3D concrete printing technology within the South African construction industry, grouped their familiarity with this technology.

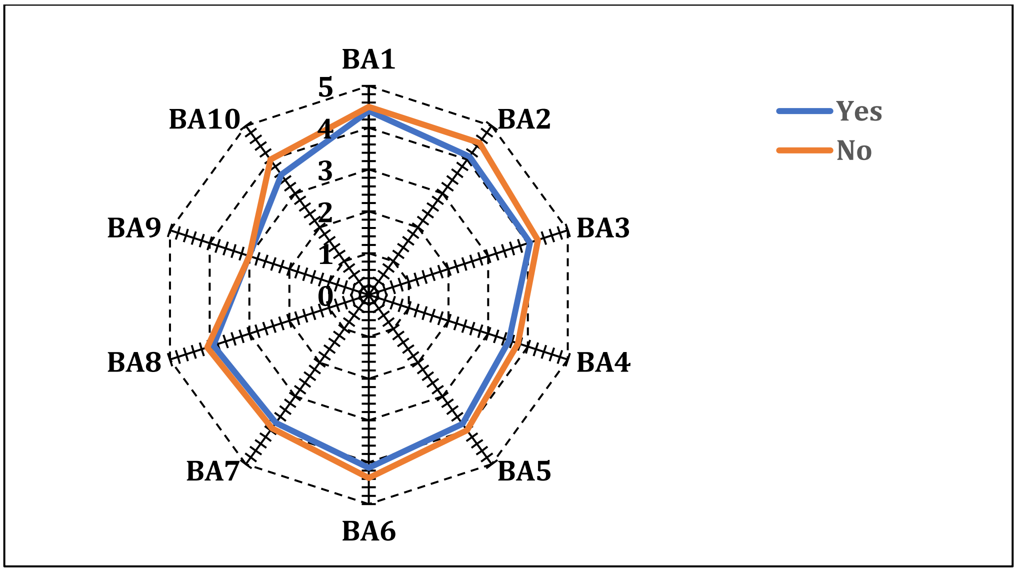

Figure 4.19: Mean rating scores of barriers based on the respondents' familiarity with 3DCP technology.

Respondents who are familiar with 3DCP technology consistently perceived the significance of potential barriers as being less significant than those who are not. Barrier BA1 was rated as significant by those familiar with the technology, with a high mean rating score of 4.5, indicating their understanding of the potential financial implications. Other barriers such as BA2, BA3, and BA4 also obtained comparatively lower mean rating scores. On the other hand, respondents who are unfamiliar with 3DCP technology highlighted barriers BA3 and BA5 as significant, with mean rating scores of 4.3 and 4.0, respectively.

The variations in barrier perceptions between respondents who are familiar with 3DCP technology and those who are not are clearly depicted in Figure 4.19. The perceived significance of barriers seems to decrease with technology familiarity. However, it is interesting to see that even respondents who are familiar with this technology still see these barriers as major obstacles to its adoption. Barriers BA1 is still a major concern for both parties, emphasising its importance in the context of 3DCP technology in South Africa. In conclusion, the analysis shows that, even though familiarity with this technology may mitigate the perceived significance of some barriers, the construction industry professionals, despite their level of knowledge, recognize the challenges posed by factors such as high initial investment and necessity for the supportive government policies and standards. These results highlight how crucial it is to address these barriers to facilitate the adoption and successful implementation of 3DCP technology in the South African construction industry.

- ***Knowledge of 3DCP technology***

The respondents' knowledge of 3DCP technology is assessed in this section. The knowledge levels of respondents and their perceptions of the potential barriers are shown visually in Figure 4.20.

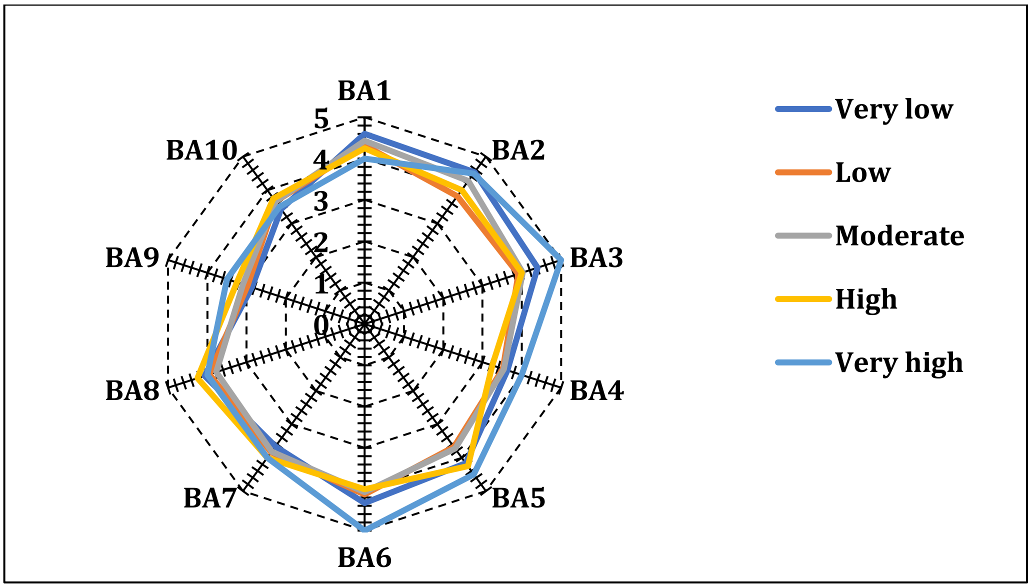

Figure 4.20: Mean rating scores of barriers based on respondents' level of knowledge of 3DCP technology.

Respondents who indicated to have "very high" level of knowledge of 3DCP technology assigned most of the barriers higher mean rating scores. For instance, barriers BA3 and BA6 both have an exceptionally high mean rating score of 5.0, highlighting the connection between the lack of design codes and standards and 3DCP experts and a greater perception of the significance of this barrier. Barriers BA7 and BA9 were both given reasonable mean rating scores of 3.6 and 3.7, respectively, in this category. On the other hand, respondents who indicated to have "low" to "moderate" have also expressed concerns regarding these barriers. Even though their mean rating scores were generally lower as compared to those with very low knowledge, they nonetheless rated some of these barriers significantly. For instance, barrier BA4 was consistently assigned higher mean rating scores ranging from 3.5 to 3.9, regardless of the level of knowledge.

Furthermore, respondents who indicated to have "high" level of knowledge expressed concerns about the potential barriers by assigning mean rating scores that are high. This group of respondents consistently assigned high mean rating scores to all the barriers, signifying that a deeper understanding of 3DCP technology is associated with a high perception of the significance of these potential barriers. Overall, Figure 4.20 visually shows a significant correlation between respondents' knowledge levels and their perceptions of these barriers. The perceived significance of these barriers decreases with an increase in the level of knowledge of 3DCP technology. This is particularly clear when it comes to barrier BA5, which has lower mean rating scores from this group of respondents.

In conclusion, the data analysis reveals that promoting 3DCP technology awareness and education could play a significant role in mitigating these barriers. Those who are highly knowledgeable about this technology appear to be more optimistic about its potential and less concerned about any challenges that may arise. Therefore, promoting a better understanding of this technology within the construction industry could aid in facilitating its smoother integration and implementation.

- ***Experience with 3D concrete printing technology***

This section examines the direct experience that the respondents had with 3DCP technology to determine how that influence their perceptions of these potential barriers. Figure 4.21 visually depicts these relationships.

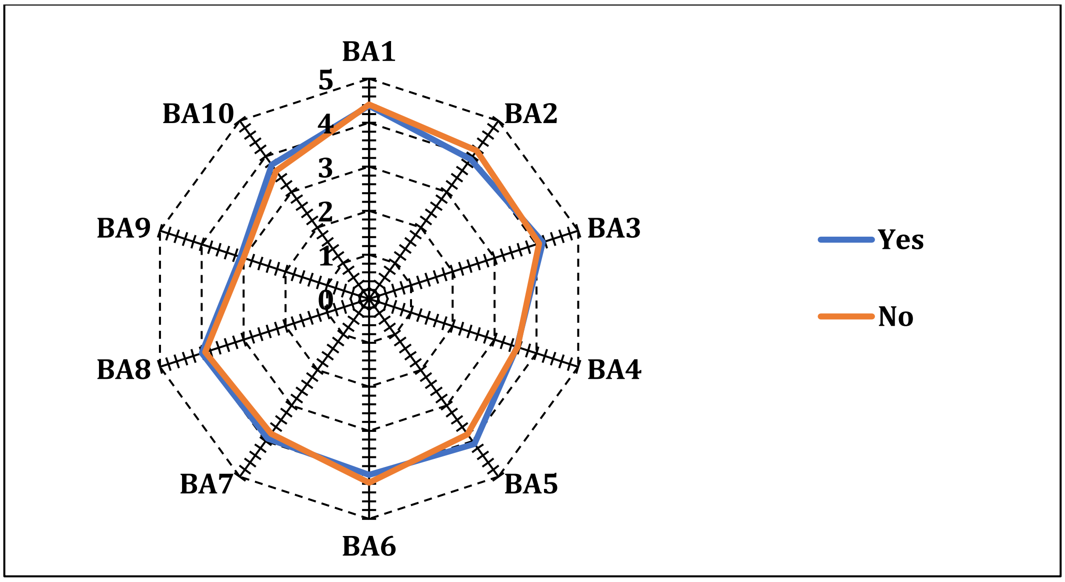

Figure 4.21: Mean rating scores of barriers based on respondents' experience with 3DCP technology.

It is interesting to observe that regardless of having prior experience with 3DCP technology or not, all the respondents rated the barriers somewhat the same way, with barrier BA1 receiving the highest mean rating score of 4.4 from both groups of respondents, indicating that they both consider this barrier to be more significant in hindering the adoption of 3DCP technology. Barriers BA3 and BA6 were also highly rated by both groups, with overall mean rating scores of 4.2 and 4.0, respectively. This implies that regardless of their experience, the perceived financial barrier remains a significant concern for both groups.

Figure 4.22 visually illustrates that both experienced and non-experienced respondents consider these potential barriers to be highly significant. These high ratings suggest that the South African construction industry perceives these barriers as major hindrances to the adoption and successful implementation of 3DCP technology in the industry.

4.5.3. Common Trends and Main Themes

- ***Financial-related barrier***: Across all demographic categories, barriers BA1 and BA4 consistently stand out as major challenges, highlighting that financial difficulties are a recurring theme, thereby emphasizing the need for financial support structures and economic adoption measures.
- ***Regulatory-related barrier***: Barriers BA2 and BA3 emerge as prevalent concerns, highlighting lack of clear regulations and government support for creating an environment that is favourable for the adoption and implementation of 3DCP technology.

- ***Expertise-related barrier***: Barrier BA6 emerged as an issue of concern, highlighting the necessity for bridging the skill gap to successfully implement 3DCP technology in the construction industry.
- ***Awareness-related barrier***: Barrier BA5 emerged as a persistent problem, highlighting the need to increase stakeholder awareness of the benefits of 3DCP technology as a key factor in overcoming this challenge.
- ***Supply chain- and procurement-related barrier***: Barrier BA7 emerged as a significant challenge, highlighting the necessity for streamlining procedures and improving collaboration in the construction supply chain to alleviate this concern.
- ***Socio-economic-related barrier***: Barrier BA8 emerged as an issue of concern in some cases, highlighting the necessity for the implementation of reskilling and workforce transitioning strategies.
- ***Production related barrier***: Barrier BA9 emerged as a concerning problem for some respondents, highlighting the need for the implementation of scalable methods and technical advancements to address this issue.
- ***Industry market culture related barrier***: Barrier BA10 emerged as being of moderate nature, highlighting the need for the implementation of change management strategies and industry-wide awareness campaigns.

- ***Outstanding barriers***

Although each of the identified potential barriers are significant, barriers BA1 and BA2 stand out as the major challenges facing the South African construction industry. Across all demographic groups, these barriers were consistently assigned the highest mean rating scores. These barriers are related since overcoming financial challenges often depends on skills and knowledge in adopting and successfully implementing 3DCP technology.

In conclusion, it is crucial that these major barriers are addressed to promote the effective adoption and implementation of 3DCP technology in the South African construction industry. This may be achieved through the implementation of a mix of financial support, clear regulations, skills development programmes, and awareness initiatives. The success of these initiatives may be further improved by focusing the suggested strategies on specific demographic traits and industry segments, which will eventually aid the industry in moving towards a more creative and sustainable future.

4.6. Likelihood of Potential Barriers Occurring

This section explores the likelihood of the potential barriers to the adoption of 3DCP technology based on respondents' characteristics. The analysis of the data received from the respondents offers insightful information on how these characteristics influence how they perceived these barriers. The mean rating scores of the likelihood of the barriers occurring visually presented on the radar charts in Appendix D. A sample is presented for professional affiliation and years of experience in Figure 4.22a, b.

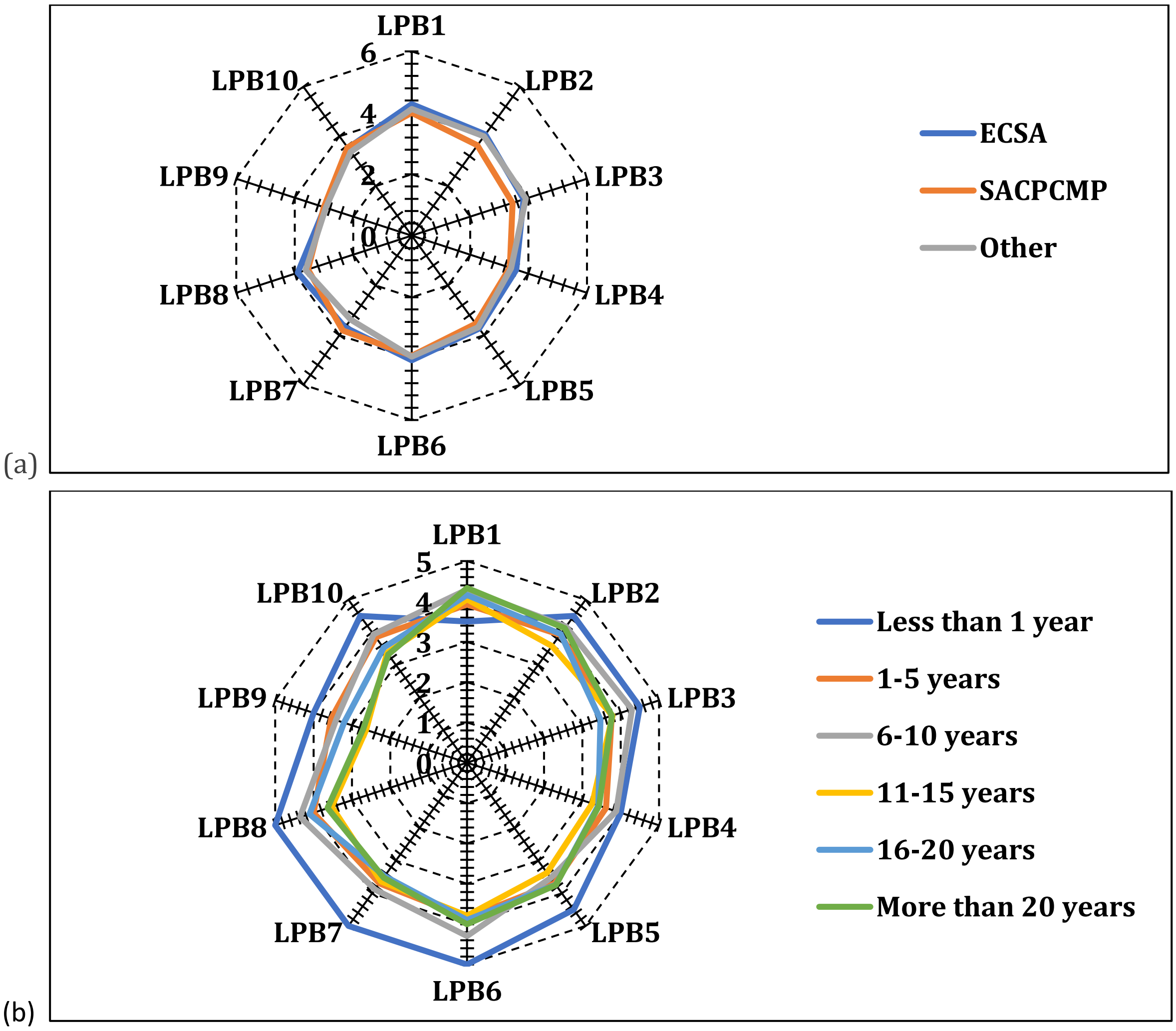

Figure 4.22: Mean rating scores on likelihood of barriers occurring by (a) Professional Affiliation, and (b) Experience.

4.6.1. Cronbach's Alpha Coefficient Test for the Likelihood of Barriers Occurring

Establishing the validity of the data collected is crucial before diving into the analysis of the likelihood of the potential barriers occurring. This high degree of internal consistency amongst the responses is indicated by the Cronbach's Alpha Coefficient value, which was computed to be 0.87. This value shows that the survey questions on the likelihood of the potential barriers have a high reliability, guaranteeing that the data analysis that follows provides precise insights into the respondent perceptions.

4.6.2. Mean Rating Scores of the Likelihood of Barriers Occurring

Table 4.3: Codes for the likelihood of barriers occurring.

Code	Likelihood of potential barriers to the adoption of 3DCP technology
LPB1	High initial investment
LPB2	Lack of government incentives and support
LPB3	Lack of design codes and standards
LPB4	Risk aversion
LPB5	Limited awareness of the benefits
LPB6	Lack of 3DCP experts
LPB7	Fragmentation of supply chain and procurement
LPB8	Concerns about job loss for unskilled workers
LPB9	Unpredictable weather conditions
LPB10	Limited production size

- ***Educational Background***

The educational background of the survey respondents provides various perspectives on the likelihood of the potential barriers occurring. Respondents in possession of a Master's and PhD/Doctorate degrees assigned the likelihood of the potential barriers occurring significantly lower mean rating scores. Across all educational levels, the respondents rated barrier BA1 to have a high probability of occurring, whereas those with higher degrees tend to be optimistic. This highlights that professionals with a higher level of education foster a more optimistic perspective, which may be due to their deeper understanding of the technology and its inherent benefits.

- ***Roles in the Construction Industry***

The roles of the respondents in the construction industry played a significant role in shaping their perceptions of the likelihood of potential barriers occurring. The mean rating scores assigned by the construction project managers and consulting engineers were slightly higher, with construction project managers expressing their concerns regarding the likelihood of barrier BA8 occurring. However, researchers, academics, government officials, and respondents in the "Other" category appear to have an optimistic view, possibly due to their participation in research and policymaking.

- ***Professional Affiliations***

Respondents affiliated with various professional bodies showed varying perceptions of the likelihood of the barriers occurring. Professionals falling under ECSA assigned lower mean rating scores in comparison to those affiliated with SACPCMP and those under the "Other" category. These results reveal that ECSA-affiliated professionals perceive the adoption of 3DCP technology as having a more favourable environment.

- ***Work Experience***

The level of work experience in the construction has a significant influence on the respondents' perception of the barriers. The likelihood of the barriers to the adoption of 3DCP technology was significantly rated higher by respondents with less than 1 year of experience, whereas those with 6-10 years and over assigned lower mean rating scores. Respondents with higher levels of experience appear to understand the significance of BA6 and BA2, possibly due to their experience and exposure to the construction industry practices.

- ***Organizational Size***

The sizes of the companies that where survey respondents work play a major role in how they perceive these barriers. Respondents from smaller organizations, with 1-10 employees, appeared to be more concerned about the likelihood of BA1 and BA3 occurring. Furthermore, respondents from larger companies, with more than 500 employees, are also concerned about similar barriers but generally appear to be more optimistic, thereby demonstrating that organizations might influence measures tailored to address these barriers.

- ***Organizational Type***

The type of organizations, be it government/public or private sector, that the respondents are affiliated with influences their perceptions of the barriers. Based on their ratings, respondents from the government/public sector were more concerned about the barriers in general, with barrier BA3 standing out to be a significant factor. On the other hand, the respondents from the private sector appeared to be more optimistic, possibly because of their decision-making and investment flexibility.

- ***Construction Project Type***

The types of projects that the respondents have been involved in also have an influence on their perception of the barriers, although with minimal variation. Respondents from all project categories share similar concerns about the barriers based on their mean rating scores. Barrier BA1 was consistently assigned the highest mean rating score, followed by barriers BA3 and BA6.

- ***Familiarity, Knowledge, and Experience with 3DCP Technology***

The familiarity, knowledge, and experience of the respondents with 3DCP technology had a major influence on their perceptions of the barriers to its adoption. Respondents with more experience and familiarity with the technology tend to hold more optimistic perspectives, illustrated by the lower mean rating scores of the barriers. Therefore, these barriers are less concerning to respondents with 3DCP technology, highlighting the importance of real-world exposure.

- ***Overall Summary***

Overall, respondents from all categories consistently rated the likelihood of barrier BA1 occurring as a persistent concern. The likelihood of barriers BA3, BA6, and BA2 also stand out as the recurring themes. These results highlight how significant it is to address financial-related barriers and encourage the development of expertise and regulatory frameworks to promote the adoption and successful implementation of 3DCP technology in the South African construction industry. These challenges can effectively be resolved by tailoring strategies to cater to the unique needs and priorities of various groups of respondents.

4.7. Ranking Strategies Based on Significance

4.7.1. Cronbach's Alpha Coefficient Test for the Improvement Strategies

Before delving into the mean rating scores of the improvement strategies for the adoption of 3DCP technology in the South African construction industry, it is important to note that the reliability of the ratings was evaluated using Cronbach's Alpha coefficient. The coefficient value of 0.94 was obtained, indicating that a high degree of internal consistency amongst the survey respondents' responses regarding the strategies.

4.7.2. Mean Rating Scores of the Improvement Strategies

To gain insight into how various industrial categories perceived the improvement strategies for the adoption of 3DCP technology, the mean rating scores for each category of respondents' profiles were computed. The improvement strategies were assigned unique codes as presented in Table 4.4. The mean rating scores are presented as radar charts for professional affiliation and years of experience in Figure 4.23, with those for all respondent profile categories in Appendix E as complete set of charts.

Table 4.4: Codes for the improvement strategies

Code	**Improvement strategies for the adoption of 3DCP technology**
IMP1	Providing subsidies or financial incentives for adopting the technology
IMP2	Offering training and educational programs for construction professionals
IMP3	Collaborating with research institutions and industry experts
IMP4	Developing design codes and standards for 3DCP technology
IMP5	Increasing awareness of the benefits and capabilities of the technology
IMP6	Developing a pool of skilled experts in 3DCP technology
IMP7	Streamlining the supply chain and procurement processes
IMP8	Implementing measures to address job loss concerns
IMP9	Mitigating the impact of unpredictable weather conditions
IMP10	Promoting research and development for larger-scale production

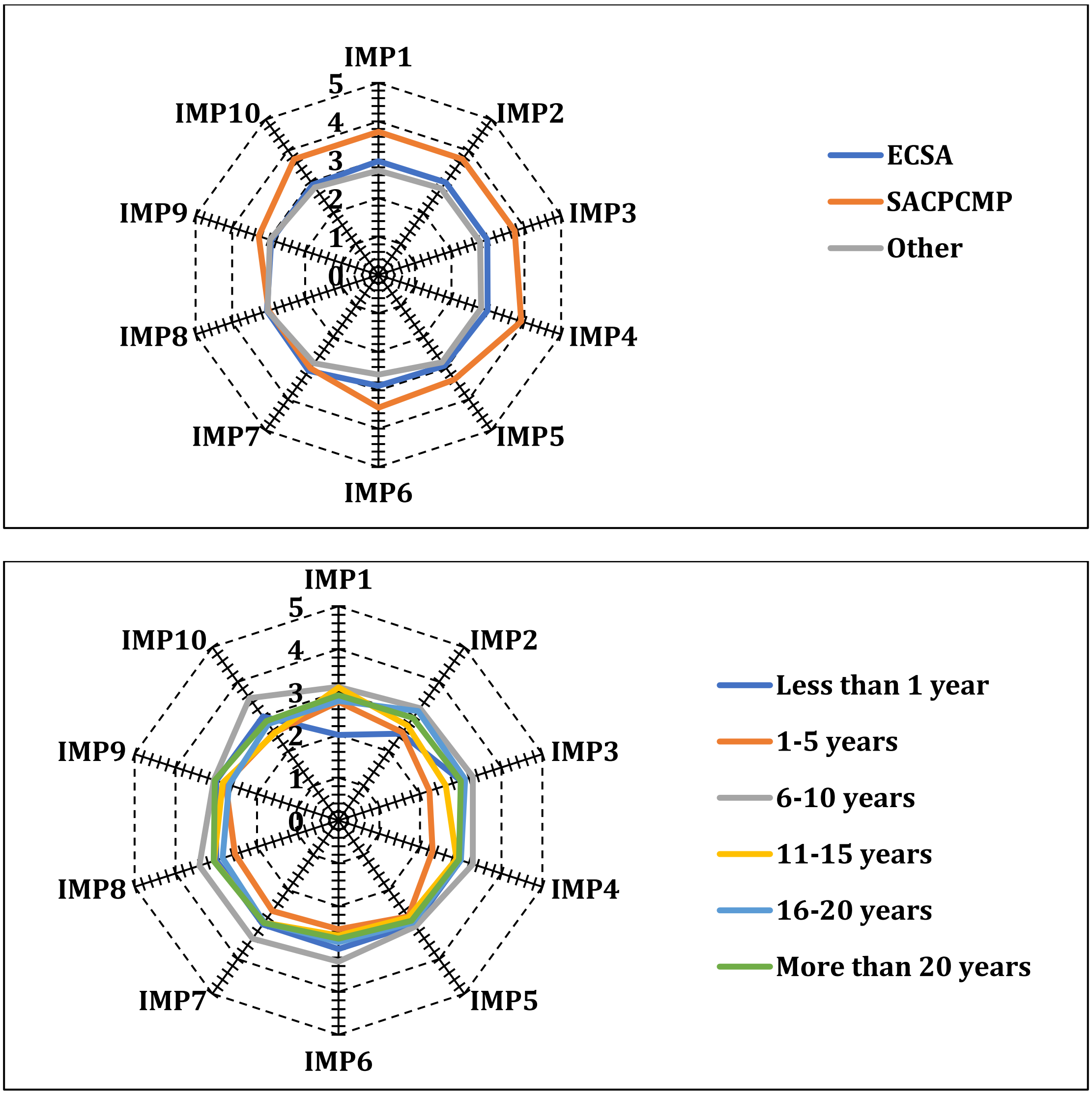

Figure 4.23: Mean rating scores on improvement strategies to overcome barriers by (a) Professional Affiliation, and (b) Experience.

- ***Educational Background***

The educational background of the respondents has an influence on how they perceive the improvement strategies for the adoption of 3DCP technology. Respondents in possession of a Bachelor's, Master's, and PhD/Doctorate degrees highly ranked improvement strategies IMP1 and IMP4 as significant, with consistency. Reading from the radar chart titled "Educational Background" in Appendix F, improvement strategy IMP1 was highly rated, with an overall mean rating score of 1.5, followed closely by IMP4, with a mean rating score of 2.3, highlighting the importance of providing financial incentives for the adoption of 3DCP technology and developing special design codes and standards for this technology.

- ***Roles in the Industry***

Various roles in the construction industry had an influence on how the respondents rated the strategies. Construction project managers and consulting engineers jointly rated improvement strategy IMP3 as the most significant, highlighting the necessity for collaboration between research institutions and industry experts. On the other hand, government officials highly rated improvement strategy IMP8 as highly significant, highlighting the importance of implementing the necessary measures to address concerns related to job losses, thereby reflecting their responsibility in dealing with societal and employment implications associated with technological adoption.

- **Professional Affiliations**

Various professional affiliations within the construction industry had an influence on how the respondents rated the strategies. Respondents affiliated with SACPCMP rated improvement strategy IMP4 as significant, highlighting the necessity of developing special design codes and standards for 3DCP technology. On the other hand, those who are affiliated with ECSA highly rated improvement strategy IMP1 as significant, emphasizing the necessity for providing financial incentives for adopting 3DCP technology, and highlighting the economic factors that engineers frequently take into consideration.

- ***Experience in the Industry***

Various degrees of experience of the respondents in the construction industry had an influence on how they rated the strategies. Respondents with between 6 and 10 years of working experience highly rated improvement strategy IMP4, highlighting the necessity for regulatory frameworks through developing special design codes and standards for 3DCP technology. On the other hand, respondents with less than 1 year of working experience assigned a high mean rating score to improvement strategy IMP2, highlighting the necessity for skill development through offering training and educational programs for construction professionals.

- ***Organizational Size***

Various organizational sizes in the construction industry had an influence on how the respondents rated the strategies. Respondents from companies with between 51 and 100 employees rated the improvement strategy IMP5 as significant, highlighting their focus on operational efficiency and the necessity for streamlining the supply chain and procurement processes. On the other hand, smaller companies with between 1 and 10 employees highly rated improvement strategy IMP1, highlighting their financial considerations and the necessity for providing financial incentives to promote the adoption of 3DCP technology.

- ***Organizational Type***

Various organizational types (sectors) in the construction industry had an influence on how the respondents rated the strategies. Respondents from both the government/public and private sectors highly rated improvement strategy IMP4 as significant, highlighting the necessity for the development of special design codes and standards from 3DCP technology. These findings suggest the importance of regulatory frameworks regardless of the sector.

- ***Familiarity with 3DCP Technology***

The ratings of the strategies by the respondents were shaped by their familiarity with 3DCP technology. Respondents who indicated that they are familiar with the technology kept an emphasis on improvement strategy IMP1, highlighting the need for providing financial incentives for the adoption of 3DCP technology. On the other hand, those who indicated to be unfamiliar with 3DCP technology highlighted improvement strategy IMP9 as significant, indicating their concerns related to operational challenges, and the necessity for mitigating the impact of unpredictable weather conditions.

- **Knowledge of 3DCP Technology**

The ratings of the strategies by the respondents were shaped by their knowledge of 3DCP technology. Respondents who indicated to have high knowledge of 3DCP technology highlighted the improvement strategy IMP4 as significant, highlighting the necessity for the development of special design codes and standards for this technology. Contrarily, those who indicated to have very low knowledge highlighted the improvement strategy IMP8 as of high significance, indicating the necessity for the implementation of strategic measures to address job loss concerns.

- **Experience with 3DCP Technology**

The ratings of the strategies by the respondents were shaped by their experience with 3DCP technology. Respondents with hands-on experience with 3DCP technology assigned highly rated improvement strategy IMP6 as significant, highlighting the necessity for the development of a pool of skilled experts in the field of 3DCP technology. On the other hand, those with no prior experience highlighted the improvement strategy IMP1 as significant, emphasizing the necessity for the provision of financial incentives to promote the adoption of 3DCP technology.

In summary, the mean rating scores of all the strategies within each category offer insightful information about the preferences of various responder groups. This information can aid the construction industry stakeholders and policymakers in creating specialized policies to promote the adoption and implementation of 3DCP technology.

4.8. Implications for the South African Construction Industry

In this section, the implication of the findings of the research study for the South African construction industry is discussed, taking into consideration the defined research objectives, results, their thorough analysis. The insightful information derived from this research study provides valuable guidance for the industry stakeholders, policymakers, and practitioners to navigate the landscape of the adoption and implementation of 3DCP technology in the South African construction industry.

4.8.1. Implications for the Study Objectives

The objectives of the research study, which were formulated to examine the benefits, potential barrier, and improvement strategies associated with the adoption and implementation of 3DCP technology in the South African construction industry.

4.8.1.1. Unveiling the Benefits of 3DCP Technology

Table 4.5 presents the overall mean rating scores assigned to the identified benefits of 3DCP technology by the South African construction industry professionals across all categories, ranked according to their significance. The presented table is followed by a detailed discussion of the results, the exploration of the benefits, and the grouping of the benefits based on their thematic relevance to provide valuable insights into the potential benefits that this technology can offer to the South African construction industry.

Table 4.5: Ranking of 3DCP Technology Benefits

Rank	Benefit	Mean Rating Score
1	Enhanced precision and accuracy (B6)	4.0
1	Improved quality control (B7)	4.0
3	Faster construction speed (B1)	3.9
3	Reduced construction material wastage (B3)	3.9
5	Improved customization (B5)	3.8
6	Reduced health and safety hazards (B4)	3.7
6	Improved performance in housing delivery (B8)	3.7
8	Cost-effectiveness (B2)	3.3

- ***Group1: Efficiency and Precision***

Benefits B6 and B7 were the two highest rated, with a similar mean rating score of 4.0, highlighting how significant precision and quality are within the South African construction industry. These benefits illustrate the ability of 3DCP technology to produce construction outcomes with exacting precision and ensure high-quality and consistent results across projects. This suggests that this technology is perceived as a game-changing construction technique by the industry professionals for improving construction precision and quality assurance.

- ***Group 2: Speed and Efficiency***

Benefits B1 and B3 were the second highly ranked, with a similar mean rating score of 3.9, highlighting 3DCP technology's capacity to speed up construction processes and minimize material wastage. This suggests that the South African construction industry professionals are aware of this technology's potential to shorten project timelines while aligning with construction sustainability goals.

- ***Group 3: Customization and Adaptability***

Benefit B5 was fairly rated above the median, with a mean rating score of 3.8, which illustrate the potential of 3DCP technology to accommodate unique projects needs and produce complex designs, offering a significant advantage in a variety of construction situations. Although this benefit was not rated as the highest, it highlights how flexible and adaptable the technology is in meeting a variety of construction project requirements in South Africa.

- ***Group 4: Safety and Health and Improved Performance in Housing Delivery***

Benefits B4 and B8 were rated as moderately significant, with a similar mean rating score of 3.7, highlighting the potential of 3DCP technology to improve safety in the construction environment as it is one of the fundamental aspects in the industry as well as improving the efficiency of housing delivery. Safer construction practices within the industry can be achieved through the recognition of benefit B4 and effective delivery of housing projects can be achieved through the recognition of benefit B8.

- ***Group 5: Cost-Effectiveness***

Benefit B2 was slightly rate lower than all the other benefits, with a mean rating of 3.3. Despite being rated the lowest, the assigned mean rating score is still above the median, indicating that the industry professionals recognise the potential of 3DCP technology to enhance the efficiency and cost-effectiveness of delivering housing projects, thereby addressing the challenge of housing in South Africa.

In summary, ranking of the potential benefits of 3DCP technology provided an insight into how the South African construction industry professionals perceive them. The benefits that were highly ranked emphasize the importance of precision, quality control, construction speed, and sustainability within the construction industry. These findings provide insights that the industry stakeholders can use to make strategic decisions and investments in the adoption of 3DCP technology.

4.8.1.2. Navigating Barriers to the Adoption of 3DCP Technology

In the process of thoroughly understanding the complexity of adopting and implementing 3DCP technology within the South African construction industry, the study delved deep into the analyses of various potential barriers that emerged. Table 4.6 presents the rankings and the mean rating scores assigned by the professionals in the construction industry across all categories, ranked according to their significance, followed by the rankings, and grouping of the barriers to provide insightful information into the potential challenges of adopting this technology.

Table 4.6: Ranking of Barriers to 3DCP Technology Adoption

Rank	Barrier	Mean Rating Score
1	High initial investment (BA1)	4.4
2	Lack of 3DCP experts (BA6)	4.2
3	Lack of government incentives and support (BA2)	4.1
3	Lack of design codes and standards (BA3)	4.1
4	Concerns about job loss for unskilled workers (BA8)	3.9
5	Limited of awareness (BA5)	3.8
5	Fragmentation of supply chain and procurement systems (BA7)	3.8
7	Risk aversion (BA4)	3.6
7	Limited production size (BA10)	3.6
9	Unpredictable weather conditions (BA9)	3.0

- ***Group 1: Financial and Regulatory Challenges***

Barrier BA1 was the highest rated across all categories, with an overall mean rating score of 4.4, highlighting the requirement for financial resources to support the adoption and implementation of 3DCP technology in the construction industry. This was closely followed by barriers BA2 and BA3, with a similar mean rating score of 4.1, highlighting the significant role that the government can play in providing financial support and regulatory frameworks to govern 3DCP technology. Including these barriers under Group 1 signifies the financial and regulatory challenges that need to be collectively addressed.

- ***Group 2: Human Capital and Skill Development***

BA8 was the fourth highest ranked barrier with an overall mean rating score of 3.9, highlighting the concerns that the industry professionals have regarding the potential of the current construction workforce having their jobs displaced due to the adoption of 3DCP technology. On the other hand, barrier BA6 was ranked as the second highest, highlighting the importance of having skilled professionals in the construction industry to harness the potential associated with this technology. In addition, this barrier emphasises the necessity to train and nurture the current workforce to be proficient in operating 3DCP technology effectively.

- ***Group 3: Awareness and Perception Challenges***

Barriers BA5 and BA7 were ranked the fifth highest, with a similar overall mean rating score of 3.8. These two barriers are grouped together since they both focus on challenges related to awareness and perception. Barrier BA5 highlights the necessity to raise awareness regarding the potential benefits of 3DCP technology, while barrier BA7 highlights the concerns related to the fragmentation of the supply chain and procurement processes. These barriers altogether highlight the importance of understanding and partnership amongst the construction industry stakeholders.

- ***Group 5: Diverse Challenges***

Barriers BA4 and BA10 were both ranked seventh, with a similar mean rating score of 3.6. These two barriers are grouped altogether given that they have the potential to influence the adoption and implementation of 3DCP technology. On the other hand, barrier BA9 was rated the lowest amongst all barriers, with an overall mean rating score of 3.0, highlighting a moderate significance of unpredictable weather conditions during construction as a potential challenge.

In summary, the ranking and grouping of these barriers, with each group presenting various challenges, offer an extensive understanding of the barriers that could potentially hinder the adoption of 3DCP technology. These challenges call for collaborative efforts and various strategies tailored to effectively mitigate them. The analysis of these barriers provides insightful information that can serve as a foundation for developing improvement strategies targeted to navigate them to facilitate the successful integration of 3DCP technology.

4.8.1.3. Strategic Measures to Overcome Barriers

In the process of identifying and analysing the barriers associated with the adoption of 3DCP technology within the South African construction industry, the study also delves into the exploration of improvement strategies to overcome these barriers. The overall mean rating scores assigned by the professionals across all categories are presented in Table 4.7, with 2.8 being the highest score and 3.0 being the lowest based on the reversed Likert scale (1 representing the most significant and 5 representing the least significant).

Table 4.7: Ranking of 3DCP Improvement Strategies

Rank	Improvement Strategy	Mean Rating Score
1	Developing a pool of skilled experts in 3D concrete printing technology (IMP6)	2.8
2	Providing subsidies or financial incentives for adopting the technology (IMP1)	2.9
3	Offering training and educational programs for construction professionals (IMP2)	2.9
4	Collaborating with research institutions and industry experts (IMP3)	2.9
5	Developing design codes and standards for 3D concrete printing (IMP4)	2.9
6	Increasing awareness of the benefits and capabilities of the technology (IMP5)	2.9
7	Mitigating the impact of unpredictable weather conditions (IMP9)	2.9
8	Promoting research and development for larger-scale production (IMP10)	2.9
9	Streamlining the supply chain and procurement processes (IMP7)	3.0
10	Implementing measures to address job loss concerns (IMP8)	3.0

- ***Group 1: Skill Development and Expertise***

Improvement strategy IMP6 was highly ranked, with an overall mean rating score of 2.8, highlighting that the South African construction industry professionals acknowledge the importance of developing a skilled workforce to be proficient in 3DCP technology. Strategies IMP1, IMP2, IMP3, IMP5, and IMP9 were also highly ranked, with a similar overall mean rating score of 2.9, highlighting the necessity of the construction industry to address the challenges associated with labour, skill development, incentives, awareness, and education.

- ***Group 2: Supply Chain and Procurement***

Strategies IMP7 and IMP8 were both assigned slightly lower mean rating scores of 3.0 even though they are still important, highlighting the necessity for the optimization of the supply chain and procurement systems and addressing job loss-related concerns. Although these strategies were ranked lower in comparison with the rest, they are still considered one of the vital aspects of adopting and implementing 3DCP technology in the South African construction industry.

In summary, the ranking of these improvement strategies offers insightful information into how the South African construction industry prioritises them when it comes to addressing the potential barriers associated with the adoption of 3DCP technology. The development of skills and expertise in the field of 3DCP technology is of paramount importance, followed by financial support, awareness, and education. The optimization of the supply chain and concerns regarding job loss are also perceived as important. The insights derived from this analysis can aid in guiding the construction industry stakeholders, policymakers, and other industry role players in tailoring strategic plans to smoothen the process of integrating 3DCP technology into the South African construction industry.

4.8.2. Implications for the South African Construction Industry

The implications of this research study go beyond just the research objectives, providing a wider view of how 3DCP technology can potentially transform the South African construction industry. The findings of this research study suggests that the adoption and implementation of 3DCP technology in the South African construction industry can enhance construction productivity through faster construction speed and cost-efficiency. This implies that the construction industry can consistently meet project deadlines, cut expenses related to operations, and boost overall competitiveness. The study further highlights the potential of this innovative technology to contribute towards to sustainability goals through minimizing construction material wastage. This suggest that the industry can support global environmental agendas by adopting more environmentally friendly construction practices.

The necessity for re-skilling and upskilling the construction workforce is highlighted by the emphasis on human capital development. This has implications for the construction industry stakeholders and training institutions who must be in collaboration with one another to close the skills gap. Moreover, collaboration with research and academic institutions and industry professionals may turn South Africa as the leading African country in the field of 3DCP technology. As a result, South Africa could be one of the leading countries in construction technology through fostering a culture of continuous technological improvement. In addition, policymakers are urged to take into consideration the implications of this research study when formulating policies for technological integration to succeed through resolving the issue of lack of government incentives and support. South African must ensure that it remains competitive as the global construction industry progressively adopts and implement 3DCP technology. Hence, adopting this innovative technology places South Africa in line with international trends in construction and promote it as a desirable investment destination.

This section concludes by highlighting the multifaced implications of this research study for the South African construction industry. The insights of the study offer a blueprint for maximizing the potential of 3DCP technology, fostering efficiency, sustainability, and innovation, and establishing South Africa as a major participant in the continuously evolving global construction industry.

4.9. Concluding Summary

To fully comprehend the potential of 3DCP technology, the challenges this technology is confronted with, and best implementation strategies for the South African construction industry, this research study delved deep into its multifaceted landscape. It is essential to consider the key insights and their wider implications before a conclusion is made.

4.9.1. 3DCP Technology's Transformative Potential

The finding of this research study holds enormous potential for the South African construction industry since 3DCP technology is positioned to be a transformative force due to its capability to speed up construction processes, increase cost effectiveness, reduce construction material wastage, and improve customization and precision. The ability of this technology to address these barriers swiftly and economically is of the utmost importance in a developing country such as South Africa where there exist housing demand crisis and rising demand for infrastructural development.

4.9.2. Strategic Action to Overcome the Barriers

To fully realise the potential of 3DCP technology, the finding of this research study has also showed serious barriers that need to be addressed. The significant barriers include high initial investment, lack of government support, lack of awareness of the benefits, fragmentation in the supply chain and procurement systems. However, these barriers can still be overcome. This research study has uncovered clear strategies that can act as a cornerstone for overcoming these barriers. Streamlining the supply chain and procurement processes, mitigating the effects of weather-related disruptions, and fostering research and development for large-scale production have been identified and highlighted as effective strategies for enabling the effective integration of 3DCP technology.

4.9.3. Significance for the South African Construction Industry

The findings of this research study have implications that go beyond the scope. These implications have a strong resonance with the South African construction industry, which is essential for both economic development and the progress of the society. The South African construction industry can enhance productivity, improve sustainability, and promote construction innovation through the adoption and implementation of 3DCP technology, thereby playing a significant role in minimizing the country's pressing housing crisis.

4.9.4. Proposed Initiatives

This research study issues out proposed initiatives in its conclusion as the South African construction industry is at crossroads, and the adoption and application of 3DCP technology offers a route to revolutionary transformation. The industry stakeholders must work collaboratively and strategically to take advantage of this opportunity. Furthermore, governmental organizations can supportively promote construction innovation through the provision of incentives, facilitating educational and training programmes as well establishing supportive regulatory frameworks. Moreover, to maximize the benefits of this innovative technology, the construction industry's role players should make investments in research and development, form alliances, and streamline operations.

To close the knowledge gap and guarantee that industry professionals are equipped and well-informed about the potential benefits associated with the adoption of 3DCP technology, education and awareness efforts are of utmost importance. Through these initiatives, the construction industry can be able to escape the potential barriers and embrace a more productive, environmentally friendly, and innovative future.

4.9.5. Final Thoughts

In conclusion, this research study supports the notion that 3DCP technology has the potential to revolutionize the South African construction industry. The inherent benefits it provides are tangible, the barriers are addressable, and the improvement strategies can be put into action. The

South African construction industry could progressively transform its future by embracing development, efficiency, and a dedication to addressing the housing and infrastructural development demands in the country by taking immediate action to adopt and implement this innovative technology. As this research study concludes, the future of construction in South Africa is very bright, if the industry rises to the change and recognizes the revolutionary potential of 3DCP technology.

Chapter 5: Conclusions

5.1. Preface

The exploration of 3DCP technology represents a crucial potential turning point in the South African construction industry, where traditional construction methods meet new innovative construction techniques. Although traditional construction methods are still much more prevalent, the quest to achieve productivity, sustainability, and technological advancement has called for a substantial shift. The adoption and successful implementation of 3DCP technology within the South African construction industry is, however, confronted with various obstacle, despite its inherent benefits. This chapter provides a summary of the extensive research conducted to explore these barriers, highlighting the inherent benefits, and providing strategic measures for improvement. The findings of this research provide the industry stakeholders and policymakers with guidance to bridge the gap.

5.2. Summary of Findings

This section presents the summary of the core research findings, highlighting the benefits, barriers, and improvement strategies related to the adoption of 3DCP technology that were highly rated based on their significance by the South African construction industry professionals.

- ***Prominent Benefits***

This research study identified several key benefits of the application of 3DCP technology, with improved precision and accuracy, and improved quality control being the most highly rated, highlighting the potential of this technology to improve construction accuracy and guarantee consistently high-quality output across projects. Furthermore, faster construction speed and reduced construction material wastage emerged as the second highest-rated benefits, highlighting the ability of 3DCP technology to accelerate construction processes while reducing construction material waste. Therefore, these findings confirm that the South African construction industry professionals are aware of the potential of this innovative technology to transform the construction landscape, thereby improving productivity, precision, and sustainability.

- ***Prominent Barriers***

Out of all the identified potential barriers to the adoption of 3DCP technology, high initial investment emerged as the most significant obstacle. This barrier underscores the financial challenges associated with integrating this technology within the construction industry. Following closely were issues such as lack of awareness about the benefits of this technology, insufficient government incentives and support, and a shortage of 3DCP experts. These findings emphasize the need to increase awareness about 3DCP's potential, secure government support to facilitate its integration, and develop a skilled workforce within the construction industry. Therefore, addressing concerns related to awareness, finances, and workforce development is crucial for the effective integration of 3DCP technology within the South African construction industry.

- ***Prominent Improvement Strategies***

Various improvement strategies were identified in this study in response to the potential barriers, with the development of a pool of skilled experts in 3DCP technology emerging as the most highly rated improvement strategy, highlighting the significance of developing a skilled workforce to take full advantage of this technology. The second highest-rated strategy was the provision of subsidies or financial incentives for the adoption of 3DCP technology, highlighting the significance of mitigating the high initial investment barrier. In addition to this, strategies to provide training and educational programmes for the industry professionals and collaborate with research institutions and industry experts also received higher ratings, highlighting the importance of forming collaborations and education to facilitate the successful integration of this innovative technology within the South African construction industry.

In conclusion, the summary of this research findings highlights how important precision, quality control, productivity, and sustainability are as the key benefits of 3DCP technology. At the same time, it draws attention to the critical challenges brought by barriers related to finances and the lack of skilled professionals to operate 3DCP technology. The recommended improvement strategies offer practical solutions to address the barriers associated with the adoption of this technology, with special emphasis on developing educational programmes, collaboration, and financial subsidies to foster innovation, productivity, and sustainability.

5.3. Conclusion

This study carried out an extensive exploration of the potential and challenges posed by 3DCP technology within the context of the South African construction industry, with specific reference to the building sector. Given the unique challenges of the country such as low levels of productivity, housing shortages, concerns related to cost-efficiency, and sustainability, the main critical problem needed to be examined in this study was the adoption and successful implementation of this technology in the South African construction industry.

The findings of this study covered a wide range of critical topics, offering insightful information and recommendations. At the core of these research findings lie substantial benefits that 3DCP technology can offer to the construction industry such as improved precision and quality control, the acceleration of construction processes, and the potential to minimize construction material wastage. However, these barriers are accompanied by several critical barriers such as the high initial investment required, lack of government support and design standards, and legitimate concerns related to the loss of jobs for the unskilled workforce. These findings led to the identification of several strategic measures tailored to improve the uptake of this technology. At the forefront of these strategies lies the necessity for the industry to develop a skilled workforce since highly skilled construction professionals are required to harness the full potential of the application of this innovative technology. Therefore, it is of paramount importance for the industry to invest in training and educational programmes to close the skills gap and ensure that the workforce is proficient in operating this technology.

Furthermore, these findings highlight the value of forming collaborations amongst various construction industry stakeholders, regulatory bodies, and research institutions to foster innovation and ensure that the operation of 3DCP technology follow the established safety and quality standards. In addition, it is advocated that financial subsidies be introduced to address the considerable challenge of the high initial investment required to adopt 3DCP technology as one of the mainstream construction methods. Finally, the application of 3DCP technology within the construction industry aligns with the global sustainability goals due to its ability to minimize construction material wastage.

In summary, this research study did not only identify the benefits and the potential barriers related to the adoption of 3DCP technology but also outlined strategic measures tailored to smoothen its integration into the South African construction industry. In addition, this research study put an emphasis on the significance of innovation, cooperation, and the development of human capital to promote sustainable and effective construction practices within the South African construction industry. Therefore, the adoption and implementation of 3DCP technology within the construction industry could potentially place South Africa as one of the leading countries in innovative construction technologies, thereby presenting the country's development towards a more sustainable and prosperous future.

5.4. Recommendations for Practice

Based on the findings of this research study, several key recommendations for practice for various industry stakeholders, aiming to effectively facilitate the adoption and implementation of 3DCP technology in the South African construction industry, can be suggested. For government and regulatory bodies, it is essential to collaborate with industry experts and establish a complete set of regulatory frameworks with special design codes and standards for 3DCP technology, develop educational and training programmes, and incentivize 3DCP-related research and development projects.

It is also essential to create awareness of the potential 3DCP technology within the construction industry for the industry professionals and practitioners to stay informed with the continuous advancements of 3DCP technology to gain more knowledge and develop the necessary skills required. Furthermore, it is recommended that 3DCP technology courses and training be included in the curriculum by educational institutions, while research institutions should collaborate with the industry experts and stay focused on practical research in the field of 3DCP technology. Moreover, construction industry associations should lobby for financial support from the government and a supportive legal environment and encourage the industry stakeholders to embrace 3DCP technology as a tool for innovation and sustainability enhancement. Overall, these recommendations place a strong focus on cooperative efforts amongst the construction industry stakeholders to successfully drive the integration of 3DCP technology within the South African construction industry to enhance productivity, innovation, and sustainability.

5.5. Recommendations for Future Research

Future research studies should focus on several crucial areas to advance the application of 3DCP technology in the South African construction industry. It is of paramount importance to start off by addressing the nature of the construction workforce which is continuously evolving. It is recommended that research studies in the future should focus on outlining the set of skills and competencies required to proficiently operate 3DCP technology, thereby resolving concerns related to potential job loss for the unskilled workforce and equipping them with the necessary required knowledge and expertise. Moreover, there is a necessity to conduct research studies aiming at developing new or modifying the current construction design codes and standards to accommodate the unique features of 3DCP technology, assuring compliance with construction safety and quality requirements.

Lastly, there is a necessity for future research studies to conduct a comprehensive cost-benefit analysis specific to South African construction projects through the application of 3DCP technology. This will provide the industry stakeholders with insightful information to make informed decisions and help them understand the financial implications associated with the adoption of 3DCP technology. Therefore, these recommendations serve as a roadmap for future related research studies aiming at addressing the associated challenges and leveraging potentials, thereby positioning South Africa as one of the leading countries in technological advancement, and promoting productivity, innovation, and sustainability within the construction industry.

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Appendices

Appendix A: Survey Questionnaire

Stellenbosch
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forward together
sonke siya phambili
saam vorentoe

3D Concrete Printing Technology: Enhancing Productivity in the South African Construction Industry – Exploring Benefits, Barriers, and Improvement Strategies.

Brief Background

Dear respondents,

Thank you for your interest in participating in our survey on 3D concrete printing technology. We appreciate your willingness to share your insights and experiences regarding this innovative tool that has the potential to enhance productivity in the construction industry. As a game-changing technology with numerous potential benefits, 3D concrete printing technology, based on additive manufacturing processes, involves the use of specialized concrete mixes to fabricate three-dimensional structures layer-by-layer. The survey consists of 14 multiple-choice questions and will take a few minutes to complete. Your input in each section is valuable as we explore the benefits, barriers, and strategies associated with the implementation of 3D concrete printing technology in the South African construction industry. The purpose of this survey is to gather your perceptions and experiences related to 3D concrete printing technology. Your valuable input will help us identify the benefits, barriers, and strategies associated with the implementation of this technology in the South African construction industry. Your participation in this survey is voluntary, and all responses will be kept confidential. We appreciate your contribution to this research. Thank you for your time and participation!

1. Please indicate your educational background *

- ○ High school/Matric
- ○ Diploma
- ○ Bachelor's degree
- ○ Master's degree
- ○ PhD/Doctorate
- ○ Other...

2. Please indicate your role in the construction industry *

- ☐ Construction Project Manager
- ☐ Consulting Engineer
- ☐ Architect
- ☐ Quantity Surveyor
- ☐ Contractor
- ☐ Government official
- ☐ Researcher/Academic
- ☐ Other...

3. Please indicate your professional affiliation *

- [ ] ACPM – Association of Construction Project Managers
- [ ] ECSA – The Engineering Council of South Africa
- [ ] SACPCMP – South African Council for the Project and Construction Management Profession
- [ ] SACAPSA – South African Council for the Architectural Profession
- [ ] SACQSP – The South African Council for the Quantity Survey Profession
- [ ] Other...

4. Please indicate the number of years of experience you have in the construction industry. *

- ○ Less than 1 year
- ○ 1-5 years
- ○ 6-10 years
- ○ 11-15 years
- ○ 16-20 years
- ○ More than 20 years

5. What is the size of your organization? *

- ○ 1-10 employees
- ○ 11-50 employees
- ○ 51-100 employees
- ○ 101-500 employees
- ○ More than 500 employees

6. Please indicate the type of organization you belong to *

- ○ Government/Public Sector
- ○ Private Sector

7. Please indicate the type of construction projects you have been involved with. (Please select all that apply) *

- ☐ Residential
- ☐ Commercial
- ☐ Industrial
- ☐ Infrastructure (roads, bridges, etc.)
- ☐ Institutional (schools, hospitals, etc.)
- ☐ Renovation/Remodelling
- ☐ Other...

8. Have you heard of 3D concrete printing technology before? *

- ◯ Yes
- ◯ No

9. How would you rate your knowledge about 3D concrete printing technology? *

- ◯ Very low
- ◯ Low
- ◯ Moderate
- ◯ High
- ◯ Very high

10. Have you personally experienced or witnessed the use of 3D concrete printing technology in the construction industry? *

- ◯ Yes
- ◯ No

11. Please rate the level of significance of the following benefits of implementing 3D concrete printing technology in the South African construction industry using a five-point Likert scale, where 1 represents "Not Significant" and 5 represents "Highly Significant": *

	1	2	3	4	5
Faster constru...	○	○	○	○	○
Cost-effective	○	○	○	○	○
Reduced const...	○	○	○	○	○
Reduced healt...	○	○	○	○	○
Improved cust...	○	○	○	○	○
Improved preci...	○	○	○	○	○
Improved quali...	○	○	○	○	○
Improved perfo...	○	○	○	○	○

12. Please rate the level of significance of the following potential barriers to the adoption of 3D concrete printing technology in the South African construction industry using a five-point Likert scale, where 1 represents "Not Significant" and 5 represents "Highly Significant": *

	1	2	3	4	5
High initial inve...	○	○	○	○	○
Lack of govern...	○	○	○	○	○
Lack of design ...	○	○	○	○	○
Risk aversion	○	○	○	○	○
Limited awaren...	○	○	○	○	○
Lack of 3D con...	○	○	○	○	○
Fragmentation ...	○	○	○	○	○
Concerns abou...	○	○	○	○	○
Unpredictable ...	○	○	○	○	○
Limited produc...	○	○	○	○	○

13. Please rate the likelihood of the potential barriers listed in question 12 occurring in the adoption of 3D concrete printing technology using a five-point Likert scale, where 1 represents "Highly Unlikely" and 5 represents "Highly Likely."

	1	2	3	4	5
High initial inve...	○	○	○	○	○
Lack of govern...	○	○	○	○	○
Lack of design ...	○	○	○	○	○
Risk aversion	○	○	○	○	○
Limited awaren...	○	○	○	○	○
Lack of 3D con...	○	○	○	○	○
Fragmentation ...	○	○	○	○	○
Concerns abou...	○	○	○	○	○
Unpredictable ...	○	○	○	○	○
Limited produc...	○	○	○	○	○

14. Please rank the strategies listed below based on their significance in promoting the adoption and utilization of 3D concrete printing technology in the South African construction industry, where 1 represents the most significant and 5 represents the least significant: *

	1	2	3	4	5
Providing subsi...					
Offering trainin...					
Collaborating ...					
Developing des...					
Increasing awa...					
Developing a p...					
Streamlining th...					
Implementing ...					
Mitigating the i...					
Promoting rese...					

Appendix B: Ethical Clearance Approval Letter

PROJECT APPROVED WITH STIPULATIONS

REC: Social, Behavioural and Education Research (SBER) - Initial Application Form

5 September 2023

Project number: 27683

Project title: 3D Concrete Printing Technology: Enhancing Productivity in the South African Construction Industry – Exploring Benefits, Barriers, and Improvement strategies.

Dear Mr SP Mogale

The Social, Behavioural and Education Research Ethics Committee (REC: SBE) has reviewed your REC: Social, Behavioural and Education Research (SBER) - Initial Application Form submitted on 22/06/2023 11:03 and approved it with stipulations on 5 September 2023 .

You can proceed with your research activities as long as you adhere to the conditions specified below.

This approval is only valid until the end of the protocol approval period:

Protocol approval date (Humanities)	Protocol expiration date (Humanities)
5 September 2023	4 September 2026

REC STIPULATIONS/CONDITIONS:

Title	Comment
6.6 Storage of electronic data files	The researcher should approach the Research ICT service desk at SU for guidance on using REDCap (https://redcap.sun.ac.za/) or MSForms to administer online surveys. Third-party applications like Google forms or SurveyMonkey are not recommended. Please log a request for assistance via the Research ICT helpdesk at: https://servicedesk.sun.ac.za/jira/plugins/servlet/theme/portal/22.
6.8 How will the data be backed up?	The SU IT division recommends that SU researchers only use SU-vetted cloud storage for their research data. This means that SU researchers should use the institutional MS OneDrive cloud or MS Teams for storage of data. Researchers who need advice or a consultation on their Data Management plan should email the Library's Research Data Management Service, specifically Mr Samuel Simango at rdm@sun.ac.za or log a request at the Research ICT service desk for guidance on Research Data Management solutions at IT: https://servicedesk.sun.ac.za/jira/plugins/servlet/theme/portal/22.

How to respond to the REC: SBE's stipulations:

If you require a final letter from REC: SBE confirming that you have complied with the stipulations mentioned above, please submit your response using the steps provided in the links below. This is a necessary step to receive the confirmation letter.

Instructional video (See: How to edit your online application)

FAQ guide (See: Form FAQs > How to revise/edit my online form)

Template for response letter (See Other templates > Response letter template)

INVESTIGATOR RESPONSIBILITIES

1. Please read the General Investigator Responsibilities attached to this approval letter.
2. Always use your project ID number (27683) in all correspondence with the REC: SBE concerning your project.
3. The REC: SBE has the prerogative to ask further questions, seek additional information, and monitor the conduct of your research, where required.

List of documents approved by the REC: SBE:

Document Type	File Name	Date	Version
Default	Prof Van Zijl CV	21/06/2023	1
Research Protocol/Proposal	Research Proposal	21/06/2023	2
Recruitment material	SURVEY QUESTIONS RECRUITMENT LETTER	21/06/2023	2
Informed Consent Form	SU HUMANITIES Consent_online survey	22/06/2023	1
Data collection tool	Survey Questionnaire Link	22/06/2023	2
Default	SURVEY QUESTIONS	22/06/2023	2

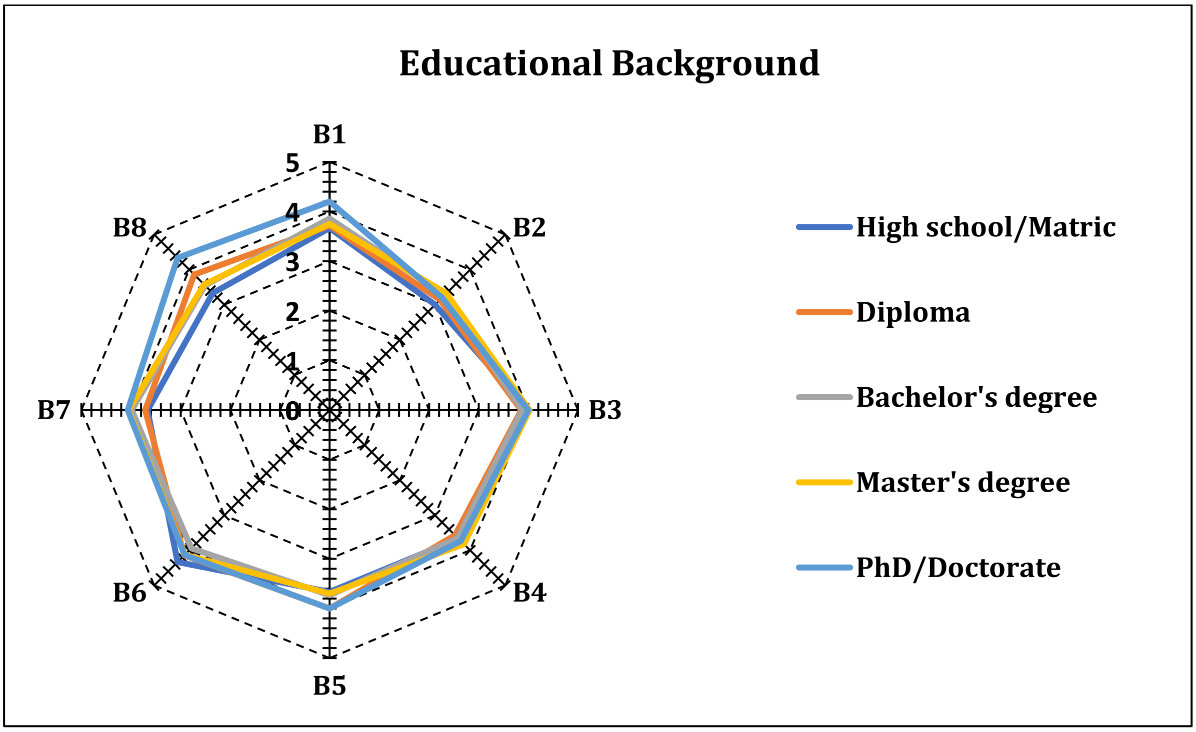
If you have any questions or need advice pertaining to the contents of this letter, please contact the REC administrative officer, Mr Aden Williams at aden@sun.ac.za.

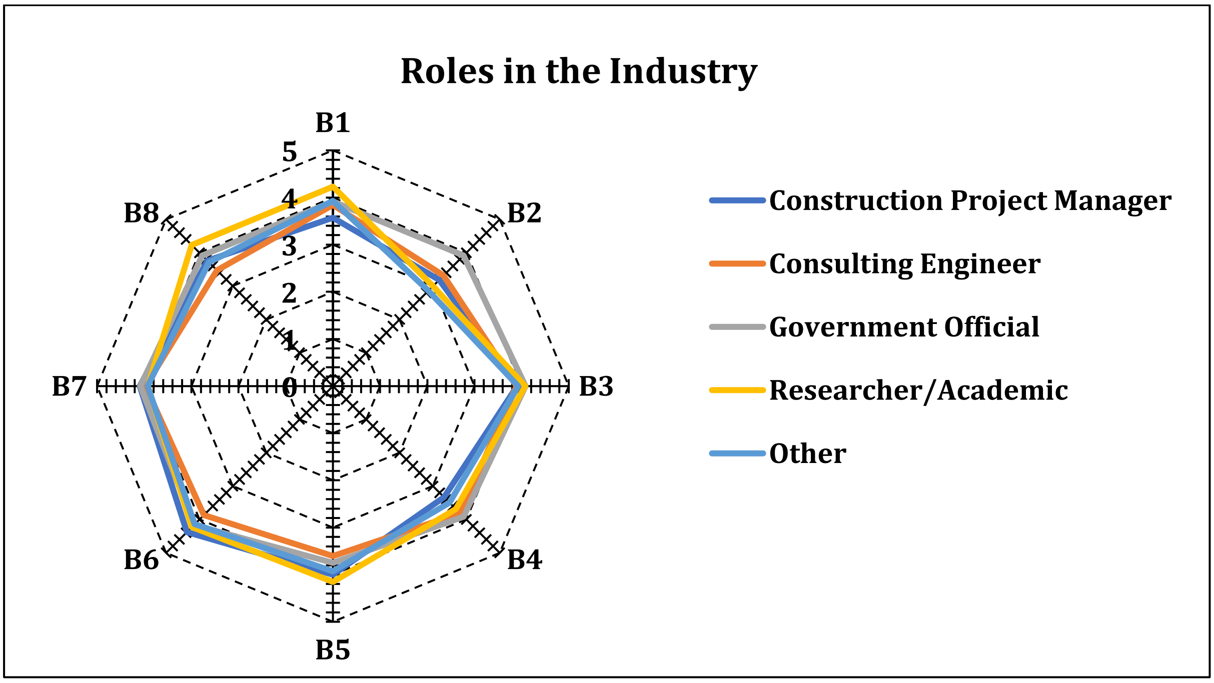
Sincerely,

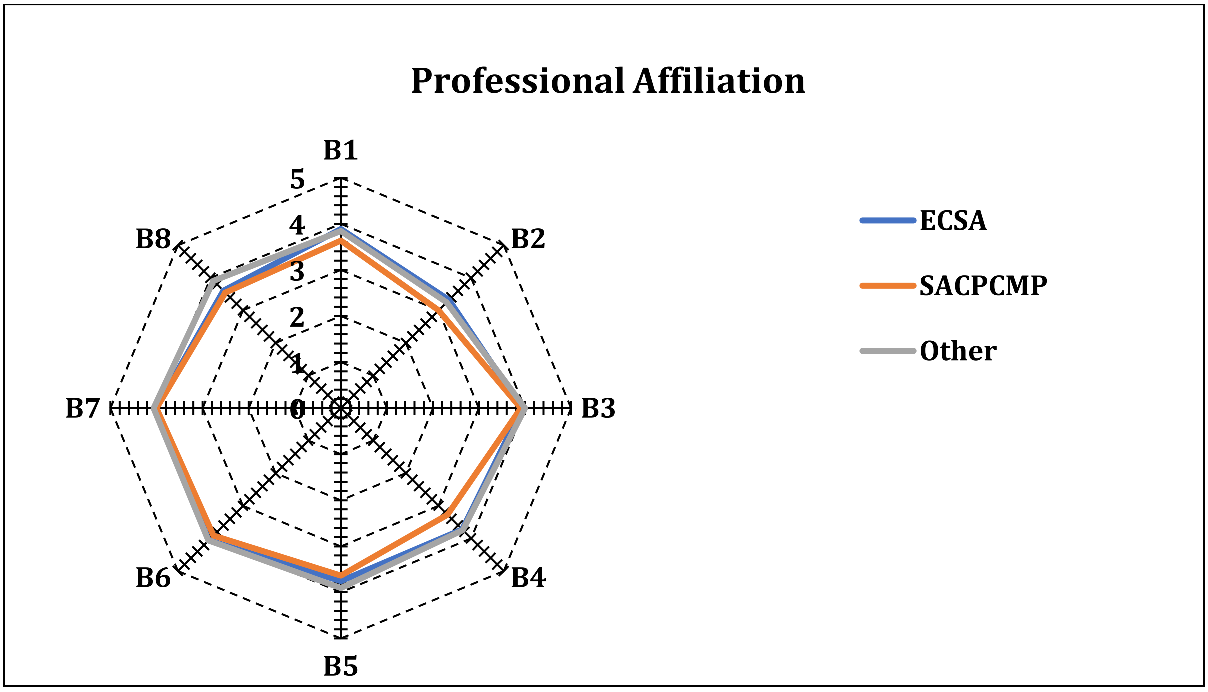
Mrs Clarissa Robertson (cgraham@sun.ac.za)
Secretariat: Social, Behavioural and Education Research Ethics Committee (REC: SBE)

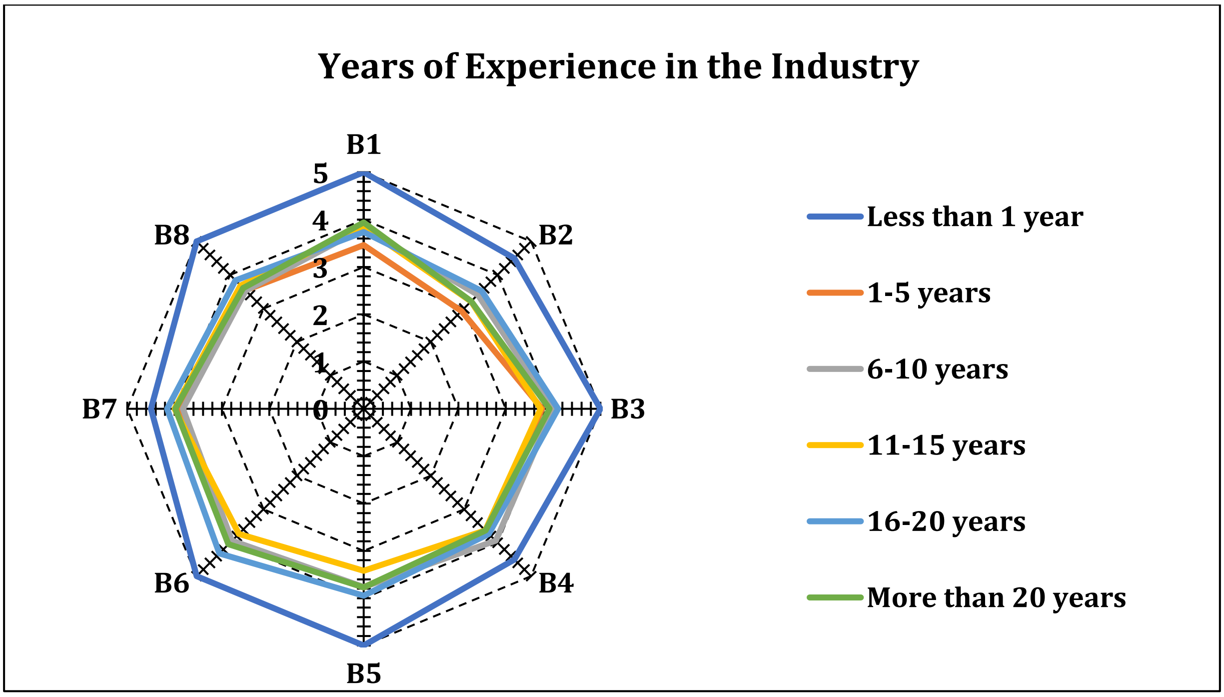
National Health Research Ethics Committee (NHREC) registration number: REC-050411-032.
The Social, Behavioural and Education Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research. In addition, this committee abides by the ethical norms and principles for research established by the Declaration of Helsinki (2013) and the Department of Health Guidelines for Ethical Research: Principles Structures and Processes (2nd Ed.) 2015. Annually a number of projects may be selected randomly for an external audit.

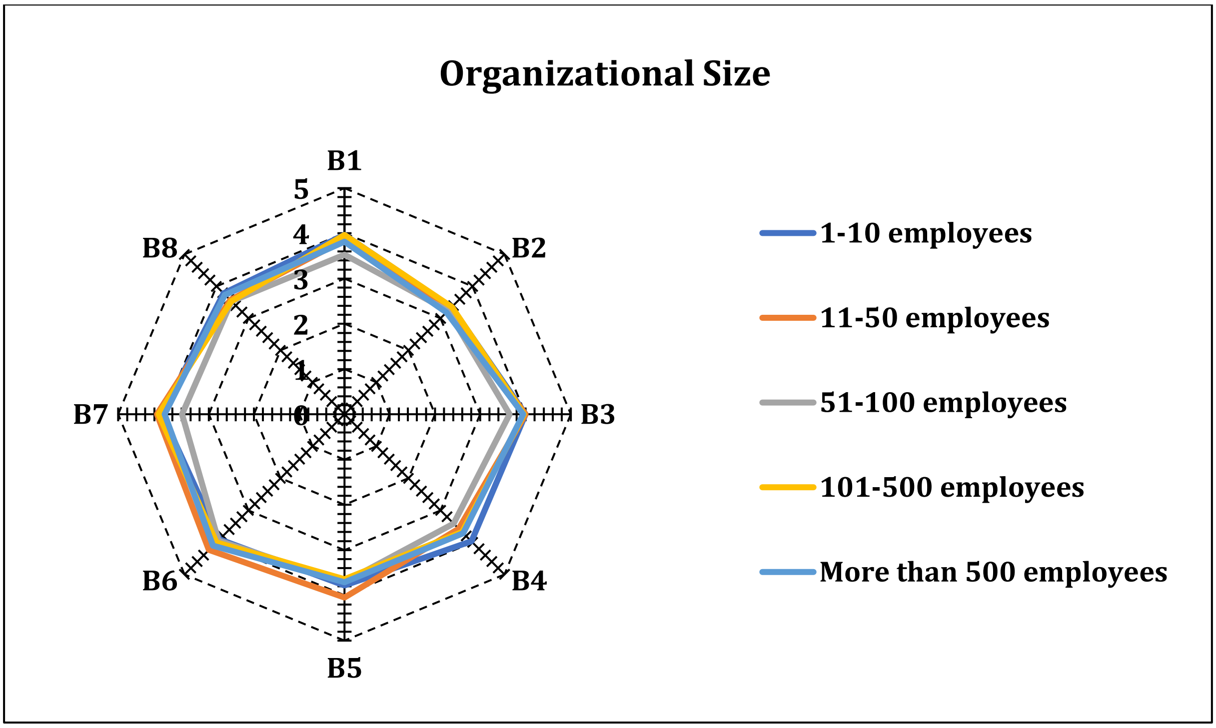
Appendix C: Radar Charts Presenting Mean Rating Scores of the Benefits.

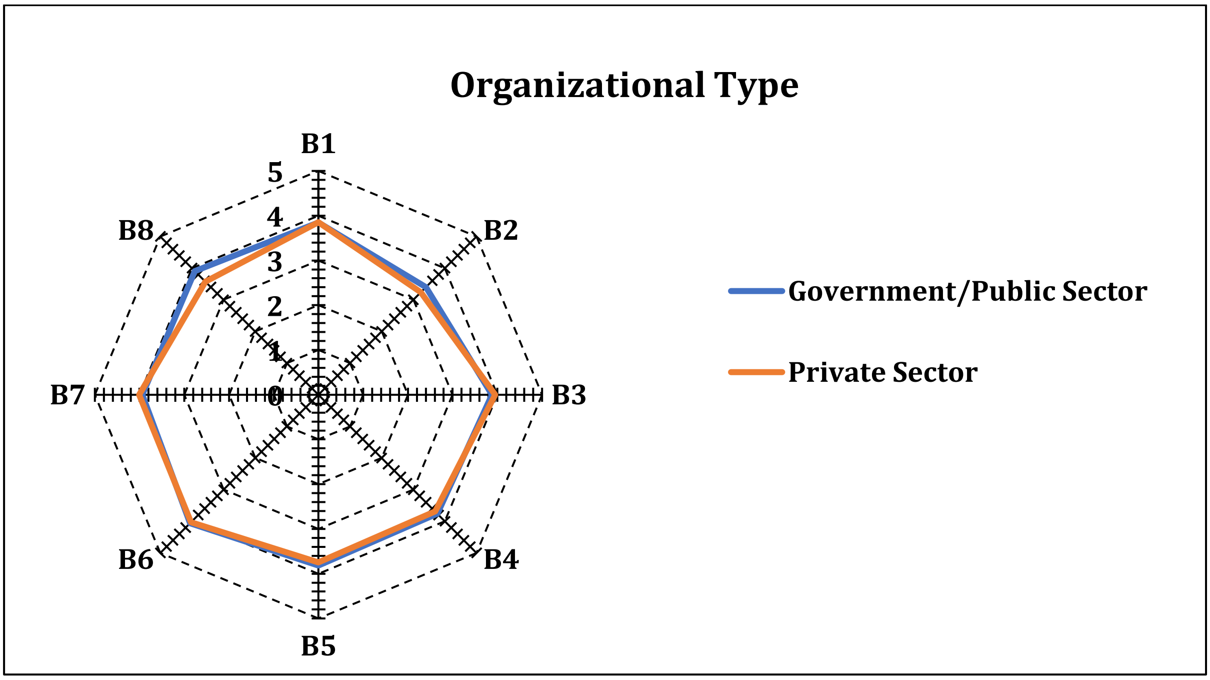


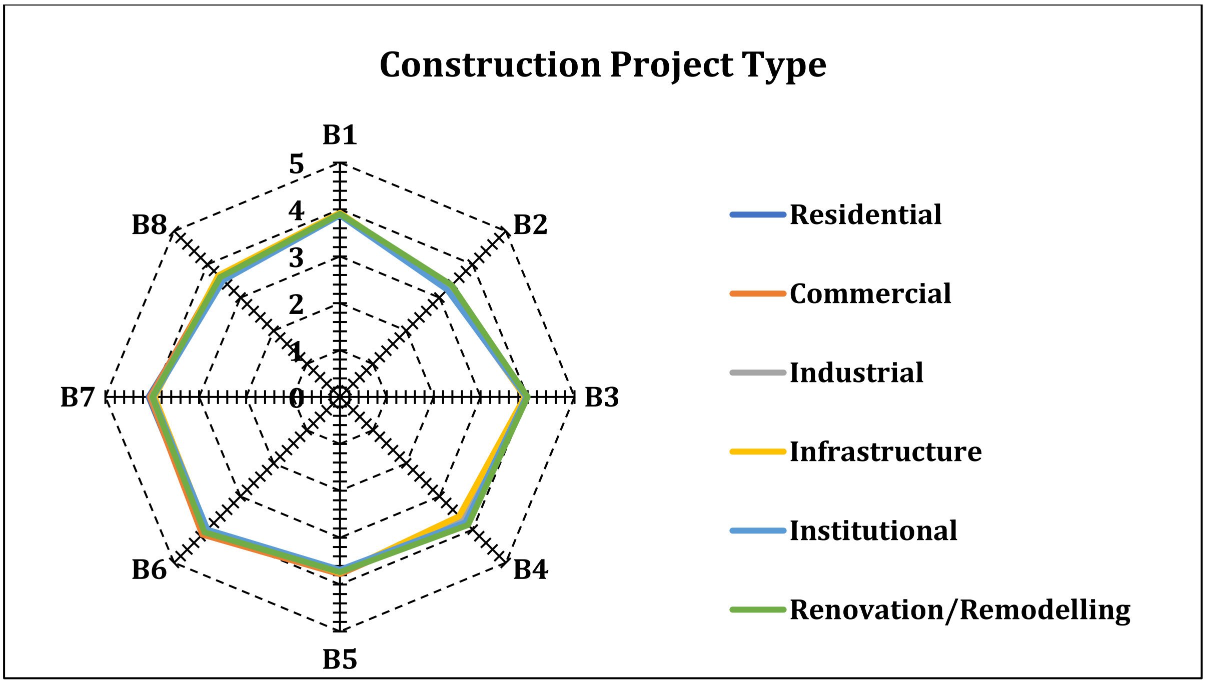



Professional Affiliation
B1
B2
B3
B4
B5
B6
B7
B8
0
1
2
3
4
5
ECSA
SACPCMP
Other


Years of Experience in the Industry
B1
B2
B3
B4
B5
B6
B7
B8
0
1
2
3
4
5
Less than 1 year
1-5 years
6-10 years
11-15 years
16-20 years
More than 20 years

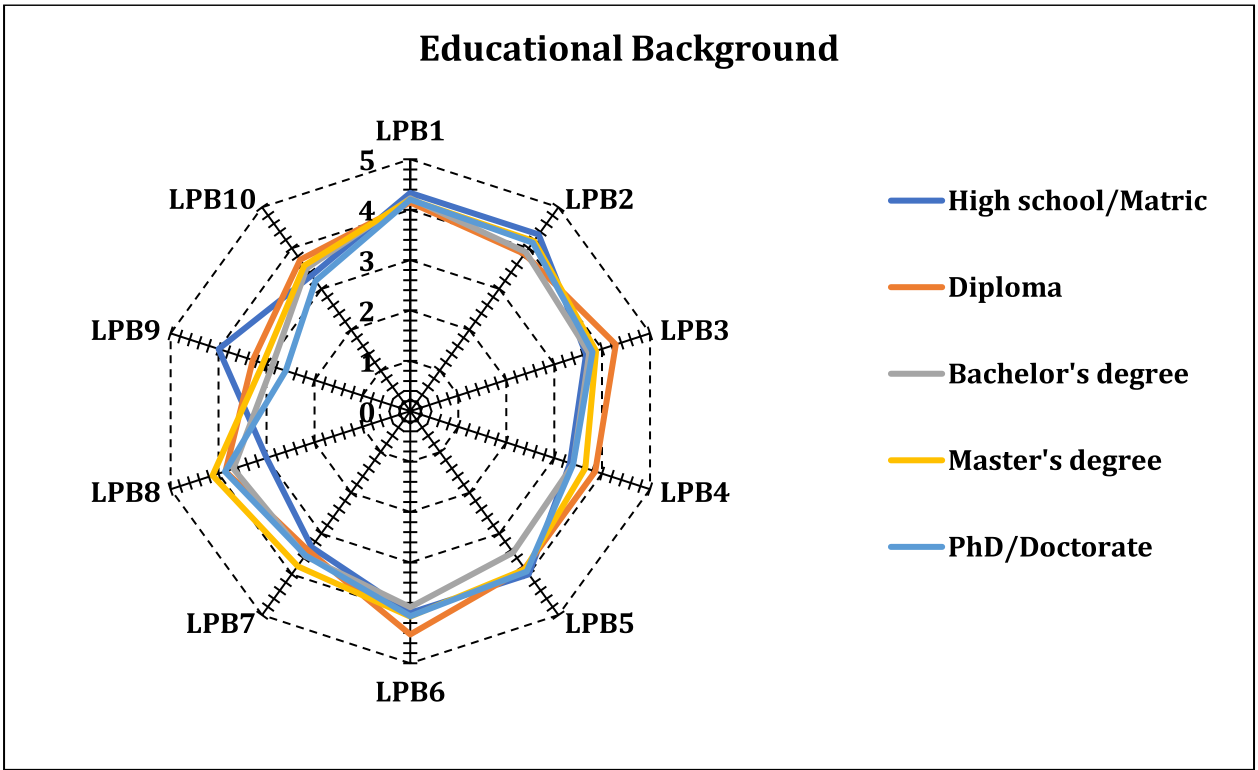

Organizational Size
B1
B2
B3
B4
B5
B6
B7
B8
0
1
2
3
4
5
1-10 employees
11-50 employees
51-100 employees
101-500 employees
More than 500 employees

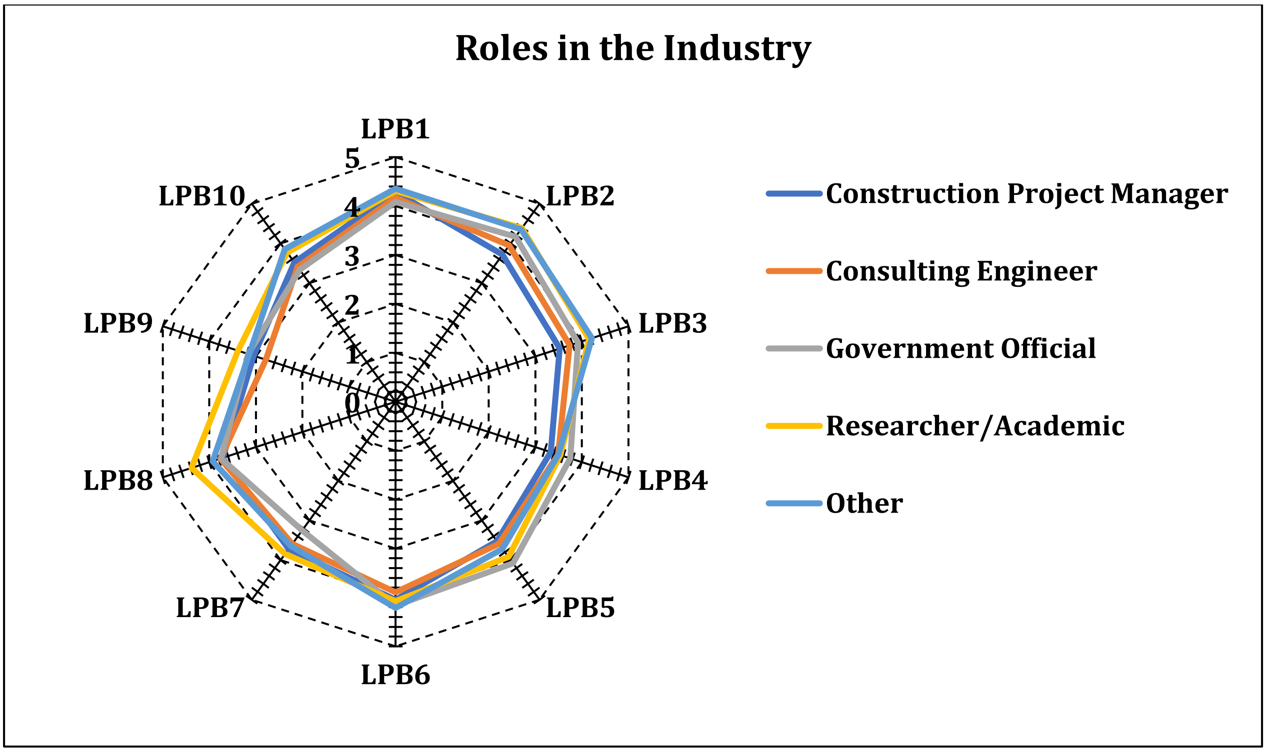

Organizational Type
B1
B2
B3
B4
B5
B6
B7
B8
0
1
2
3
4
5
Government/Public Sector
Private Sector

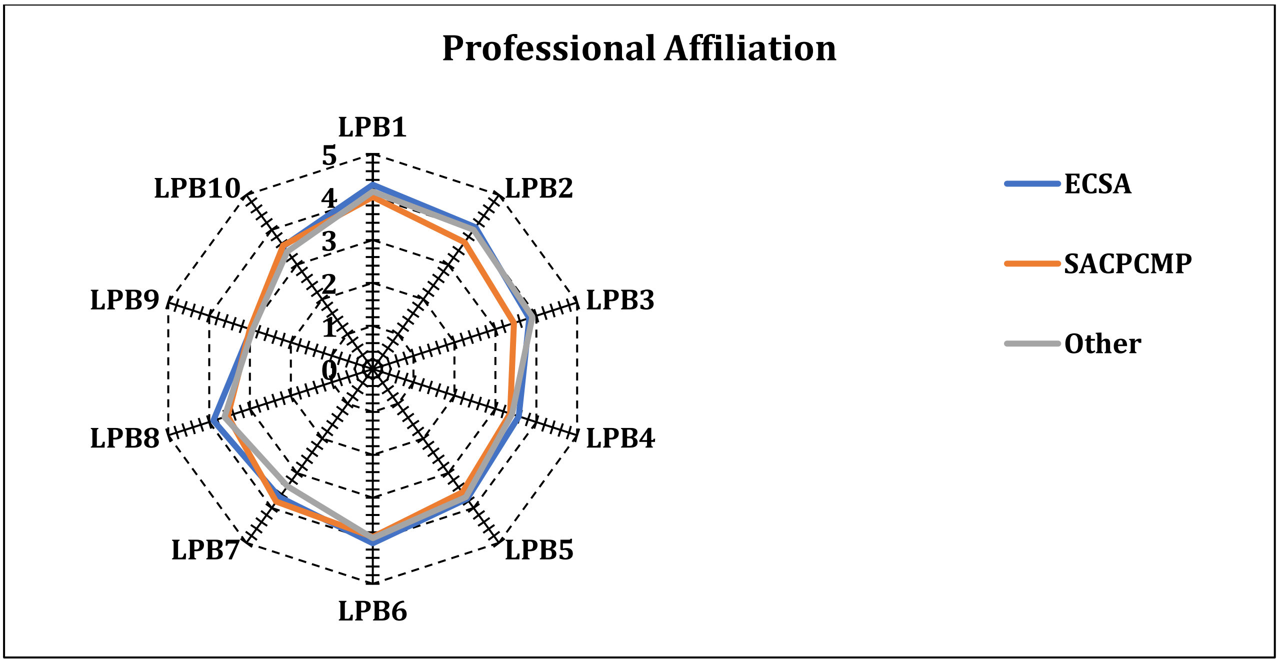

Construction Project Type
B1
B2
B3
B4
B5
B6
B7
B8
0
1
2
3
4
5
Residential
Commercial
Industrial
Infrastructure
Institutional
Renovation/Remodelling

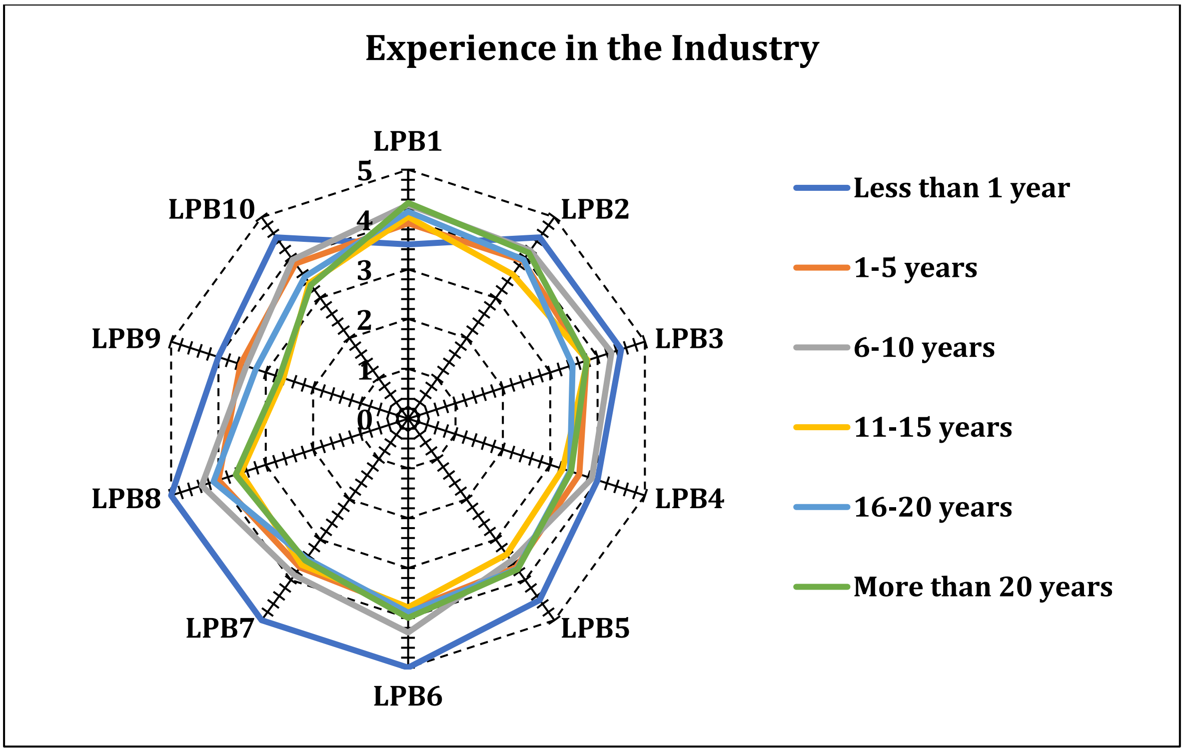
Appendix D: Radar Charts Presenting Mean Rating Scores of the Likelihood of Benefits Occurring.

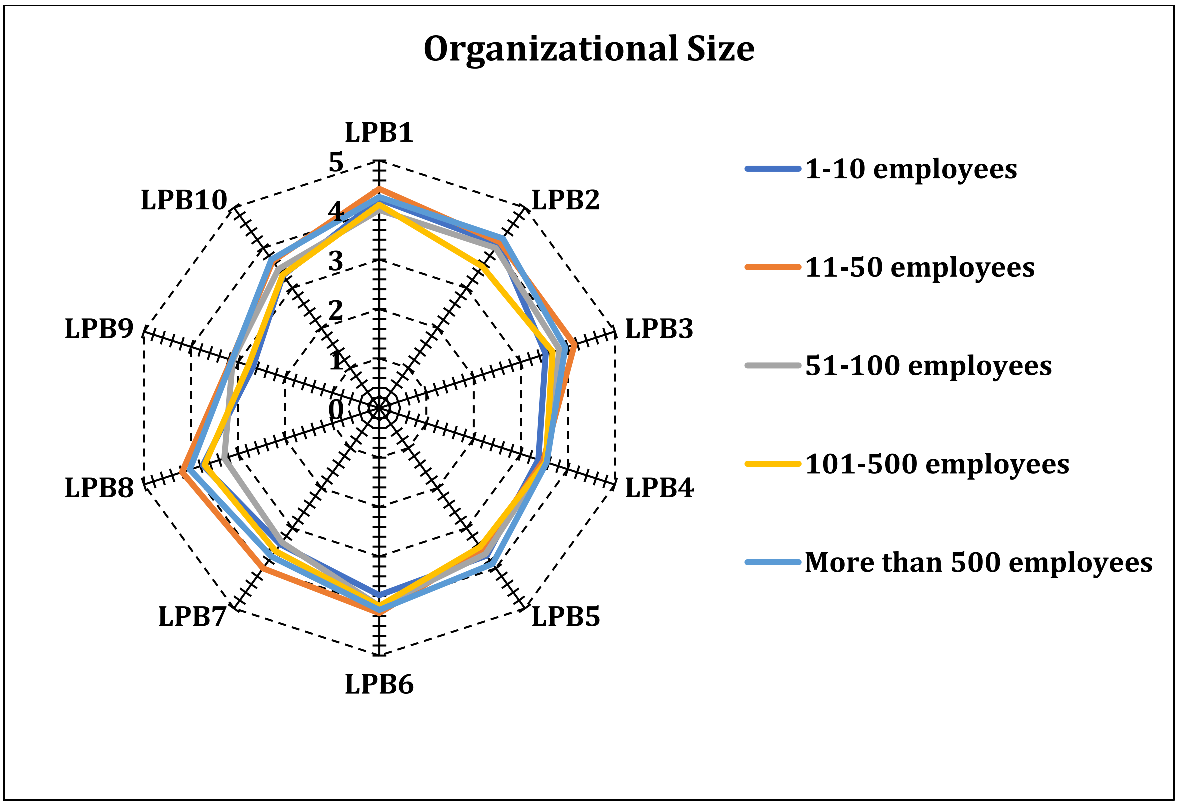
Code	Likelihood of potential barriers of 3DCP technology occurring
LPB1	High initial investment
LPB2	Lack of government incentives and support
LPB3	Lack of design codes and standards
LPB4	Risk aversion
LPB5	Limited awareness of benefits
LPB6	Lack of 3D concrete printing technology experts
LPB7	Fragmentation of supply chain and procurement systems
LPB8	Concerns about job loss for unskilled workers
LPB9	Unpredictable weather conditions
LPB10	Limited production size

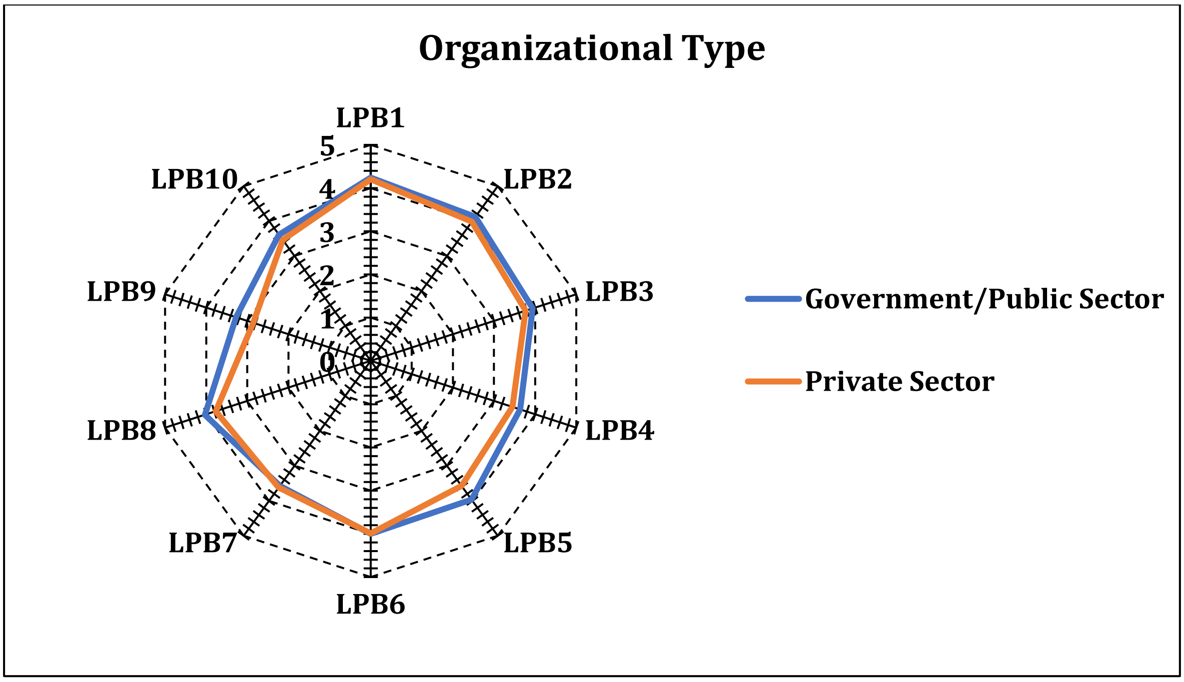


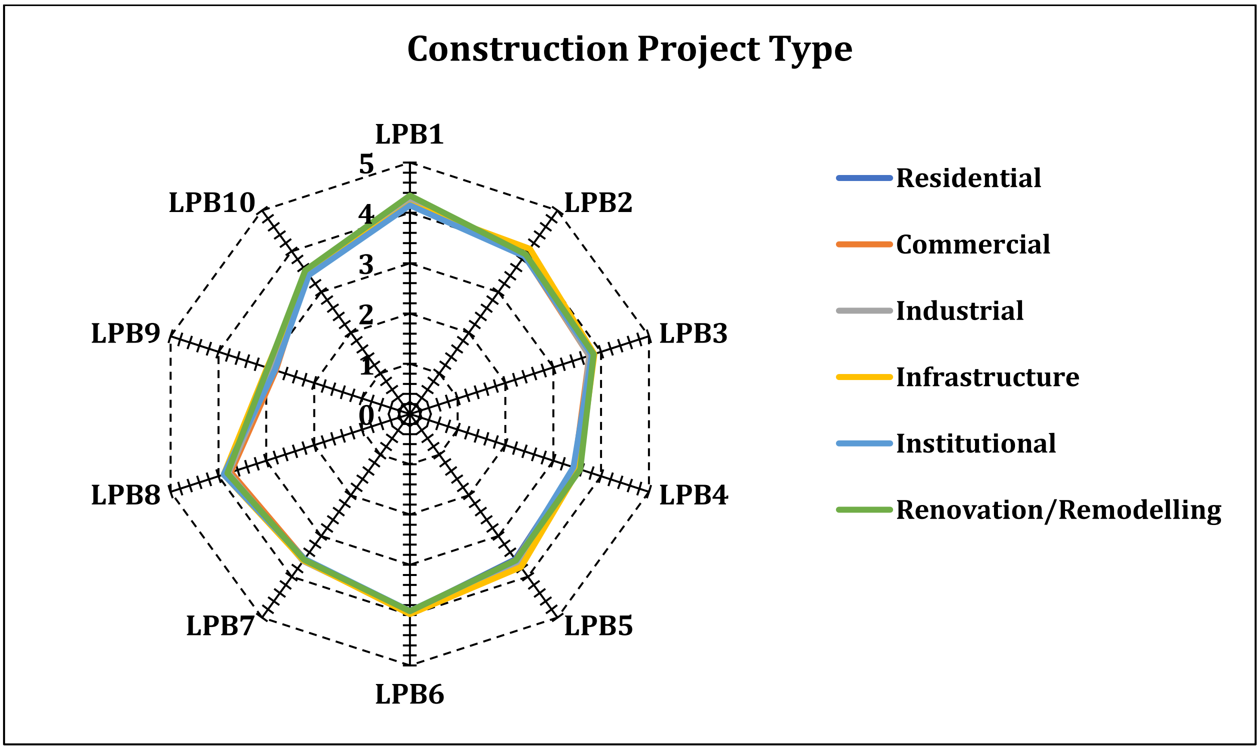

Roles in the Industry
LPB1
LPB2
LPB3
LPB4
LPB5
LPB6
LPB7
LPB8
LPB9
LPB10
5
4
3
2
1
0
Construction Project Manager
Consulting Engineer
Government Official
Researcher/Academic
Other

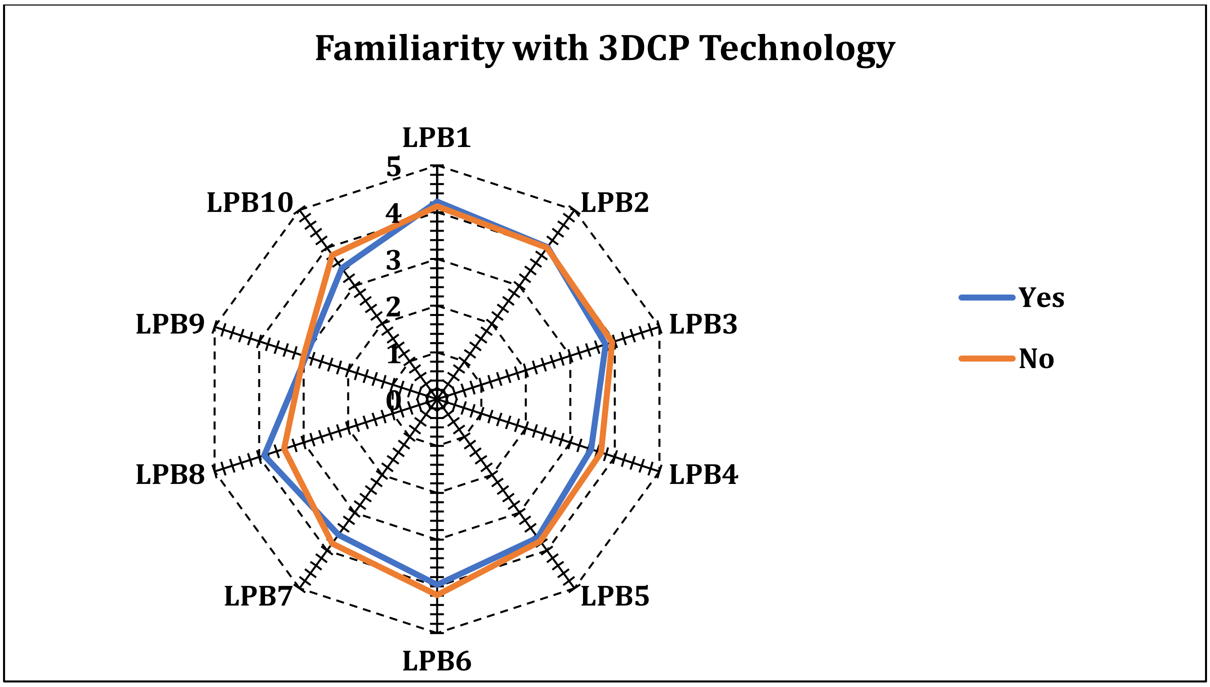

Professional Affiliation
LPB1
LPB2
LPB3
LPB4
LPB5
LPB6
LPB7
LPB8
LPB9
LPB10
5
4
3
2
1
0
ECSA
SACPCMP
Other

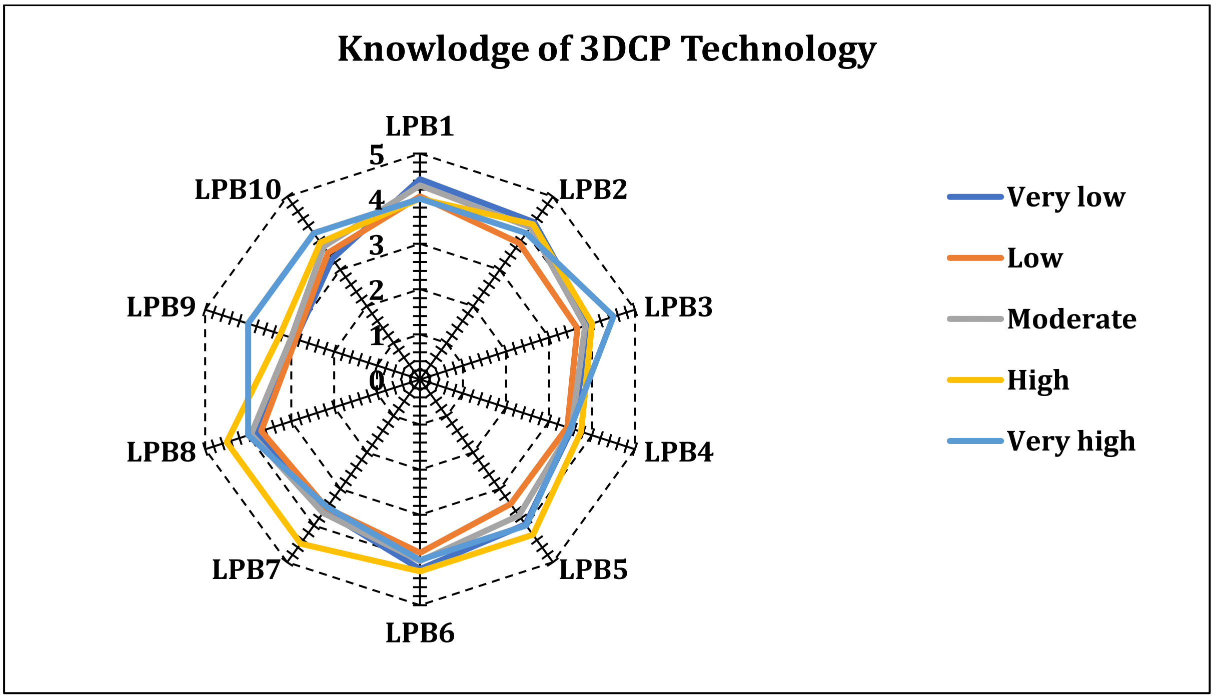

Experience in the Industry
LPB1
LPB2
LPB3
LPB4
LPB5
LPB6
LPB7
LPB8
LPB9
LPB10
5
4
3
2
1
0
Less than 1 year
1-5 years
6-10 years
11-15 years
16-20 years
More than 20 years

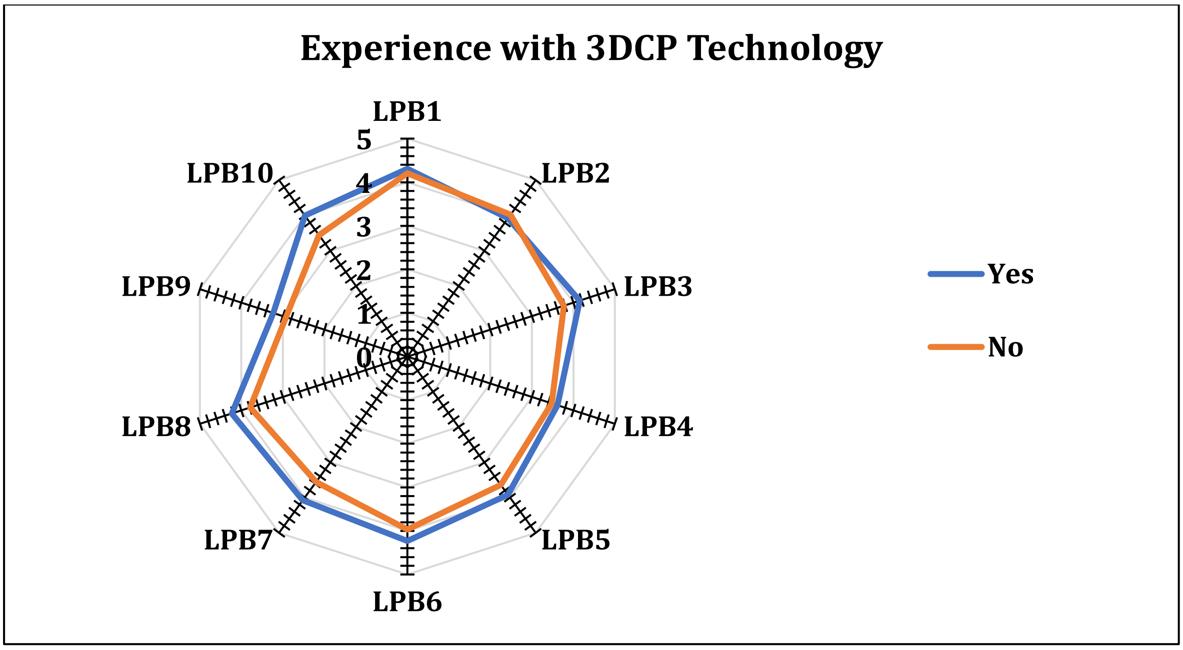

Organizational Size
LPB1
LPB2
LPB3
LPB4
LPB5
LPB6
LPB7
LPB8
LPB9
LPB10
5
4
3
2
1
0
1-10 employees
11-50 employees
51-100 employees
101-500 employees
More than 500 employees


Organizational Type
LPB1
LPB2
LPB3
LPB4
LPB5
LPB6
LPB7
LPB8
LPB9
LPB10
0
1
2
3
4
5
Government/Public Sector
Private Sector

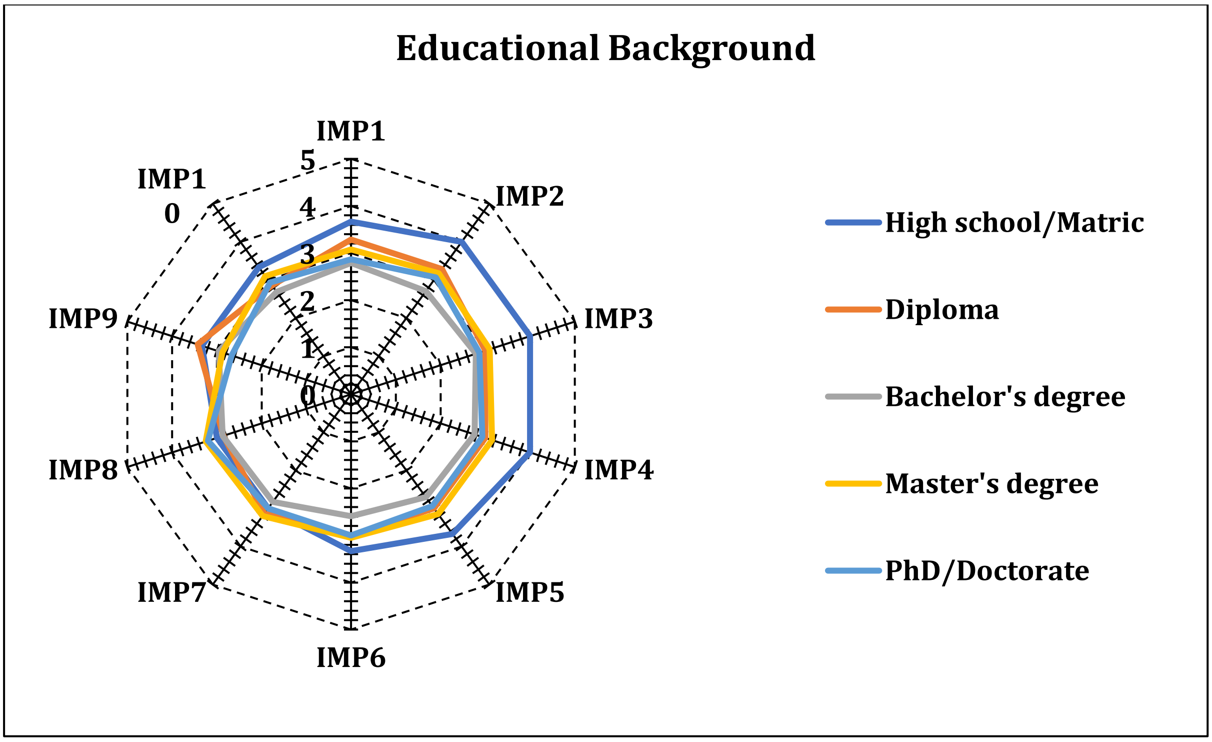

Construction Project Type
LPB1
LPB2
LPB3
LPB4
LPB5
LPB6
LPB7
LPB8
LPB9
LPB10
0
1
2
3
4
5
Residential
Commercial
Industrial
Infrastructure
Institutional
Renovation/Remodelling

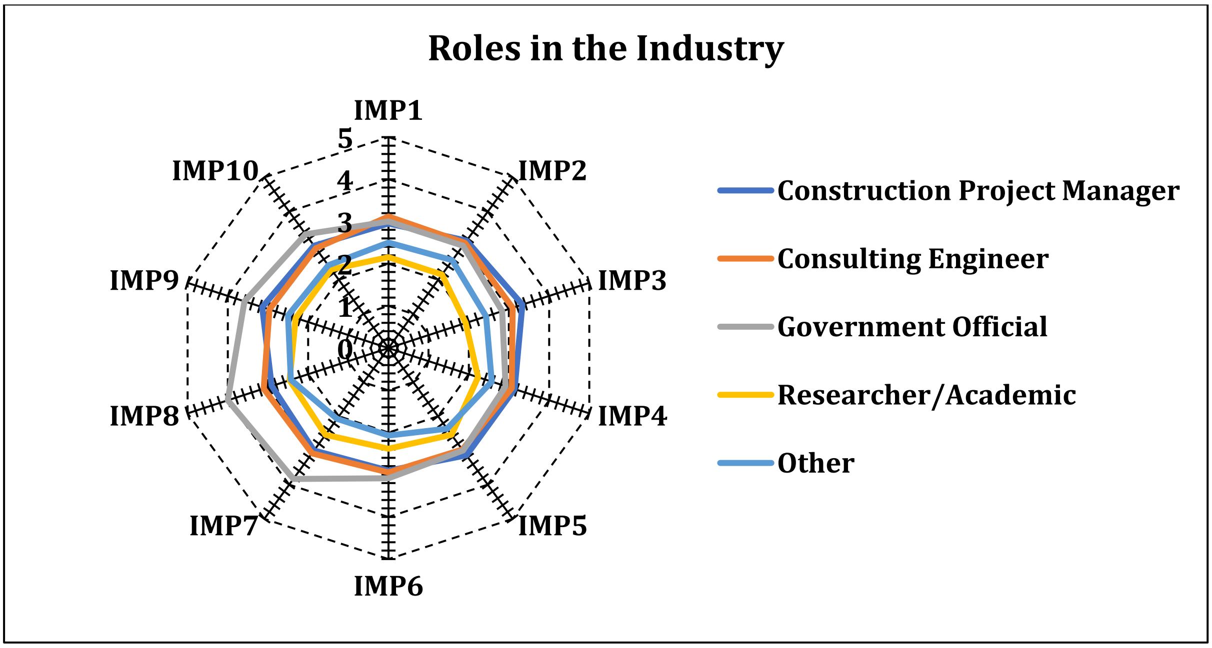

Familiarity with 3DCP Technology
LPB1
LPB2
LPB3
LPB4
LPB5
LPB6
LPB7
LPB8
LPB9
LPB10
0
1
2
3
4
5
Yes
No

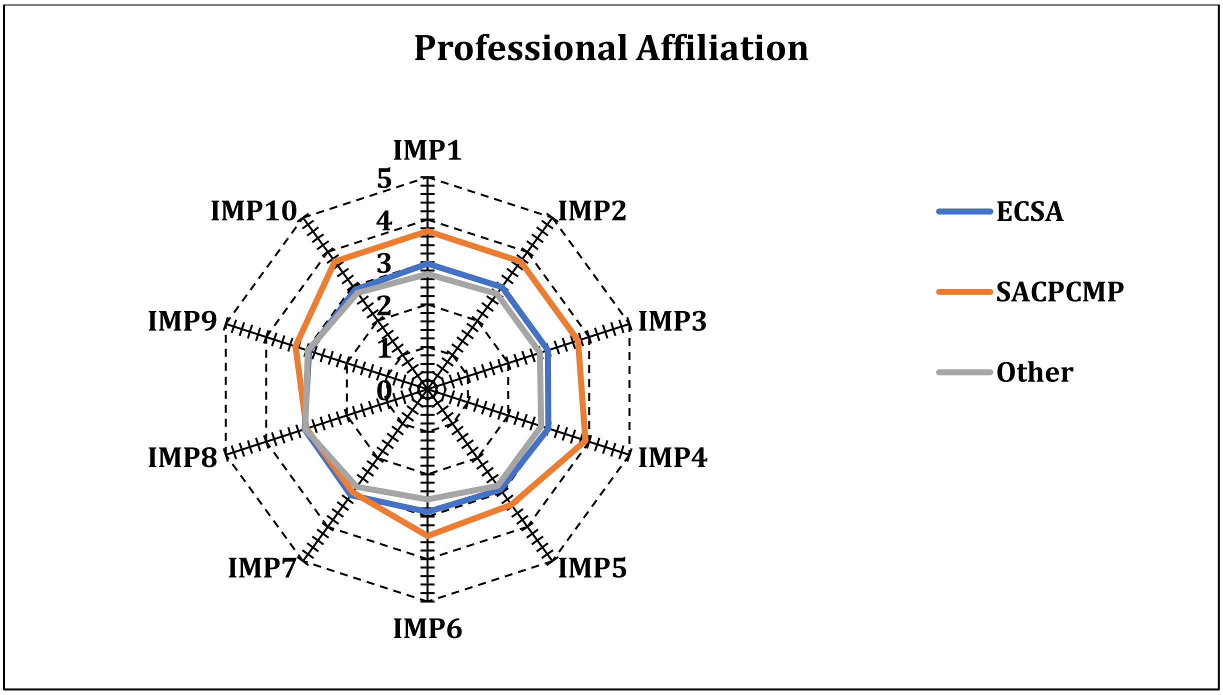

Knowlodge of 3DCP Technology
LPB1
LPB2
LPB3
LPB4
LPB5
LPB6
LPB7
LPB8
LPB9
LPB10
0
1
2
3
4
5
Very low
Low
Moderate
High
Very high

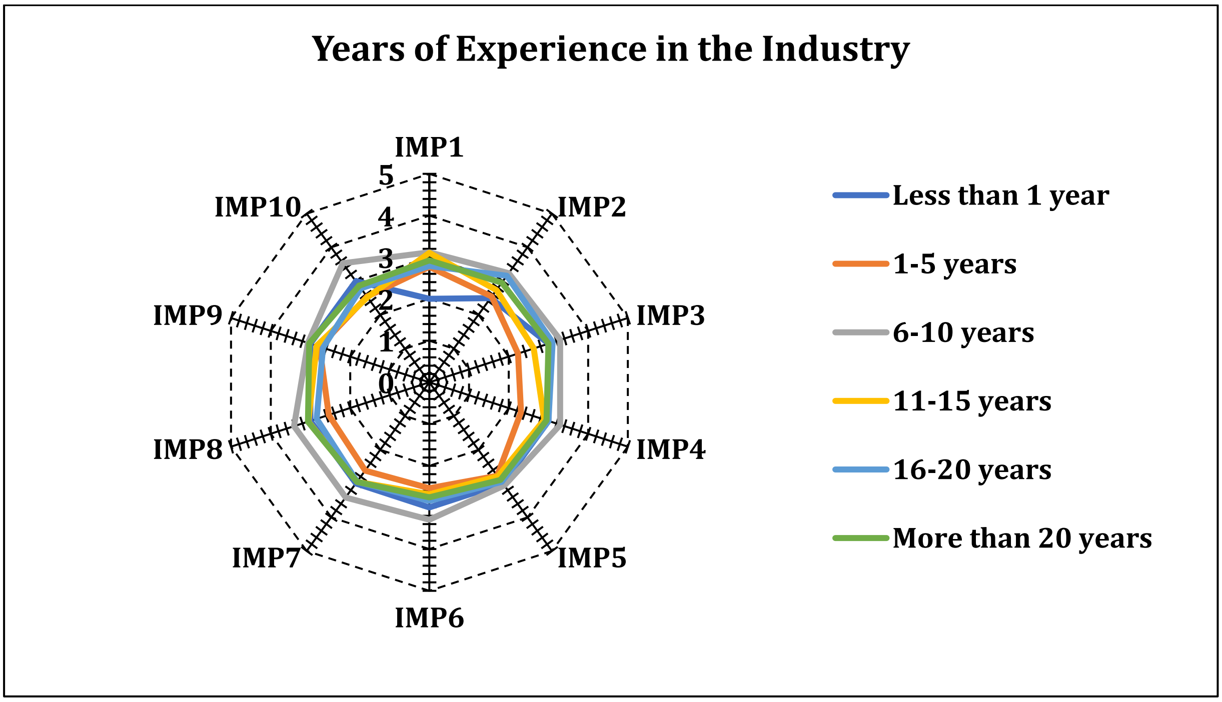

Experience with 3DCP Technology
LPB1
LPB2
LPB3
LPB4
LPB5
LPB6
LPB7
LPB8
LPB9
LPB10
0
1
2
3
4
5
Yes
No

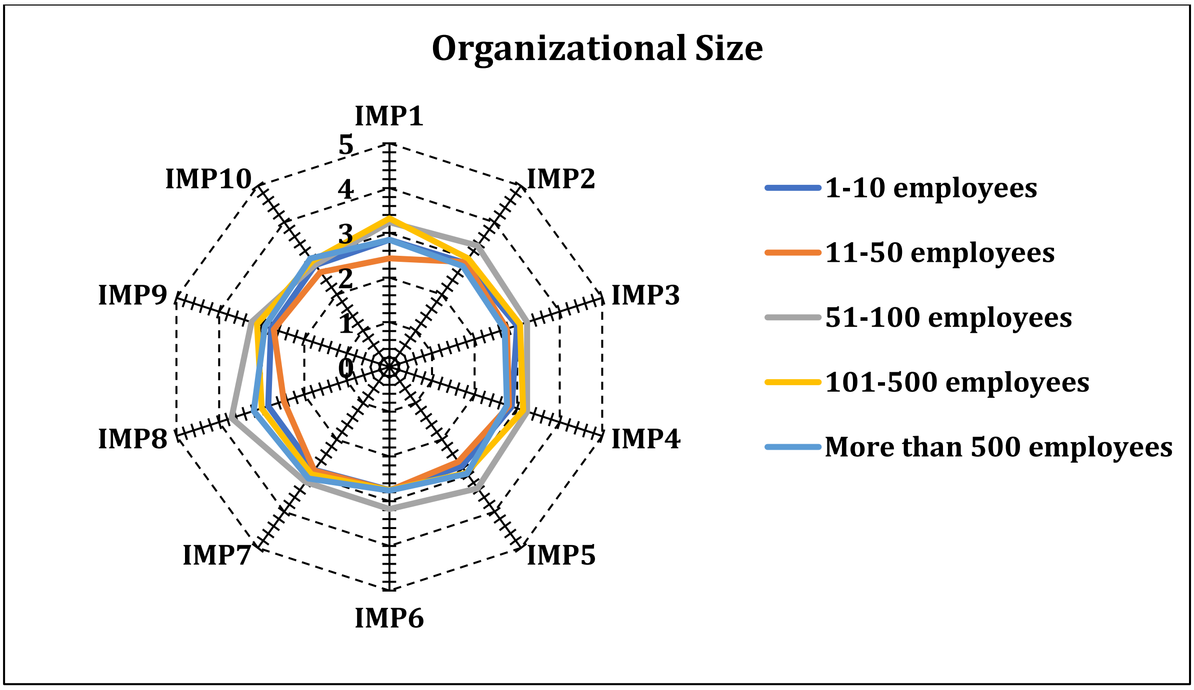
Appendix F: Radar Charts Presenting Mean Rating Scores of the Improvement Strategies.

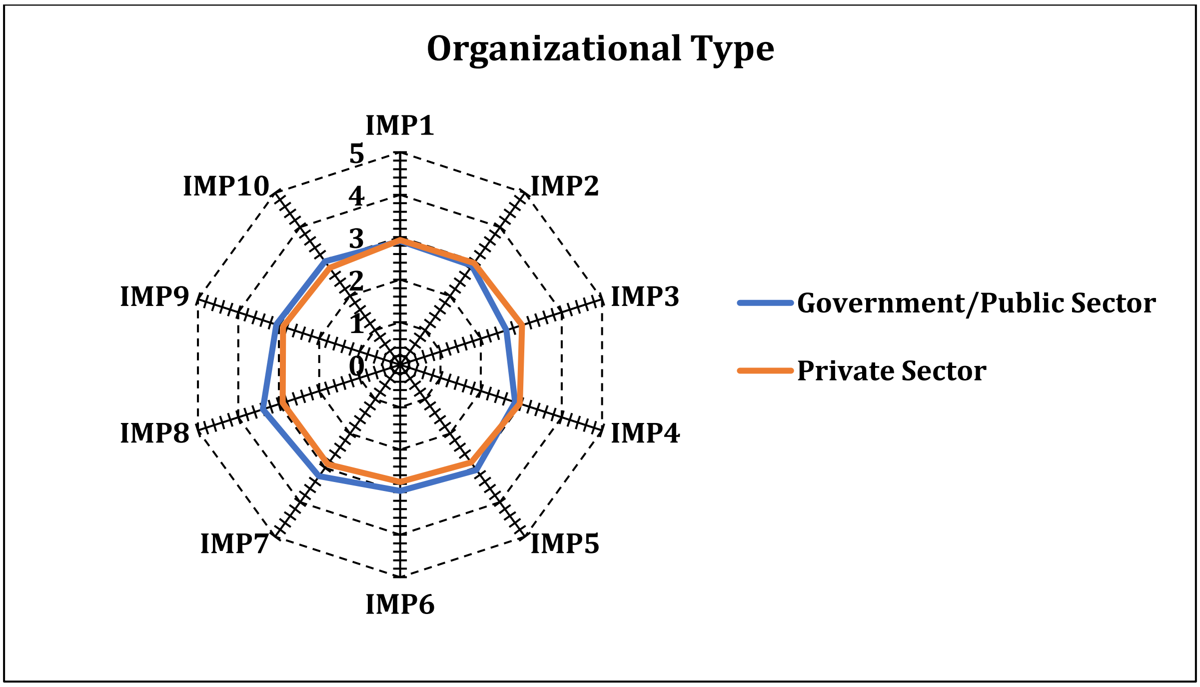


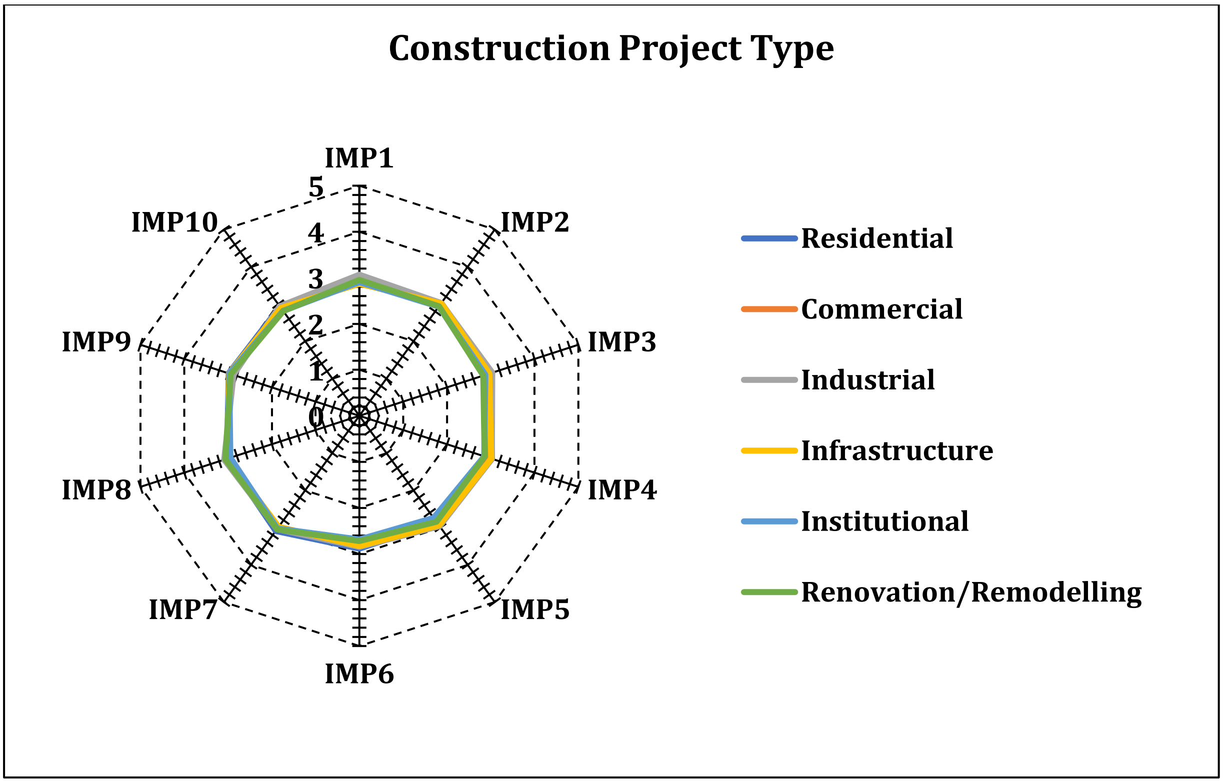


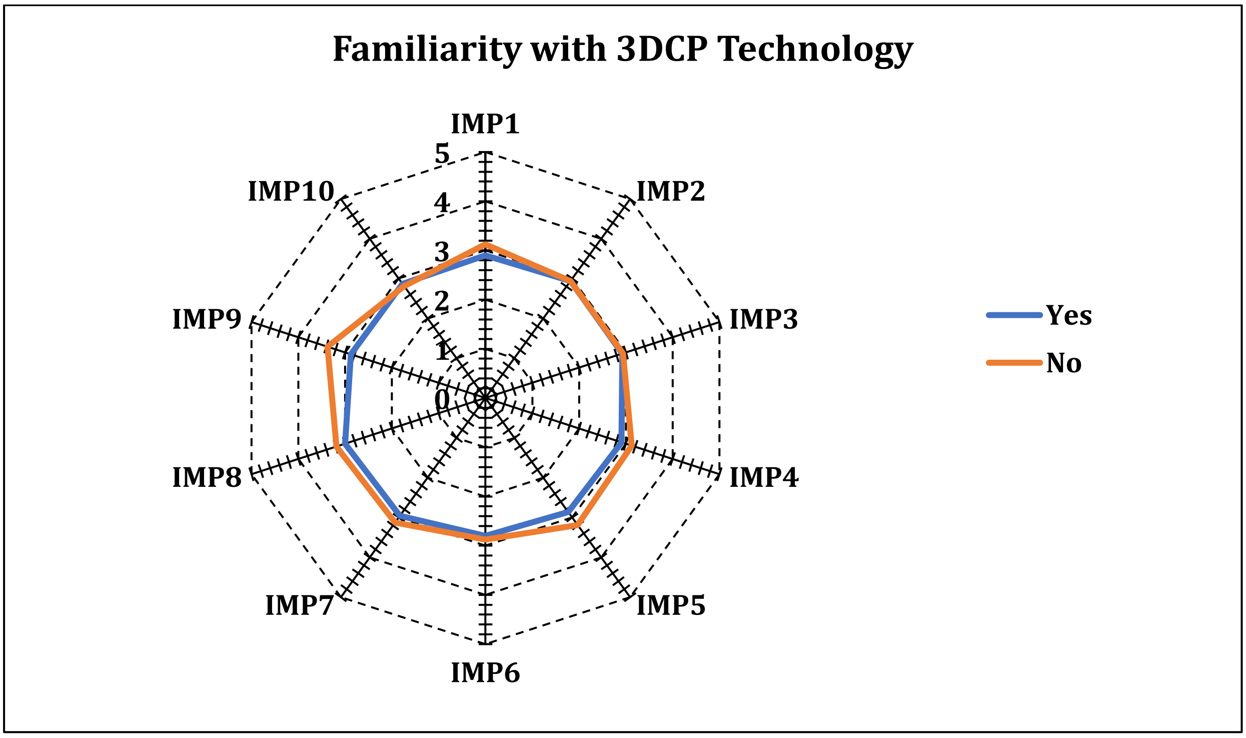

Professional Affiliation
IMP1
IMP2
IMP3
IMP4
IMP5
IMP6
IMP7
IMP8
IMP9
IMP10
0
1
2
3
4
5
ECSA
SACPCMP
Other

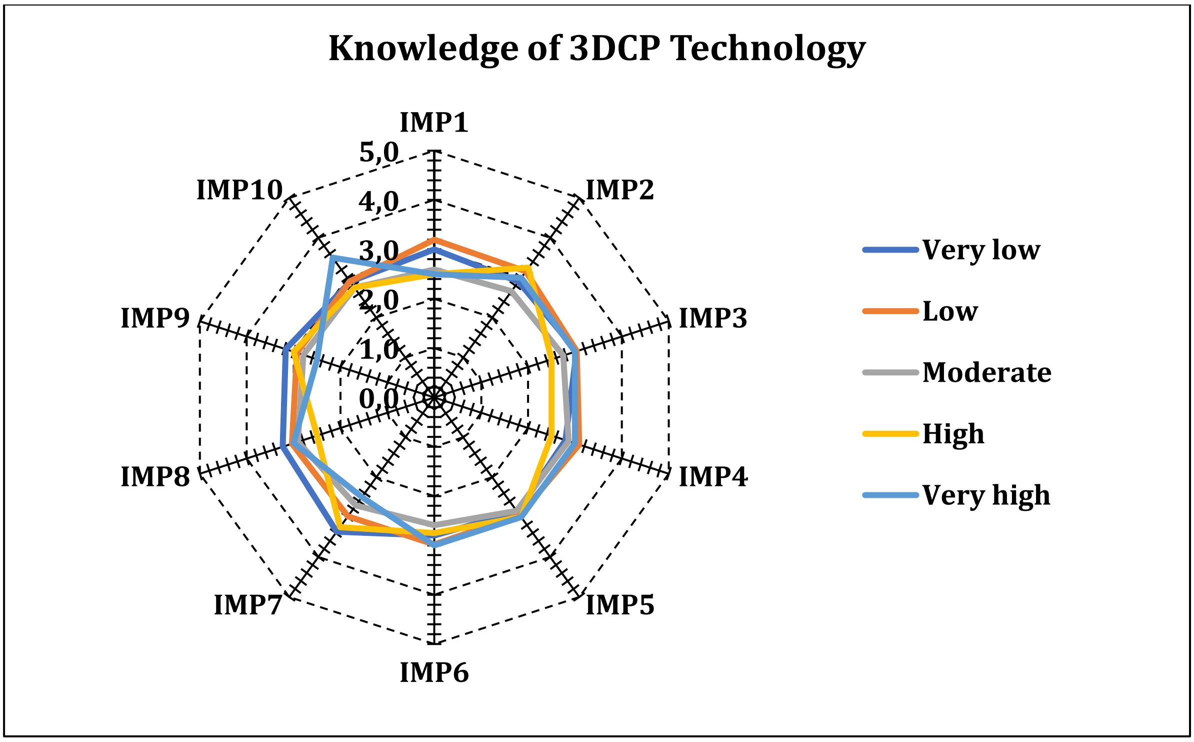

Years of Experience in the Industry
IMP1
IMP2
IMP3
IMP4
IMP5
IMP6
IMP7
IMP8
IMP9
IMP10
0
1
2
3
4
5
Less than 1 year
1-5 years
6-10 years
11-15 years
16-20 years
More than 20 years

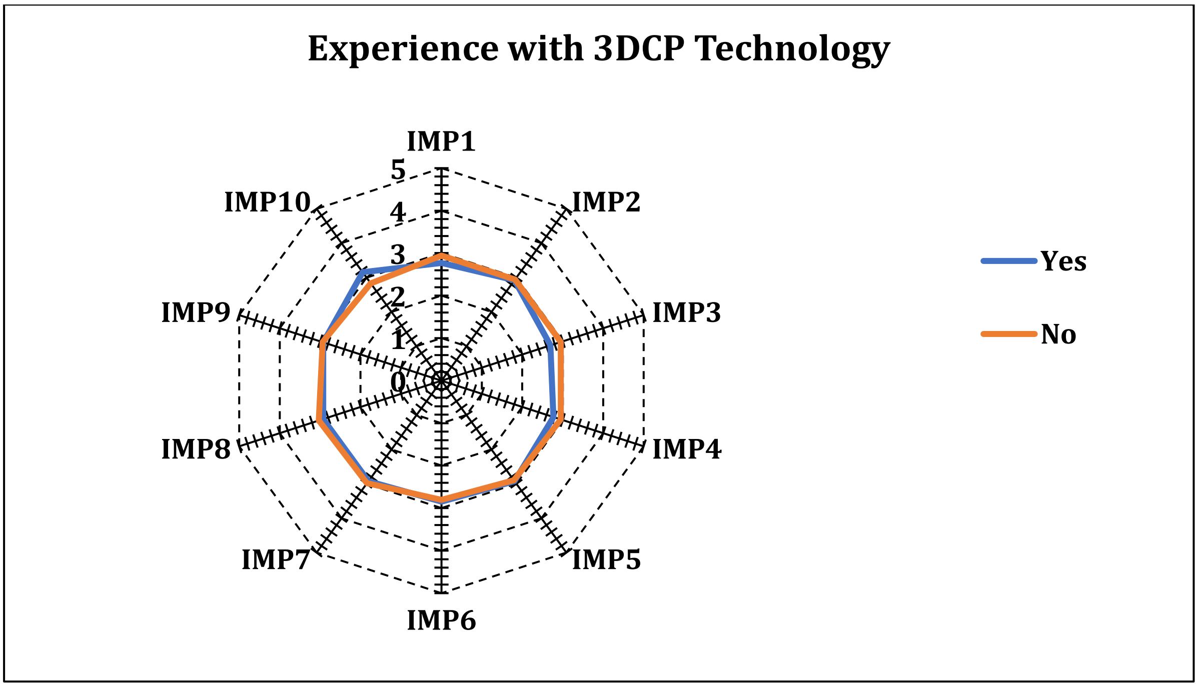

Organizational Size
IMP1
IMP2
IMP3
IMP4
IMP5
IMP6
IMP7
IMP8
IMP9
IMP10
0
1
2
3
4
5
1-10 employees
11-50 employees
51-100 employees
101-500 employees
More than 500 employees


Organizational Type
IMP1
IMP2
IMP3
IMP4
IMP5
IMP6
IMP7
IMP8
IMP9
IMP10
0
1
2
3
4
5
Government/Public Sector
Private Sector


Construction Project Type
IMP1
IMP2
IMP3
IMP4
IMP5
IMP6
IMP7
IMP8
IMP9
IMP10
0
1
2
3
4
5
Residential
Commercial
Industrial
Infrastructure
Institutional
Renovation/Remodelling


Familiarity with 3DCP Technology
IMP1
IMP2
IMP3
IMP4
IMP5
IMP6
IMP7
IMP8
IMP9
IMP10
0
1
2
3
4
5
Yes
No


Knowledge of 3DCP Technology
IMP1
IMP2
IMP3
IMP4
IMP5
IMP6
IMP7
IMP8
IMP9
IMP10
5,0
4,0
3,0
2,0
1,0
0,0
Very low
Low
Moderate
High
Very high


Experience with 3DCP Technology
IMP1
IMP2
IMP3
IMP4
IMP5
IMP6
IMP7
IMP8
IMP9
IMP10
5
4
3
2
1
0
Yes
No

Appendix G: Raw Data from the Survey Questionnaire

Mean Ratings Score of the Benefits and Barriers

	Benefits								Barriers									
Respondent	B1	B2	B3	B4	B5	B6	B7	B8	BA1	BA2	BA3	BA4	BA5	BA6	BA7	BA8	BA9	BA10
1	5	4	5	3	3	3	4	5	3	4	5	4	5	5	4	4	3	3
2	5	5	2	3	2	4	3	3	5	1	5	3	4	5	2	2	3	5
3	3	3	4	4	4	4	4	2	5	4	5	2	3	4	4	5	2	2
4	3	4	3	4	4	3	3	4	4	4	4	4	5	5	3	3	2	2
5	4	3	4	4	4	4	5	2	5	5	3	4	5	4	3	5	3	4
6	5	3	5	3	5	5	5	3	5	3	4	2	4	4	4	4	2	4
7	5	3	5	5	2	3	4	3	5	4	4	4	3	4	4	5	2	3
8	4	4	4	2	4	2	3	4	4	4	4	4	4	4	4	4	4	4
9	5	4	5	4	4	4	4	5	5	4	5	4	5	5	4	4	3	4
10	4	2	4	4	4	5	5	4	4	4	4	3	3	2	4	3	3	3
11	4	3	5	4	5	5	4	5	5	5	4	3	3	4	4	4	3	4
12	5	3	5	5	5	5	3	5	4	5	4	5	5	4	4	2	3	2
13	5	5	5	5	5	5	5	5	5	3	3	1	3	3	1	2	1	2
14	3	5	4	4	3	3	4	3	4	3	2	2	4	3	3	3	2	4
15	2	1	2	2	1	2	2	2	4	3	3	3	4	5	4	5	4	5
16	3	3	4	4	2	4	4	3	4	5	5	4	5	5	4	5	2	4
17	4	4	5	5	5	5	5	5	4	4	2	3	4	4	3	3	2	3
18	3	4	4	4	4	4	3	3	5	4	4	4	4	4	4	5	4	3
19	5	5	5	5	4	5	5	3	5	5	5	3	4	4	4	5	3	3
20	5	2	4	4	4	3	3	2	5	4	5	4	4	5	5	5	5	5
21	2	3	2	3	3	3	3	3	5	5	5	5	5	5	5	5	3	4
22	3	3	4	4	3	4	4	3	5	5	5	5	5	5	5	5	5	5
23	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4
24	5	3	4	5	5	5	5	4	5	5	5	3	5	5	5	5	5	5
25	5	2	5	5	5	5	5	2	5	5	5	3	5	5	5	5	3	3
26	5	3	5	3	5	5	5	5	5	5	5	5	3	5	5	5	1	5
27	4	4	5	5	5	5	5	5	4	5	4	4	4	4	4	4	4	4
28	4	2	4	4	3	4	4	1	5	3	3	3	3	4	3	2	3	5
29	4	3	5	5	5	5	5	3	5	4	4	3	5	5	3	2	1	5
30	4	4	4	4	4	4	4	4	3	4	3	3	4	4	4	4	4	4
31	4	4	4	4	3	4	4	3	4	5	5	4	5	5	4	5	2	3
32	5	2	4	4	2	2	3	4	5	5	5	3	3	4	4	5	3	2
33	5	4	3	4	2	2	4	4	2	4	5	5	4	4	5	2	2	5
34	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
35	3	3	4	4	4	4	5	4	5	5	5	4	4	4	4	4	4	4
36	4	2	4	4	4	4	4	4	4	4	4	4	3	4	4	5	2	3
37	3	3	4	5	3	4	4	4	5	5	5	5	5	5	5	5	5	5
38	4	5	5	3	5	5	4	5	3	4	5	3	3	5	4	3	3	3
39	2	2	2	3	3	3	3	3	5	2	2	2	2	2	2	4	2	2
40	4	4	4	4	4	4	4	4	4	4	4	4	5	4	4	4	4	4
41	4	4	3	3	4	5	4	3	5	5	5	4	4	5	5	5	3	3
42	4	4	3	4	3	2	3	4	5	4	4	3	3	3	3	3	2	4
43	5	5	5	5	5	5	5	5	5	1	5	5	3	5	5	4	3	5
44	4	3	4	3	4	4	3	4	4	4	5	4	4	5	4	5	4	4
45	3	4	2	3	4	4	4	2	5	5	5	5	5	5	5	5	5	5
46	4	2	4	4	2	2	4	4	3	4	4	4	2	2	2	4	2	2
47	3	5	4	4	4	4	4	4	5	5	5	4	4	4	4	5	3	2
48	5	5	5	5	4	5	5	5	5	4	5	5	3	3	3	3	3	4
49	4	2	3	2	4	4	4	3	4	4	3	3	3	4	4	3	4	4
50	2	2	3	3	3	4	4	3	4	4	4	3	4	3	3	4	3	3
51	5	3	4	4	5	5	5	5	5	5	4	4	2	4	4	5	4	4
52	5	3	5	3	4	4	3	5	4	5	4	3	4	5	5	5	4	3
53	4	5	5	5	5	5	5	4	5	1	1	1	1	5	1	2	1	5
54	3	4	4	4	4	5	4	4	4	4	3	3	4	4	4	4	3	4
55	4	3	4	4	4	4	4	4	4	4	3	3	3	4	3	2	2	4
56	4	4	4	3	3	4	4	4	3	4	2	2	3	3	4	2	2	2
57	4	5	5	5	4	4	5	5	5	2	4	4	4	5	4	5	3	5
58	4	3	5	4	4	5	4	4	5	5	4	4	4	5	4	5	2	3
59	4	3	3	2	2	4	3	3	4	4	5	5	4	3	5	5	3	4
60	5	2	3	3	5	5	5	4	5	5	5	5	5	4	4	5	2	4
61	4	4	5	5	4	5	5	5	5	5	5	4	5	5	5	5	5	5
62	2	4	5	4	3	3	3	3	5	5	5	3	3	4	3	5	3	4
63	4	4	5	3	4	4	4	3	3	4	3	3	4	4	4	4	3	4
64	4	3	4	5	4	4	3	4	4	2	2	3	2	4	2	2	2	2
65	5	5	5	4	4	4	4	4	4	5	5	5	4	3	4	4	1	2
66	4	4	4	4	4	4	4	4	5	5	5	3	5	5	3	5	3	3
67	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
68	5	3	4	4	4	4	4	4	5	5	5	5	5	4	4	5	2	4
69	4	4	3	4	2	2	3	4	5	4	3	3	3	4	4	4	3	3

70	4	3	4	4	4	5	5	5	5	5	4	3	4	5	4	4	4	4
71	4	2	5	3	5	5	5	4	5	5	5	3	3	3	3	2	2	2
72	1	2	3	3	1	3	3	2	3	3	3	4	4	4	4	3	1	4
73	5	3	5	5	5	5	5	5	5	5	5	3	5	5	5	2	2	4
74	5	4	4	3	2	4	4	4	5	5	5	4	4	4	4	5	2	4
75	4	4	2	2	5	5	5	3	5	5	5	4	4	5	4	3	3	3
76	1	3	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	5
77	3	2	3	5	3	5	4	3	5	4	3	3	3	3	5	5	5	5
78	3	2	4	4	4	4	4	4	3	4	5	3	4	4	4	5	3	3
79	4	4	4	4	5	5	5	5	5	5	4	4	3	5	5	5	5	4
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Mean Rating Scores of the Likelihood of Barriers and Improvement Strategies

Responden t	Likelihood of Barriers Occurring										Improvement Strategies									
	LPB 1	LPB 2	LPB 3	LPB 4	LPB 5	LPB 6	LPB 7	LPB 8	LPB 9	LPB1 0	IMP 1	IMP 2	IMP 3	IMP 4	IMP 5	IMP 6	IMP 7	IMP 8	IMP 9	IMP1 0
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