APPLICATION OF SMART TECHNOLOGIES IN CONSTRUCTION PROJECT MANAGEMENT

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Science (Honours) Quantity Surveying

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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ABSTRACT

The integration of smart technologies in construction project management has emerged as a transformative approach to optimising time, cost, and quality, addressing long-standing challenges in project efficiency and productivity. Malaysia's National Construction Policy 2030 emphasises the adoption of digital technologies to modernise the sector, promoting automation and advanced data-driven solutions. This study examines the application of Building Information Modelling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), and automation tools in enhancing project planning, resource allocation, communication, and risk mitigation. Moreover, existing literature has highlighted the growing application of smart technologies across multiple industries including healthcare, education, agriculture, and general construction, emphasizing their role in enhancing efficiency, sustainability, and innovation. Studies by Jakobsen et al. (2023), Khan et al. (2024), and Pandey et al. (2022) illustrate the broad potential of smart technologies in various sectors. Within construction, prior research (e.g., Carolina Hernández García et al., 2024; Nilimaa, 2023) has focused on the technological adoption at a general level, such as eco-friendly materials and safety systems. However, there is a noticeable gap in understanding how smart technologies specifically impact construction project management practices such as planning, scheduling, cost control, and quality assurance. Few studies provide empirical evidence directly linking smart technologies with measurable improvements in project performance. This study aims to fill that gap by focusing on how digital tools contribute to key project management functions within the Malaysian construction industry. A quantitative research approach is employed, using a structured questionnaire survey to gather insights from experienced industry professionals in Malaysia's construction sector. The data is analysed through descriptive and inferential statistical techniques, including reliability analysis, correlation tests, and factor analysis, to identify key factors influencing the effective adoption of smart technologies. A total of 110 responses were collected and analysed through descriptive and inferential statistical techniques, including reliability analysis, correlation tests, and factor analysis, to identify key factors influencing the effective adoption of smart technologies. The findings reveal that smart technologies enhance project planning through improved scheduling, resource optimization, and stakeholder coordination. Cost reductions stem from minimized budget overruns, reduced material waste, and automation-driven productivity gains. Quality improves via automated defect detection, BIM-driven accuracy, and standardized workflows, while risk mitigation benefits from real-time safety monitoring and AI-driven analytics. However, challenges such as high initial investment costs, limited technical expertise, resistance to change, and the lack of standardized implementation frameworks hinder the widespread adoption of these technologies. Statistical analysis confirms a strong correlation between smart technology implementation and project performance, with cost, training, and organizational readiness as key influencing factors. The findings are expected to provide empirical insights into the impact of digital innovations on improving project performance, enabling practitioners to make informed decisions in adopting technology-driven solutions. Additionally, the study contributes to the development of strategic frameworks for integrating smart technologies into construction project management, aiding policymakers and industry leaders in overcoming implementation barriers. The research offers a practical roadmap for fostering more efficient, cost-effective, and high-quality construction practices, ensuring greater predictability and control over project outcomes.

Keywords: Smart technologies, construction project management, time-cost-quality, digital innovation, project performance

Subject Area: TA190-194 Management of engineering works

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

α	Cronbach's Alpha Value
k	Number of Sample
N	Number of Items
$\bar{c}$	Mean Covariance between Items
$\bar{v}$	Average Varience
AI	Artificial Intelligence
AR	Augmented Reality
BD	Big Data
BIM	Building Information Modeling
CLT	Central Limit Theorem
COBOT	Collaborative Robot
CVD	Cardiovascular Disease
CPM	Critical Path Method
CPS	Cyber Pyshical System
DLT	Distributed Ledger Technology
EFA	Exploratory Factor Analysis
EVM	Earned Value Management
GIS	Geographic Information System
IFC	Industry Foundation Classes
IoT	Internet of Things
ML	Machine Learning
QS	Quantiti Surveying
RFID	Radio-frequency identification
R&D	Research and Development
ROI	Return on Investment
TQM	Total Quality Management
UAVs	Unmanned Aerial Vehicles
UAS	Unmaed Aircarf System
UAE	United Arab Emirates
VDC	Virtual Design Construction
VR	Virtual Reality
4IR	Fourth Industrial Revolution

CHAPTER 1

INTRODUCTION

1.1 Introduction

The global construction industry is currently experiencing robust growth, driven primarily by strong demand from key economies such as China, the United States, and India. By 2037, these three countries are projected to collectively account for 51% of all global construction activities (Brown et al. 2023). This underscores their pivotal role in not only driving sectoral growth but also stimulating global economic expansion, given their significant populations and economic outputs, which collectively represent more than a third of the world's total. This growth is complemented by significant advancements in Construction 4.0 technologies, as highlighted by Forcael et al. (2020). Technologies such as 3D printing, big data analytics, virtual reality, and the Internet of Things (IoT) are revolutionizing construction processes worldwide. Leading countries like the USA, UK, and China are at the forefront of research and innovation in these areas, shaping the future of the industry. Their leadership underscores their ability to leverage technology to enhance efficiency, sustainability, and productivity in construction practices.

Huge investments in the construction sector funded by China through the Belt and Road Initiative have also encouraged the development of the construction industry in Malaysia. According to Chin et al. (2022), Malaysia should maintain an open-door policy to welcome foreign direct investment from China. Collaborating with China on planning and executing construction projects could stimulate the development of the construction sector and support long-term economic growth. Deputy Works Minister Datuk Seri Ahmad Maslan stated that the outlook for Malaysia's construction industry is expected to improve further entering the second half of 2024, with both the private and government sectors allocating a total of RM180 billion (Birruntha, 2024). Recent studies have highlighted the positive impacts of Chinese investments in

Malaysia, noting improvements in infrastructure quality, job creation, and technology transfer (Todd and Slattery, 2018).

Additionally, the implementation of smart technologies in the Hong Kong-Zhuhai-Macao Bridge project has indeed set a notable precedent (Zeng et al., 2018). Inspired by such a successful project, Malaysia may explore similar smart technologies integrations in its own infrastructure developments. Tan Sri Abdul Rahman Mamat, emphasized that the application of smart technologies and automation can enhance the construction sector by boosting productivity and improving quality (Birruntha, 2024). The National Construction Policy 2030 (NCP 2030) is a significant government initiative by CIDB Malaysia to modernize and transform the construction sector using digital technologies (Birruntha, 2024). These, in turn, would make the sector more competitive on a global scale. This policy is expected to drive innovation, increase productivity, and promote sustainable practices within the industry (Farhan Roslan et al., 2022).

However, the rapid growth of construction industry faces significant challenges related to time, cost, and quality. Time management is a critical issue, as delays can significantly impact project schedules and budgets. Poor site management, inadequate planning, and insufficient communication are primary contributors to project delays. For example, Ahmed and Hassam (2023) identified that project delays in Egypt were often due to contractor inefficiencies, financial issues, and material shortages. Effective time management requires robust scheduling, real-time tracking, and proactive problem-solving to mitigate delays.

Cost management is another critical challenge in construction project management. Cost overruns are common due to unexpected changes, inaccurate estimates, and poor financial management. Ahmed and Hassam (2023) highlighted that inadequate cost control mechanisms, inflation, and variations in project scope are significant factors leading to budget overruns. Implementing advanced cost estimation techniques and continuous monitoring can help address these issues. Another study by Haslinda et al. (2018) found that effective cost management practices, including regular financial reviews and contingency planning, are essential for managing construction project costs.

Quality management is equally challenging, as maintaining high standards requires careful oversight and adherence to specifications. Poor quality management can lead to rework, increased costs, and project delays. Chen et al. (2023) emphasized that rework due to quality defects is a major issue in the construction industry, often resulting from inadequate supervision and poor communication among project stakeholders. Adopting quality management systems and fostering a culture of continuous improvement are essential for ensuring high-quality outcomes. For instance, a study by Chong et al. (2017) found that implementing Total Quality Management (TQM) principles can significantly enhance quality performance in construction projects.

In conclusion, the global construction industry is rapidly growing, led by China, the U.S., and India, and driven by advancements in Construction 4.0 technologies. Malaysia is poised to benefit from this growth, especially through collaborations like the Belt and Road Initiative. However, the industry must address challenges in time, cost, and quality management by adopting smart technologies and improving project management practices to achieve sustainable and high-quality results.

1.2 Problem Statement

The smart technologies is increasingly integrated into our daily routines. Oosthuizen (2022) conducted a critical review to examine the role of industrial psychologists in future workplaces during the Fourth Industrial Revolution (4IR) with smart technologies, discussing the evolution of digital workspaces and the anticipated impact of smart technologies in reshaping organisational dynamics.

Smart technologies are becoming increasingly prevalent worldwide across various industries. Jakobsen et al. (2023) analyzed the application of smart technologies in enhancing rural community development. Similarly, Nesterenko (2023) researched the application of smart technologies in education, particularly through smart education and smart complexes, aiming to improve educational processes. Beyond education and development, smart technologies is also transforming the medical field. According to Khan et al. (2024), smart technologies have significantly advanced cardiovascular disease (CVD) management, leveraging innovative tools to enhance patient care, diagnostics, and treatment strategies. Meskó et al. (2017) stated that the advancement and adoption of smart technologies have comprehensively transformed the traditional medical system, introducing a new era of efficient medical services. Moreover, smart technologies in agriculture, encompassing applications from soil preparation and seeding to fertilization, irrigation, harvesting, and storage, is also gaining prominence (Pandey et al., 2022).

In line with Industrial Revolution 4.0, the construction industry has begun to apply smart technologies. This trend is evidenced by research from Carolina Hernández García et al. (2024), which examines the current status of smart technologies in the construction industry, and Nilimaa (2023), which explores advanced materials and smart technologies for eco-friendly concrete construction. Additionally, Umar et al. (2022) emphasizes the necessity of implementing sustainable practices and smart technologies to reduce the construction industry's environmental footprint. Zairi et al. (2016) investigates the use of smart technologies to enhance safety in the construction industry. Similarly, Fredriksson et al. (2021) assessed stakeholder understanding of smart safety technologies in construction, aiming to improve awareness and commitment toward these technologies among stakeholders.

Smart technologies brings myriad advantages and disadvantages. Wilson et al. (2017) investigated and characterized the perceptions, benefits, and risks associated with smart home technologies from various perspectives. McCabe et al. (2017) researched how UAVs and UAS (smart technologies) can automate data capture in indoor construction, evaluating benefits, addressing challenges, and proposing solutions for integrating them with emerging technologies.

Based on the analysis of previous studies, it was observed that the majority of research tends to concentrate on the broad concept and applications of smart technologies across different industries and contexts, addressing a wide array of challenges. However, a significant research gap exists in understanding how smart technologies specifically enhance construction project management practices, especially in terms of improving time management, cost control, quality assurance, and safety performance on project sites. While numerous studies have acknowledged the broad benefits of smart technologies, few have empirically investigated how tools like Building Information Modelling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), and automation technologies contribute to project planning, real-time monitoring, communication, and decision-making throughout construction project life cycles. Moreover, there is limited evidence linking these technologies directly to quantifiable project outcomes in terms of efficiency and productivity improvements.

This study distinguishes itself by focusing on the practical application of smart technologies in construction project management within the Malaysian context, specifically investigating how these tools support project success across key performance indicators. A quantitative method using structured questionnaires was employed to collect data from 110 construction professionals across Malaysia, covering various types of construction projects including residential, commercial, and infrastructure. The research spans across all major phases of the project cycle from initial planning and scheduling to execution, quality control, and risk management.

By narrowing its focus to the impact of smart technologies on core project management functions, this study not only addresses a critical gap in current literature but also contributes practical insights for industry practitioners, project managers, and policymakers aiming to modernize the Malaysian construction sector through digital transformation. This exploration is especially relevant in achieving the goals outlined in Malaysia's National Construction Policy 2030, which promotes digital integration to improve project delivery, reduce waste, and enhance sustainability and competitiveness.

1.3 Research Aim

This research aims to explore the application of smart technologies in construction project management, focusing on how these innovations can enhance efficiency and quality, reduce costs, and ensure timely project delivery.

1.4 Research Objectives

The following research objectives had been developed in order to achieve the research aims:

1) To investigate the application of smart technologies in the management of time, cost, and quality in construction projects.
2) To explore the challenges in implementing smart technologies in construction project delivery.
3) To recommend strategies in adopting smart technologies in the construction industry.

1.5 Research Methodology

To achieve the objectives of this research, a quantitative approach was employed. To enhance the response rate, the questionnaire was designed using Google Forms. This survey was distributed to participants via email and social media platforms. The study specifically targeted respondents who are key stakeholders in the procurement process, including clients, consultants, contractors, and suppliers in Malaysia. A total of 110 responses were collected. The collected data was analysed both analytically and descriptively, employing methods like the Cronbach's Alpha Reliability Test, Mean-ranking, Kruskal-Wallis Test, Spearman’s Correlation Test, and Factor Analysis. Information about the specific research methods and goals is illustrated in Figure 1.1.

Aim: To explore the application of smart technologies in construction project management, focusing on how these innovations can enhance efficiency and quality, reduce costs, and ensure timely project delivery.		
Objectives 1:	Objectives 2:	Objectives 3:
To investigate the application of smart technologies in the management of time, cost, and quality in construction projects.	To explore the challenges in implementing smart technologies in construction project delivery.	To recommend strategies in adopting smart technologies in the construction industry.

Literature review to identify the application of smart technologies, the challenges and strategies to implement smart technologies.	Empirical data collection on how the strategies deal with the challenges of implement smart technologies in construction industry.	Evaluate and examine the information collected from the different respondents to look at current corelation and patterns.

Figure 1.1: Research Plan

1.6 Research Scope

This study investigated the perspectives of construction professionals on the practicality of implementing smart technologies in Malaysian construction projects. The research aimed to identify the challenges of implementing smart technologies in these projects. The study's sample was drawn from construction industry participants in the construction industry of Malaysia, specifically targeting stakeholders involved in the procurement process, including clients, consultants, contractors, and suppliers.

1.7 Outline of the Report

Chapter 1: Introduction
This chapter provided an overview of the study, offering readers a concise understanding of the research conducted. It covered the research background, problem statement, research aim and objectives, research questions, research scope, significance and justification of the study, and the report outline. This chapter aimed to give readers a clear concept of the purpose behind the research and highlighted existing issues within the construction industry.

Chapter 2: Literature Review
This chapter presented a review of literature based on previous studies by other researchers. It began with a brief introduction to the chapter's content, followed by a discussion on the concept of green procurement. The benefits of green procurement were explored to enhance readers' understanding of the research topic. The chapter also addressed the barriers to adopting green procurement and identified strategies to promote its implementation in the construction industry.

Chapter 3: Research Methodology
This chapter outlined the methods and mechanisms employed to conduct the research. It examined the types of research, research and sampling design, data collection methods, and data analysis techniques used in the study.

Chapter 4: Result and Discussion

In this chapter, the data collected from respondents were thoroughly analyzed and discussed. The evaluation of both qualitative and quantitative data was aligned with the research aims and objectives to ensure the research goals were achieved.

Chapter 5: Recommendations

This final chapter summarized the overall findings and emphasized key points discussed in the previous chapters. It also included recommendations for future research and addressed the limitations encountered during the research process.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter aims to assess and analyze the existing research conducted by previous journals and studies. It starts with a brief introduction to smart technologies in construction industry. To provide a deeper understanding of the research topic, the literature review includes an extensive examination of both global and regional disputes in the construction sector. Moreover, this chapter outlines the challenges of implementation of smart technologies in construction project management. Following this, the chapter delves into and examines the strategies to implement smart technologies in construction project management.

2.2 Definition

Table 2.1: Definition

Terms	Definition	In-Text Citation
Smart technologies	"Smart technology refers to integrating advanced technology into various aspects of our daily lives, such as homes, cities, and transportation."	Katuk et al. (2023, p.1)
Project management	"Project management involving utilizing expertise and resources to plan and schedule project, enhancing the project objectives."	Ghorbani, (2023, p.1)

Smart technologies can be defined as an autonomous device, system, or application that integrates advanced computation, connectivity, and sensing to improve performance, productivity, and user experience. These technologies are often embedded with artificial intelligence (AI), machine learning (ML), and the Internet of Things (IoT) to enable automated decision-making, data-driven insights, and seamless communication between devices and networks. By integrating these features, smart technologies can adapt to user behaviour, optimize performance, and provide personalized experiences across various sectors, including healthcare, transportation, and home automation.

Project management is the application of knowledge, skills, tools, and techniques to project activities to meet specific objectives within defined constraints, such as time, cost, and scope. It involves planning, organizing, leading, and controlling resources and processes to achieve project goals and deliverables efficiently. The discipline encompasses various phases, including initiation, planning, execution, monitoring, and closing, and is applicable across diverse industries and contexts. Effective project management ensures that projects are completed on time, within budget, and to the desired quality standards, while also addressing potential risks and stakeholder expectations.

2.3 Smart Technologies in Construction Project Management

Smart technologies in construction project management represents the convergence of cutting-edge digital tools, IoT-enabled devices, and advanced data analytics designed to optimize various aspects of construction project workflows, including the critical factors of time, cost, and quality. This technological integration includes Building Information Modelling (BIM), drones, sensors, AI-driven analytics, and other automated systems, all of which contribute to enhanced efficiency, productivity, and decision-making in project management (Silverio and Eng, 2019). For example, BIM facilitates the digital representation of a facility's physical and functional characteristics, improving visualization, collaboration, and coordination among project stakeholders, which can lead to faster project delivery and reduced errors (Mesároš and Mandičák, 2017). Drones and sensors play a critical role in site monitoring, providing real-time data that helps in managing safety, tracking progress, and ensuring that resources are allocated efficiently. AI algorithms contribute to predictive analysis and risk management, which are crucial for maintaining budgetary constraints and ensuring that projects meet the desired quality standards. By integrating these smart technologies, project managers can effectively manage the complexities of time, cost, and quality, ultimately leading to more successful project outcomes and better alignment with stakeholder expectation (Pasi et al., 2020).

2.4 Time, Cost, Quality in Construction Project Management

In construction project management, time, cost, and quality are often referred to as the "triple constraint," forming the core criteria that determine the success of a project (Walker, 2015). These three elements are interdependent, meaning that changes to one often impact the others. For example, reducing the project duration may lead to increased costs due to the need for additional resources or may compromise quality due to the rushed execution of tasks (Ogunrinde et al., 2020).

Quality management in construction is not only about meeting technical specifications but also involves ensuring that the project meets the needs and expectations of stakeholders (Keenan and Rostami, 2019). However, maintaining high-quality standards often requires additional time and resources, which can increase costs. Conversely, projects that prioritize cost reduction might achieve this by compromising on quality, potentially leading to rework, delays, and additional costs in the long term (Webb et al., 2015).

Effective project management involves balancing these three constraints. Tools such as Earned Value Management (EVM) and Critical Path Method (CPM) are frequently employed to monitor and control time and cost while ensuring that quality standards are upheld (Kerzner, 2015).

2.5 Sustainability, Safety and Productivity in Construction Project Management

Modern construction project management extends beyond the traditional focus on time, cost, and quality, incorporating sustainability, safety, and productivity as critical factors that drive project success (Xie et al., 2020).

Sustainability in construction project management involves practices that minimize the environmental impact of construction activities while ensuring economic viability and social responsibility (Nilimaa, 2023). Sustainable construction practices include the use of eco-friendly materials, energy-efficient building designs, and waste reduction strategies. These practices not only contribute to environmental protection but also enhance the economic performance of projects by reducing operational costs and increasing the building’s life cycle value (Wu et al., 2021).

Safety is a paramount concern in construction project management, given the high-risk nature of construction sites (Chan et al., 2023). Effective safety management is essential to prevent accidents, reduce injuries, and avoid project delays caused by safety incidents (Ranasinghe et al., 2023). The promotion of a strong safety culture within construction organizations has been shown to significantly reduce the occurrence of accidents and improve overall project outcomes.

Productivity in construction refers to the efficiency with which resources, such as labour, materials, and equipment, are utilized to achieve project goals. High productivity is essential for completing projects on time and within budget, while maintaining the desired quality standards (Ofori et al., 2022). The adoption of advanced technologies, such as Building Information Modeling (BIM) and lean construction techniques, has been shown to significantly enhance productivity by streamlining processes, reducing waste, and improving coordination among project stakeholders (Liu et al., 2017). Additionally, productivity improvements contribute to sustainability by minimizing resource use and waste generation, thus creating a more efficient and environmentally responsible construction process (Ibrahim et al., 2021).

2.6 Smart Technologies in Driving Success and Improvement

Success in construction project management is often defined as the ability to deliver projects within the specified time, budget, and quality parameters while ensuring safety, sustainability, and high productivity levels

(Ika and Pinto, 2022). Achieving these outcomes requires a holistic approach that integrates advanced planning, efficient resource management, and continuous monitoring.

Improvement in construction project management, on the other hand, involves ongoing efforts to enhance these key areas (Stanitsas et al., 2021). For example, integrating real-time data analytics with existing scheduling tools could further refine time management, while fully integrating cost management software with other project management systems could lead to even better budget control. In quality management, continuous improvement in quality assurance protocols is necessary to keep pace with the growing complexity of projects (Rauzana, 2017). Safety management systems also require continuous development, particularly through the adoption of wearable technology and real-time monitoring systems, which can significantly reduce workplace accidents (Webb et al., 2015). Advancements in sustainability practices and safety management systems, particularly through technology adoption, represent critical areas for ongoing development. Moreover, widespread adoption of automation and robotics is essential to fully realize the potential productivity gains in construction (Bock, 2015).

2.7 Types of Smart Technologies in Construction Project Management

2.7.1 Building Information Modeling (BIM)

Building Information Modeling (BIM) is the process of creating and maintaining data on a building model across its life cycle. BIM not only generates a 3D representation but also incorporates time (4D), cost (5D), and other dimensions. Information derived from BIM is essential for the precise and efficient creation of construction documents, construction scheduling, cost estimation, and forecasting traffic flow.

Using 3D software tools such as Revit or ArchiCAD, BIM allows architects, engineers, and construction professionals to design, visualize, and analyze various aspects of a project in a digital environment. These applications facilitate cost estimation, project scheduling, project management practices, safety requirements, and sustainability parameters, making BIM a centralized repository of information that all stakeholders can rely on (Mesároš et al., 2022).

Additionally, BIM software's Application Programming Interface (API) enables developers to programmatically access and manipulate data. This capability facilitates customization, automation, and seamless integration with other software systems, enhancing efficiency, reducing manual errors, and accelerating project timelines (Olawumi and Chan, 2018).

BIM also plays a critical role in quality control throughout construction projects. Utilizing tools like Navisworks, BIM allows for thorough analysis of building models to detect clashes and ensure seamless coordination among architectural, structural, and mechanical, electrical, and plumbing components before construction begins. Compliance rules are formalized using Semantic of Business Vocabulary and Business Rules, enabling BIM to interpret and enforce regulations through semantic models. This rigorous checking against regulatory requirements ensures accuracy and adherence to design specifications, and visualizing conflicts and compliance status in 3D provides clear insights, empowering stakeholders to address issues promptly and improve project outcomes (Kovacs and Micsik, 2021).

An additional advantage of BIM is cost evaluation facilitated by 5D BIM, which automates the time and effort spent on cost estimation. Software such as Revit allows project teams to prioritize high-value items and efficiently identify project components (Hamid and Abdelhaleem, 2023). Companies utilizing BIM have reported positive returns on their investments (Adel et al., 2022).

Moreover, BIM enhances collaboration among contractors and subcontractors by enabling coordination through internet-connected BIM applications. This allows project stakeholders to access planning data and make necessary corrections as required, minimizing the time of construction projects (Sholeh et al., 2020).

2.7.2 Drones

Originally developed for military applications, drones have seen significant advancements in size, weight, and cost-effectiveness, making them increasingly accessible across various industries (Holton et al., 2015). In the construction sector, drones are utilized to optimize operations, enhance project management practices, and mitigate risks (Choi et al., 2023).

Drones can help alleviate these issues by automating tasks that traditionally require manual labor. For instance, drones can conduct site surveys and mapping quickly and accurately, reducing the need for human surveyors and expediting the initial stages of construction projects (Elghaish et al., 2021). Additionally, drones can fly over large areas, capturing data that can be processed into detailed 3D models and topographical maps, which are critical for project planning and management (Albeaino et al., 2019).

Furthermore, drones provide real-time data and high-resolution images, enabling construction managers to monitor project progress effectively. Drones can perform monthly overflights of construction sites, providing detailed progress updates for managers. This information helps managers engage with stakeholders and keep them informed about the project's status. Keyvanfar and Shafaghat, (2022) highlight their use in 3D modeling and progress monitoring. By capturing images and data at regular intervals, drones offer detailed insights into construction project advancement.

Next, drones equipped with advanced cameras and sensors play a crucial role in inspecting infrastructure to measure signs of wear and tear in bridges, ships, and tunnels (Floreano and Wood, 2015). They capture high-resolution images and data that enable inspectors to detect cracks, wear, and structural issues.

Utilizing these devices enables companies to achieve high-quality results efficiently, saving both time and money. In conclusion, drones significantly enhance construction project management by improving time efficiency, reducing costs, ensuring high-quality outcomes, and enhancing safety through automated tasks, detailed data collection, real-time progress monitoring, and precise inspections of hard-to-reach areas.

2.7.3 Internet of Things (IOT)

The implementation of widespread 5G standards will significantly boost the adoption of IoT in the construction industry (Reja and Varghese, 2019). IoT devices can forecast product supply and demand well in advance, supporting the construction industry in developing flexible logistics systems. Feedback from customers using IoT devices, such as smartphones, can be directly transferred to manufacturers, allowing companies to provide efficient customer service and improve construction project quality (Pasi et al., 2020).

IoT enhances project lifecycle management by enabling better monitoring and control of machinery, materials, and labor usage, while also providing flexibility in sequencing project tasks (Tahir et al., 2018). Tang et al. (2019) stated that the concept of IoT extends beyond sensors and actuators to emphasize the interconnectedness of these devices, enabling information sharing over the internet. This interconnectedness improves project lifecycle management through enhanced monitoring and control of resources (Ibrahim et al., 2021).

Additionally, IoT is utilized to monitor and manage employee productivity, on-site project progress, environmental conditions, and waste management. By connecting sensors and actuators via the internet and transferring data into digital platforms, construction teams gain insights into potential errors, project performance, and productivity metrics in digital formats (Mahmud et al., 2018). This application of IoT in project management enhances efficiency by digitally monitoring project progress through 3D model visualization, optimizing resource use, tracking equipment, detecting errors early, providing real-time reporting, and managing scheduling and costs effectively (Ibrahim et al., 2021).

Furthermore, Zhong et al. (2017) propose a multi-dimensional IoT-enabled Building Information Modeling (BIM) platform (MITBIMP) to enhance real-time visibility and traceability in prefabricated construction. The Data Capture Service collects data from smart objects, enabling real-time logistics tracking by the Visibility and Traceability Service on Cloud Manufacturing shop floors. This involves monitoring the materials used in different precast IoT oversees smart construction objects using wired and wireless communication, allowing real-time access to prefabrication production status and supporting prefabrication-based construction services.

2.7.4 Artificial Intelligence (AI)

According to Patil (2019) , the use of artificial intelligence (AI) in construction engineering and management has grown significantly, largely due to its potential to enhance construction performance and efficiency. AI is anticipated to transform business models in the construction industry, impacting logistics, customer relationship management, support, workflow automation, and finance. Additionally, AI can enhance training by simulating realistic scenarios, reducing injuries and costly errors, and improving operational efficiency. This technology can help operators optimize existing labor resources, addressing the skilled labor shortage.

AI also plays a crucial role in organizing and managing construction disputes, thereby enhancing overall construction project management. AI facilitates settlement-oriented systems to support negotiation for reaching agreements, aids in method selection-oriented systems for choosing appropriate dispute resolution methods such as mediation or arbitration and supports dispute evaluation-oriented systems to analyze causes, likelihoods, and impacts of disputes (Putera et al., 2021). These applications aim to enhance decision-making and efficiency in managing construction disputes.

Moreover, AI application models are essential for accurately predicting construction costs and project schedules. By integrating 4D and 5D visualization into Building Information Modeling (BIM), these models mitigate risks related to unexpected expenses and project milestones. Advanced technologies such as deep learning, a branch of machine learning that mimics human brain functions using statistical analysis and predictive modeling, enhance the precision of time and cost estimates in construction projects (Regona et al., 2022).

AI techniques revolutionize construction by enhancing efficiency through advanced capabilities. Process mining, driven by AI, analyzes workflows to predict deviations and pinpoint bottlenecks, fostering streamlined operations and improved collaboration. Optimization algorithms leverage AI to craft construction plans that achieve optimal balances between time, cost, and quality, ensuring projects remain on budget and schedule. Furthermore, AI-driven robots perform repetitive tasks like bricklaying and welding autonomously, reducing labor costs and accelerating project timelines with consistent precision. These advancements not only streamline operations but also enhance overall project efficiency and profitability in construction (Pan and Pan, 2020).

2.7.5 Augmented Reality (AR) and Virtual Reality (VR)

Davila et al. (2020) stated that approximately 32.4% of construction firms in the UK have employed augmented reality (AR) or virtual reality (VR) in various ways. VR tools have proven highly effective in revolutionizing design approaches by enabling direct input from end-users, such as owners or project managers, without requiring expertise in interpreting 2D drawings or CAD models. These tools immerse stakeholders in scaled virtual environments where they can thoroughly inspect various aspects and details of proposed designs. As infrastructure projects become increasingly complex, VR offers significant advantages in enhancing communication among stakeholders, potentially addressing a major challenge in understanding and approving change orders (Balali et al., 2018).

In addition, Noghabaei et al. (2020) have developed a framework for construction cost estimation using VR technology. Their approach involves a real-time VR model where stakeholders can modify materials such as walls and floors, receiving instant feedback on cost implications. This innovation aims to improve communication among stakeholders in construction projects, facilitated by a cloud-based VR system.

Several AR systems have also been developed for construction applications. These include a projection-based AR approach for visualizing vital manufacturing information with precision, an AR system assisting in building complex double-curved brick walls using markers for accurate alignment, another system facilitating the precise installation of electrical conduits through 3D overlays, and AR-guided assembly tasks improving spatial understanding among furniture components. These innovations aim to enhance construction efficiency and accuracy by integrating virtual information directly into the real-world environment (Davila et al., 2020).

2.7.6 Robotics

The building and construction sector faces significant challenges, including rising costs, skill gaps, and an aging workforce. Robotics in construction signifies a notable shift from traditional methods (Pan et al., 2020), addressing these challenges by improving time efficiency, reducing costs, and enhancing quality.

Autonomous robotic assembly and automated installation systems have been widely adopted, particularly in interior finishing and the installation of building exteriors. These technologies not only streamline processes to save time but also reduce labor costs and ensure high-quality construction. For masonry walls, robotic bricklaying and automated assembly technologies show great promise in improving efficiency and precision, leading to cost savings and superior quality (Gharbia et al., 2020).

New types of robots have emerged to further address these challenges. These include aerial robots for integration tasks, exoskeletons for enhancing worker strength, additive manufacturing technologies, collaborative robots (cobots), and humanoid robots. These versatile robots assist with various construction tasks, enhancing efficiency and precision. Larger, comprehensive systems, referred to as integrated automated and robotic systems or on-site automated factories, further optimize time, cost, and quality in construction projects (Pan et al., 2020).

Collaborative robot teams are being introduced to work alongside human workers in the construction industry. This approach aims to alleviate human workers from hazardous and repetitive tasks, allowing them to focus on higher-level planning and cognitive work as cobot supervisors. By handling physically demanding jobs like heavy lifting and precise tool control, cobots not only improve overall efficiency and reduce project timelines but also cut labor costs and enhance the quality of work on construction sites (Liang et al., 2021).

2.7.7 Prefabrication And Modular Construction

Prefabrication and modular construction are increasingly recognized for their potential to revolutionize the construction industry by enhancing efficiency, sustainability, and cost-effectiveness. These methods involve manufacturing building components in controlled environments and assembling them on-site, which reduces construction time, improves quality, and minimizes waste. Research shows that prefabrication can lead to significant time savings, as factory-controlled settings reduce weather-related delays and ensure consistent quality (Rocha et al., 2022). Additionally, the modular construction approach allows for greater design flexibility and scalability, enabling the efficient replication of building modules across various projects (Wu et al., 2021).

The sustainability benefits of prefabrication and modular construction are also well-documented. By reducing material waste and energy consumption during the construction process, these methods contribute to lower carbon footprints compared to traditional construction techniques (Lu et al., 2021). Furthermore, prefabrication can improve worker safety by minimizing on-site activities and exposure to hazardous conditions. However, challenges remain and the need for standardization to facilitate broader adoption.

2.7.8 3D Printing

Technological advancements such as 3D printing are fundamentally transforming the construction industry, moving beyond traditional methods reliant on onsite assembly of raw materials. 3D printing facilitates the off-site production of intricate components while reintegrating value-adding activities back into the construction site. This approach represents a modern industrialization of construction, optimizing efficiency by combining advanced off-site manufacturing with on-site assembly. Unlike subtractive manufacturing methods that involve cutting away materials, 3D printing builds objects layer by layer from digital models, offering unparalleled design flexibility and precision (Olsson et al., 2021).

Critical to successful 3D printing are the choice of materials, the printing process itself, and the initial digital design typically created in CAD software (Olsson et al., 2021). For instance, WinSun Decoration Design Engineering Co. utilized 3D printing to construct a six-storey apartment building in Shanghai using recycled materials and a diagonal reinforced print pattern, demonstrating the technology's integration with traditional construction practices (Schutter et al., 2018).

A paste made of cement and several admixtures is currently the most used printing material (Besklubova et al., 2021). Romero and Rodrigues (2016) highlight that 3D printing can lead to significant manufacturing, material, and time benefits in construction project management by eliminating the need for tooling, reducing investment costs, and geometric constraints, while enabling the creation of dense, high-quality parts with excellent mechanical properties. 3D printing maximizes material savings by reducing waste and enabling high recyclability, while also significantly shortening production times by eliminating tooling and facilitating rapid prototyping and design changes.

2.7.9 Smart Materials

Smart materials are increasingly being integrated into construction to enhance the functionality, sustainability, and durability of structures. One of the key applications of these materials is in self-healing concrete, which can autonomously repair cracks, thereby extending the lifespan of buildings and reducing maintenance costs (Khaled et al., 2018). Additionally, phase-change materials are used to regulate indoor temperatures by absorbing and releasing thermal energy, contributing to energy efficiency in buildings (Rane et al., 2024). Nanomaterials, another category of smart materials, are being incorporated into construction materials to improve their mechanical properties and resistance to environmental factors. For instance, the use of nanomaterials in coatings can provide buildings with enhanced resistance to weathering and pollutants, leading to longer lasting and more resilient structures.

Moreover, these innovations are supported by advancements in digital technologies like Building Information Modeling (BIM) and Digital Twins, which allow for better integration and management of smart materials in construction projects. These technologies facilitate the simulation of material performance and environmental impacts, aiding in the design of more sustainable and efficient buildings. As research continues to explore new applications and improvements in smart materials, their role in transforming the construction industry is expected to grow significantly (Nilimaa, 2023; Rane et al., 2024).

2.7.10 Geographic Information System (GIS)

Geographic Information System (GIS) is a structured framework designed for capturing, storing, processing, and presenting spatial information using a geomatic model. It transforms abstract data into digital, geo-referenced maps, facilitating the visualization and analysis of geographical information through a structured design and functional components (Akindele et al., 2023). GIS is widely applied to infrastructure projects due to its expansive and interconnected nature, enabling the comprehensive visualization and utilization of information associated with each element of the infrastructure across large geographical areas. This technology supports diverse applications such as pavement condition assessment, traffic management, sustainability initiatives, optimization of transport networks, and understanding the relationship between the landscape and roads (Cepa et al., 2023).

According to Han et al. (2022), their study introduces a novel framework that integrates Building Information Modeling (BIM) and Geographic Information System (GIS) to enhance the evaluation of asphalt pavement construction quality, addressing deficiencies in existing approaches. GIS offers georeferenced data with topological information, enabling 3D analysis, spatial assessments, and functionalities like measuring distances between points, determining routes, and identifying optimal locations (Al-Saggaf and Jrade, 2015). Furthermore, GIS integrates BIM data to estimate demolition waste and manage construction projects effectively by calculating material volumes and conditions, using tools like "select by location" and "select by attribute" for analysis, and supporting advanced spatial functions for waste estimation and planning (Al-Saggaf and Jrade, 2015).

In addition to these capabilities, GIS in construction integrates geographical data with CAD drawings to create 4D models, enhancing project scheduling and visualization by linking PRIMAVERA and Microsoft Project schedules with 3D drawings. It serves as a platform for integrating project databases and satellite imagery, enabling detailed 3D modeling and scheduling to improve project management and coordination in construction (Kumar and Reshma, 2017).

Moreover, Kumar and Reshma (2017) propose integrating GIS into construction supply chain management by utilizing geographic data to optimize material supplier locations. GIS facilitates the alignment of detailed building project information, including material demand, with spatial data. This capability to integrate and analyze geographic and building data enables a more effective approach to managing supply chains in construction projects.

2.7.11 Digital Twin Technolgy

Digital twin technology is revolutionizing the construction industry by providing a dynamic, real-time virtual representation of physical assets and processes. The most important application of digital twin technology in construction is in the design and planning phase, where it extends the capabilities of BIM by incorporating real-time data, allowing for a more detailed and adaptable model that evolves as the project progresses. It can visualize the entire lifecycle of a project from design to demolition (Almatared et al. 2022). Besides, digital twin technology can stimulate different scenarios to predict potential issues to occur, optimize construction methods, and ensure that design plans will perform as intended under various conditions (Park et al. 2024).

During the construction phase, Digital Twins play a crucial role in real-time monitoring and risk management. By continuously gathering and analyzing data from the construction site, Digital Twins enable project managers to track progress, monitor equipment usage, and identify potential issues before they become critical. This proactive approach not only helps in minimizing delays and preventing costly mistakes but also enhances overall project efficiency (Park et al. 2024a). Additionally, Digital Twins contribute to asset management and maintenance post-construction by providing a detailed model that can be used to monitor the condition of assets, schedule maintenance, and optimize energy usage, ensuring the long-term sustainability of the facility (Omrany et al. 2023).

2.7.12 Blockchain

Blockchain technology, a type of Distributed Ledger Technology (DLT) where encrypted data is stored across a network in interconnected blocks, has evolved significantly in terms of interoperability, scalability, and security. In the construction industry, blockchain holds promise for diverse applications, including supply chain management, project bidding, contract management, and the management of certifications and permits (Celik et al., 2024). It serves as a secure platform for storing and managing digital property records, ensuring transparency and immutability in ownership and transaction history (Turk and Klinc, 2017). Each block in the blockchain chronicles crucial project details, such as design revisions, material purchases, and construction progress, linked with cryptographic hashes to uphold data integrity and transparency.

The decentralized nature of blockchain mitigates risks of fraud and errors, while its transparent ledger enables smart contracts for automated payments and compliance, enhancing overall project accountability and efficiency (Celik et al., 2024). Blockchain provides a granular view of payments, as transactions recorded on the blockchain are visible to all stakeholders of the construction project, allowing for better financial performance analysis and increased productivity. This capability is particularly useful for tracking subcontractor performance and optimizing integrated project delivery methods

The use of blockchain technology in managing documents within the construction industry is a prominent focus of current research. Álvarez et al. (2021) suggested employing a network of interconnected dynamic objects managed by a DLT database to monitor their access, while Das et al. (2022) proposed an integrated document management framework for construction applications based on blockchain technology. This framework ensures the integrity of data through irreversible approval workflows, the permanent recording of document changes, and maintaining the integrity of document version history using blockchain's data structure.

In the bidding process, blockchain records and evaluates bids in a tamper-proof system, while smart contracts automate supplier selection and contract formation based on predefined criteria. For contract execution and change management, blockchain ensures that all amendments are transparently documented, and smart contracts automatically adjust terms and conditions.

Additionally, blockchain facilitates progress and interim payment management by verifying completed work and releasing payments upon milestone completion, and it provides end-to-end traceability in supply chain management by recording each transaction and movement of materials (Kim and Kim, 2024).

Table 2.2: Summary of Types of Smart Technologies and Their Benefits

Smart technologies	**Benefits**	**Citation**
Building information modeling (BIM)	Improved project coordination and collaboration; enhanced cost estimation and management	(Olawumi and Chan, 2018; Sholeh et al., 2020; Kovacs and Micsik, 2021; Adel et al., 2022; Mesároš et al., 2022; Hamid and Abdelhaleem, 2023)
Drones	Increased efficiency and speed; enhanced project monitoring and data collection; high-quality results	(Floreano and Wood, 2015; Holton et al., 2015; Elghaish et al., 2021; Choi et al., 2023, Keyvanfar and Shafaghat, 2022)
Internet of things	Enhanced monitoring and control in project quality; real time data access	(Zhong et al., 2017; Mahmud et al., 2018; Tahir et al., 2018; Reja and Varghese, 2019; Tang et al., 2019; Pasi et al., 2020; Ibrahim et al., 2021)
Artificial intelligence (AI)	Enhanced decision-making, accurate cost and schedule predictions, increased efficiency.	(Putera et al., 2021; Pan and Zhang, 2021; Regona et al., 2022; Patil, 2019)
Augmented reality (AR) and virtual reality (VR)	Enhanced stakeholder communication, real time cost estimation, increased construction accuracy.	(Davila et al., 2020; Noghabaei et al., 2020; Balali et al., 2018)
Robotics	Accelerating progress by replacing manual labour	(Gharbia et al., 2020; Pan et al., 2020; Liang et al., 2021)
Prefabrication and modular construction	Reduced construction time; greater sustainability	(Lu et al., 2021; Wu et al. 2021; Rocha et al., 2022)
3D printing	Increased design flexibility and precision; material efficiency; time savings and rapid production	(Romero and Rodrigues, 2016; Schutter et al., 2018; Besklubova et al., 2021; Olsson et al., 2021)
Smart materials	Enhanced durability of materials; time management efficiency; higher quality structure of buildings.	(Khaled et al., 2018; Nilimaa, 2023; Rane et al., 2024)
Geographic information system (GIS)	Quality enhancement; improved project scheduling; cost optimization.	(Kumar and Reshma, 2017; Han et al., 2022; Akindele et al., 2023; Cepa et al., 2023; Al-Saggaf and Jrade, 2015)

Table 2.2: Summary of Type of Smart Technologies and Their Benefits

Smart technologies	Benefits	Citation
Digital twin	Improved timeline management, minimize delays, facilitate effective asset management.	(Almatared et al., 2022; Omrany et al., 2023; Park et al., 2024)
Blockchain	Enhanced transparency and accountability, streamlined contract management with smart contracts, improved supply chain management	(Hamadneh et al., 2021; Álvarez et al., 2021; Das et al., 2022; Celik et al., 2024; Kim and Kim, 2024)

2.8 Challenges in Implementing Smart Technologies in Construction Project Management

2.8.1 Financial Challenges

2.8.1.1 Initial Investment and Capital Cost

The most prevalent and widely known challenges is the potential for costs to exceed budget expectations due to the high expense of smart technologies. This statement can be proved by Hatem et al. (2018), initial investment to implement smart technologies such as BIM is considerable, as it involves significant expenses for purchasing the necessary software and hardware, along with costs for training and specialist salaries. Most of the businesses have experience with two-dimensional (2D) computer-aided take-off activities such as bill of quantities and cost planning. However, they have limited experience with automated quantity extraction from 3D models as it is costly to integrate BIM features and required times to adapt to them.

Besides, Hwang et al. (2022) had highlighted that the costs associated with RFID systems are the most significant challenges to the adoption of RFID technology in the construction industry. Hamadneh et al. (2021) also mentioned that senior management in companies are often reluctant to adopt new technology, especially when the advantages are not clearly proven and are weighed against the substantial costs involved. They argue that unless the technology's value is convincingly demonstrated, the high expenses associated with its adoption can deter top executives from moving forward with its implementation. The COVID-19 pandemic could significantly boost the adoption of smart, health and safety technologies, whereas internal factors such as cost, might pose major obstacles to their implementation in recent years (Yang et al., 2021), which aggravated by the economic downturn.

Refering to the studies above, the most significant challenges facing the implementation of smart technologies in construction management is their high cost. The high cost of these advanced technologies always avoids widespread implementation.

2.8.1.2 Uncertainty In Estimating Financial Benefits Of Smart Technologies

Smart technologies shift the emphasis from manual labor to technology-assisted work processes. This can create new obstacles and uncertainty about the outcomes during the adoption phase, particularly regarding outcomes and return investment. Senior managers noted that the vast scale of the construction goods industry makes it challenging to estimate profitability. The management's dedication and desire to make investments in advancing and growing RFID technology are impacted by this challenge. Besides, participants also mentioned that a lot of the items in construction projects such as heavy machinery are expected not to have very profitable and have relatively low margin, which can deter management from using RFID in construction processes (Hamadneh et al., 2021).

Cost, schedule, project quality, and other pertinent considerations should all be included in the project's actual economic benefits. BIM-based smart building projects often overlook certain cost factors (Yang et al., 2021). For instance, Ahn et al. (2023) only accounted for direct costs such as materials, labor, and equipment, while neglecting indirect costs like management, insurance, and contingency expenses in their project cost estimates. Therefore, due to the inaccurate assessment of the project’s financial, this error could result in an exaggerated perception of profitability and a subsequent loss of confidence in the application of smart technologies in construction project management.

So that smart technologies can be effectively and efficiently integrated and show positive return of investment, costs must be analyzed in detail (not only direct costs, but also indirect ones, so that proper financial assessments are made by construction managers. This transparency can avoid illusions of profits and incentivize investment in technology that drives long-term value creation for the company (Hewavitharana et al., 2021).

2.8.1.3 High Maintenance Cost

Among the major challenges of implementing smart technologies in construction project management is the high maintenance cost. Most advanced systems, like sensors, automation tools, and data management software, used for smart buildings require specialized knowledge and continuous upgrade, hence attracting substantial expenses in the long run. According to several studies, the cost of maintaining these complex systems, the routine updating of software and hardware, specially trained personnel, and energy consumption controls, may at times outweigh the efficiency benefits brought about by smart technologies (Viana et al., 2022).

Besides, proactive and predictive maintenance for smart equipment also includes systems connected via the Internet of Things, which is another cost burden. These systems require regular diagnostics and repairs, increasing the overall cost despite reducing operational downtime (Affonso et al., 2024).

The impact of high maintenance costs extends beyond budget constraints. They can squeeze profit margins, raise the possibility of quality issues, and divert funds from innovation, thereby affecting business operations and productivity. A good example is in smart technologies, such as drones, where the annual maintenance cost has been estimated to be up to 18% of the initial investment annually (Skibniewski, 2024). On the other hand, these costs can be indicating quality problems that will further depreciate trust in this technology and the perceive reliability and attractiveness in the future.

2.8.2 Organisation Challenges

2.8.2.1 Skill Shortages And Training Gaps

The lack of skilled employees proficient in using digital technologies is a significant barrier in the construction industry, with challenges in automating Quantity Surveying (QS) tasks due to insufficient 3D BIM data. Additionally, there is a notable deficiency of employees who are proficient in utilizing BIM features (Skibniewski, 2024). Many construction workers lack education and training only have a limited knowledge and skill of BIM technology.

Inadequate training and expertise with digital tools exacerbate this problem and makes it more difficult to employ these technologies to improve construction project management and building procedures. According to studies, for example, consumers' lack of familiarity and unfamiliar with digital systems hindered the use of visualization tools in Sweden while developing healthier and safer workplaces (Daniel et al., 2024).

Shafiq and Afzal (2020) further observed that limited knowledge and inadequate training in technologies like virtual design construction (VDC) impede their application for enhancing job-site safety, particularly in the UAE. Similarly, Wolf et al. (2022) highlighted that participant in augmented virtuality (AV) environments often struggled with hazard recognition due to their lack of experience, underscoring the need for comprehensive training. They emphasized that to assist employees recognize threats more effectively, they must provide them with thorough, step-by-step and detailed training. Besides, as a small nation with limited resources, Singapore's construction sector heavily depends on foreign manual laborers, who generally possess lower levels of technological skills (Hwang et al., 2022). In short, particular concern that impedes the efficient use of digital tools is the shortage of workers with the necessary skills to operate these smart technologies.

Organizations must address these human-centric barriers by enhancing the perceived usefulness of these technologies and providing adequate training to facilitate smoother transitions. Improving user acceptance through targeted training and demonstrating clear benefits can help mitigate resistance and improve project outcomes.

2.8.2.2 Organisation Data Privacy And IT Security

As smart technologies continue to pervade in construction project management, cybersecurity becomes a major issue. In the construction process, sensitive data such as designs of projects, financial records, and information of clients, are stored in the cloud platforms and therefore are prone to cyber-attacks (Tanga et al., 2022). The integration of smart technologies in construction project management faces significant challenges related to organizational data. Exchanges of information and data through smart technologies may be subject to dangers and threats, raising several IT security issues about organisation data privacy and protection (Alaloul et al., 2020). Many construction firms struggle with the lack of robust data management systems capable of handling such complex data due to limited digital infrastructure. Moreover, concerns around organizational data privacy such as project involved, and security complicate the ability to share data across platforms without risking sensitive information (Merschbrock and Munkvold, 2015).

Additionally, the poor integration between organizational data from BIM and asset management systems often results in underutilization of data, reducing the value from smart technologies investments. This issue is exacerbated by the challenge of establishing unified data systems capable of leveraging analytics to improve project performance, making the adoption of smart technologies costly and difficult (Soman and Whyte, 2020).

2.8.2.3 Organisation Size

Smaller businesses are less likely to implement new technologies unless there is a pronouncedly favourable ROI or cost-benefit analysis. For example, the $15,000 Daqri Helmet in 2018 is a substantial outlay for small and medium-sized enterprises (Silverio and Eng, 2019). Competition from larger companies that launch new goods and services can pose a significant threat to small businesses. Many smaller businesses, according to the respondents, find it difficult to compete with these rivals, and this pressure saps their internal drive to innovate (Suprun and Stewart, 2015).

2.8.2.4 Organisation Structural and Adoption

Soto et al. (2022) examined the impact of the Fourth Industrial Revolution (4IR) on workforce and organizational structures in the built environment sector through a case study. They found that traditional roles and responsibilities of project participants are anticipated to evolve, particularly during the planning and execution stages, changes in organizational structures can make it difficult to apply smart technologies. As traditional roles and responsibilities shift due to new technologies, adapting existing structures and workflows can be challenging. This can create barriers to effectively implementing and integrating smart technologies. For example, an organisation may be reluctant to embrace smart technologies if its organizational structure is based on conventional practices and methods. This resistance results from the possibility that the existing structure does not correspond with the new technological processes, which makes it difficult to successfully integrate and apply innovative solutions. Compared to their younger colleagues, older professionals tend to view things from a more traditional standpoint. Additionally, because these senior professionals are frequently in top management positions, they are usually the ones who decide which technologies to implement (Lee et al., 2021). Besides, if a company is managed by a single individual, all decisions will be solely at the discretion of that person. Conversely, if the company has multiple shareholders, decisions will necessitate discussions and consensus among them.

2.8.3 Technological Challenges

2.8.3.1 Impact of Poor Network Connectivity

Poor network connectivity can hinder the effective application of smart technologies. Technologies such as IoT devices, smart sensors, and real-time data analytics rely on robust network connections to function properly. Without a reliable network, the performance and quality of these smart technologies can be significantly compromised.

Zhong et al. (2015) explored IoT applications in prefabricated housing in Hong Kong and discovered that issues with network connectivity and hardware limitations are significant challenges to IoT adoption in construction. The immense volume, variety, and speed of data produced by CPS and IoT systems highlight the need for big data (BD) technologies. For example, there may be locations without wired or Wi-Fi/3G/4G connectivity during logistics or on-site tasks, such as when driving across a sea bridge or through a long tunnel.

Hwang et al. (2022) examined the issues impacting data quality necessary for effective data analysis and underscored the critical role of network connectivity and consistency in maintaining high data quality.

2.8.3.2 Environmental Condition

Research in the past on smart technologies associated with 4IR identified the following benefits: process optimization considering the conditions of the physical environment; mass customization by means of personalized information; automatization of hazardous and routine tasks; and value chain integration to reduce waste and improve sustainability performance (Stock et al. 2018).

However, though important for the economy of Singapore, its construction industry presents an enormous environmental impact during the construction process. It produces massive solid wastes that are accompanied by air and noise pollution and vast energy use. The setting of Singapore with its strict regulations and dependence on immigrant manual labourers, usually at a low level of technology expertise, further enhances these environmental impacts (Hwang et al., 2022; Ofori et al., 2022).

Something observable is that existing studies have not conclusively argued out how these specific environmental conditions impact the application of smart technologies in Singapore's construction industry. Environmental factors referring to logistics, transportation, assembly, manufacturing, asset tracking, location monitoring, and general environmental conditions related to RFID in supply chains have been studied (Hamadneh et al., 2021). In this respect, coping with these environment-related challenges becomes critical to the successful application of smart technologies in the management of construction projects.

2.8.3.3 Outdated and Ineffective Regulatory Frameworks for Smart Technologies

Frameworks of regulations and policies are essential for the effective application of smart technologies in construction project management. Hwang et al. (2022) noted that despite the government's substantial investments in research and development (R&D) to advance technology, the policies and incentive programs are still unclear. Ineffective or outdated regulatory and policy frameworks can significantly impede technology integration by creating unclear guidelines, inadequate standards, and insufficient incentives (Ghansah et al., 2019). For instance, vague rules may not clearly outline the criteria specific to smart technologies or may not offer obvious routes for compliance, which could cause industry stakeholders to become uneasy and reluctant. In addition to the technical complexities of certain technologies, the construction sector faces significant challenges due to policies that are not aligned with technological advancements. the lack of collaboration between government agencies and the construction industry has resulted in policies that hinder the implementation of technological advancements in construction (Chen et al., 2022).

A study carried out by M. Reza et al. (2015) in Iran had proven that it will not be possible for smart technologies such as BIM to be widely used in Iran without the financial and regulatory backing of decision-makers. With a mean score of 4.78 and a standard deviation of 1.43, the study shows how this factor significantly restricts the implementation of smart technologies in Iran.

Singapore's regulatory landscape has been known to be transparent, predictable, impartial, and efficient, resulting in heavy emphasis placed on regulatory compliance by organizations to prevent unwarranted costs and delays (Hwang et al., 2022). All three interviewees also highlighted the possible consequences of noncompliance in Singapore's strong regulatory environment, which may lead to significant project delays and cost overruns.

2.8.3.4 Difficulties in Attaining Effective Interoperability

Interoperability is essential for data to flow easily across various Building Information Modelling (BIM) platforms, such as Revit and Tekla, as well as between corporate systems and smart components (Yang et al., 2021) , speeding up the return on investment and reducing project expenses. However, there are also high costs associated with attaining interoperability, such as the time, money and effort needed for development lead to inadequate of software interoperability (Costin and Eastman, 2019).

The primary cause of inadequate interoperability among BIM software is the lack of uniformity in relevant standards, including data models and exchange formats. Industry Foundation Classes, or IFC, is an open data file format that facilitates information sharing, storing, and exchange across various software applications. However, even when using IFC, information flow still can be impeded if disparate BIM software fails to export IFC reliably and consistently (Yang et al., 2021). It highlights the difficulty with centralized building information management.

According to Mazars and Francis (2020), because of the lack of interoperability among current software BIM 3D software and the 4D stimulation, when spatiotemporal conflicts are identified, each software program must undergo the appropriate modification again and again to measure its impact. Interoperability problems can impede communication, whether the data is transmitted via internal servers or cloud platforms. In discussing the difficulty of accomplishing smooth global integration and interoperability in Building Information Modelling (BIM), emphasizes that technical constraints and data integration across multiple software platforms lead to complexity. These problems might make it difficult to share data, especially in cloud-based systems, which emphasizes the necessity to fix technological problems in order to increase the use and efficiency of BIM.

A few studies have demonstrated that a significant obstacle to integrating smart technologies into construction project management is due to the absence of interoperability in Building Information Modelling (BIM). It is imperative to tackle these concerns to improve productivity.

2.8.3.5 Existing System Interrupt and Clash with New Smart Technologies

Constructing with modern technologies brings with it several significant obstacles. Standards and procedures must be improved and redefined to meet the specific needs of the construction environment, which can be complicated and disruptive(Alaloul et al., 2020). Additionally, equipment designed for other industries or project may not durable enough for the unique characteristic demanding conditions of current construction sites, requiring adaptation or replacement to ensure functionality.

The introduction of advanced technologies also requires enhanced skills and extensive training for workers, adding to the complexity and cost of implementation. Furthermore, new smart technologies may clash with or disrupt existing systems and workflows, making the integration challenging and potentially disruptive. This issue is highlighted by Qi et al. (2019) that the requirements for frequent hardware and software upgrades, including security patches, can significantly clash with operational constraints and existing budget allocations. Additionally, the lack of standardization data format between the existing technologies such as Excel and new smart technologies such as BIM, VR and AR can complicate the construction process and lead to potential conflict and misunderstanding.

In summary, integrating with new smart technologies into the construction industry can be challenging since they often clash with existing procedures and processes.

2.8.4 Societal Challenges

2.8.4.1 Personal Privacy and Cybersecurity Concerns

Nnaji et al. (2023) created the "Perceived Privacy Risk" concept after realizing that mistrust of the way personal data is handled is a major barrier to wearable technology. They discovered that this mistrust is exacerbated by worries about the privacy of company projects and the possibility that smart technologies will expose sensitive data. Furthermore, by tracking activities and gathering private data, linked site management tools and cameras may cause privacy issues. Similarly, cybersecurity is also the main struggle for construction organizations to adopt IoT in their projects (Lee et al., 2021). Workers are also disinterested towards application of smart technologies due to concerns about data privacy. (Häikiö et al., 2020) suggest that construction workers are hesitant to use digital technologies because of fears about identity exposure and privacy issues. Concerns about adhering to legal requirements grow as ethics and privacy become more important, particularly when smart technologies are collecting personally identifiable information (Hwang et al., 2022). This reluctance can hinder the adoption of smart technologies that improve safety, productivity, and overall project quality.

2.8.4.2 Reluctance to Adopt and Change

Implementing smart technologies in construction project management faces significant challenges, particularly due to human factors such as resistance to change and stress induced by new systems. Research indicates that employees' attitudes, such as fear of the unknown and discomfort with advanced technologies, can hinder digital transformation. This resistance often arises from a lack of perceived benefits and concerns about complexity, which can lead to stress and decreased willingness to adopt new processes. The unfamiliarity with smart construction tools, such as IoT and AI, can exacerbate feelings of uncertainty and reduce confidence among workers, further impeding their effective implementation (Liu et al., 2024).

Despite these efforts, the construction industry remains reluctant to integrate innovative technologies into standard practices. This reluctance is partly due to the resistance from stakeholders who find new technologies incompatible with current procedures (Qi et al., 2019). This resistance stems from an antiquated mindset that stifles creativity and leads to stagnation in project quality and business performance. As a result, the industry struggles with lower efficiency, cost-effectiveness, and competitiveness, causing companies to fall behind their rivals in a rapidly evolving sector (Ogunrinde et al., 2020). Addressing these issues is crucial for successfully adopting and benefiting from smart technologies in construction.

2.8.4.3 Workforce Dynamics

Soto et al. (2022) found that traditional roles and responsibilities of project participants in the built environment sector are expected to evolve due to the Fourth Industrial Revolution (4IR). Older professionals, who often hold senior management positions, may have a more traditional perspective on technology adoption compared to their younger colleagues. This generational difference can influence decision-making processes regarding which technologies to implement (Lee et al., 2021). As these roles shift and the workforce adapts to new technologies, challenges arise in aligning with innovative solutions.

2.8.5 Implementation Challenges

2.8.5.1 Complexity of Smart Technologies

The complexity of implementing smart technologies in construction project management presents significant challenges. The integration of advanced technologies such as Building Information Modeling (BIM), the Internet of Things (IoT), and artificial intelligence (AI) requires a high level of coordination and standardization, which is difficult to achieve due to the fragmented nature of the construction industry. This complexity is compounded by the diverse range of stakeholders involved, each with their own systems and processes, leading to difficulties in data integration and communication (Sacks et al., 2020). Moreover, the rapid pace of technological change necessitates continuous learning and adaptation by industry professionals, which can overwhelm project teams and create resistance to technology adoption (Perera et al., 2022). Consequently, these complexities can lead to increased costs, project delays, and reduced effectiveness in implementing smart technologies in construction projects.

2.8.5.2 Sustainablity Integration Gap

Besides, the sustainability issues hampering the adoption of smart technologies in the construction industry are high and go beyond environmental factors. Key among them ought to be the lack of integration between new technologies and innovations such as Building Information Modeling, Internet of Things, and Industry 4.0 with sustainable construction (Stock et al. 2018). Although there is rapidly growing interest in the use of smart technologies for process optimization and efficiency, little is really known about their contribution to other dimensions of sustainability, notably including economic and social benefits (Olawumi and Chan, 2018).

Sustainable construction should balance environmental, economic, and social factors. However, most of the technologies are merely oriented toward technological advancement. This lack of comprehensiveness in addressing sustainability, on the economic viability of such technologies, handicaps their adoption. For example, while technologies like BIM can be harnessed to enhance resource efficiency, they are normally deficient in dealing with complexities of sustainable project management through the provision of cost-benefit analyses that consider the long-term impacts on sustainability. This deficiency riles a sense of hesitation among stakeholders who are driven by ROI and economic viability in smart technologies integration within sustainable frameworks (Alireza et al., 2017).

In summary, although smart technologies have major benefits, the lack of fit between those and the full sustainability agenda in general presents a challenge to the adoption of smart technologies in construction project management.

2.8.5.3 Gap between Theoretical Research and Practical Implementation

The lack of practical guidelines and standardized frameworks for implementing these technologies further widens the gap between research and practice. This misalignment leads to slow adoption rates and underutilization of smart technologies, which hinders the industry's overall progress toward digital transformation (Chen et al., 2022).

The status of smart technologies demonstrate that industry adoption is still in its early stages, despite extensive research from academic institutions exploring its potential. Developers must follow industry standards and concentrate on building reliable, useful systems for everyday use if they want to see IoT advance in the market. This strategy will assist in bringing IoT from academic research to a broad range of real-world applications in smart buildings (Jia et al., 2019).

2.8.5.4 Fragmented Integration

The adoption of IoT in construction has been limited in its impact due to the decentralized and project-oriented nature of construction processes. In the construction industry, there has been inadequate management of technology succession planning. Woodhead observed that construction firms employing IoT for decision-making tend to adopt it in a piecemeal fashion, addressing specific issues rather than establishing a cohesive ecosystem that supports comprehensive business decision-making (Woodhead et al., 2018). This fragmented approach to IoT adoption results in a lack of integrated solutions, which hampers the overall effectiveness and efficiency of technology deployment.

The construction industry's intrinsic fragmentation poses notable obstacles to the integration of smart technologies in project management. This fragmentation, which creates major barriers to the successful integration of smart technologies, is characterized by the fragmented operations among diverse stakeholders, including suppliers, contractors, and designers. Project stakeholders may not communicate and coordinate well, which can lead to errors, inefficiencies, and increased costs. The fragmented structure of construction projects can pose challenges to the efficient implementation of smart technologies, such as Internet of Things (IoT) devices and Building Information Modelling (BIM). Real-time communication and seamless data sharing are necessary for these technologies. To fully achieve the benefits of smart technologies in the construction sector and get past these challenges, enhanced stakeholder collaboration and integrated project delivery approaches are essential (Riazi et al., 2020).

2.8.6 Data Management Challenges

2.8.6.1 Data Management

Data management presents a significant challenge in the integration of smart technologies within construction project management. The construction industry often suffers from fragmented data systems, where information is stored across disparate platforms, creating difficulties in achieving interoperability. This fragmentation hampers the effective use of smart technologies such as Building Information Modeling (BIM), drones and robotic system, which rely on the continuous and accurate flow of data across all project stages. The lack of standardized data protocols and challenges in integrating legacy systems with new technology further exacerbate these issues. This leads to inefficiencies, increased errors, and ultimately undermines the potential benefits that smart technologies could bring to construction project management (Ofori et al., 2022).

Additionally, existing technology platforms lack the capability to efficiently handle large volumes of data from various dispersed locations, which is essential for the construction industry (Reja and Varghese, 2019). The difficulty in managing and processing this data effectively undermines the potential benefits of IoT technology. Besides, the inability to handle vast and varied data stream limits the industry’s capacity to leverage insights and make informed decisions, further restricting the impact of IoT on construction processes. collaboration among prefabrication manufacturers, transporters, and on-site assemblers depends heavily on real-time information such as the status of precast components, delivery progress, and component locations.

However, delays in manually inputting this information into the BIM system create gaps among parties, reducing visibility and traceability of construction progress (Zhong et al., 2017).

Table 2.3: Summary of Challenges in Implementing Smart Technologies

Ref	Challenges	Sources
	Financial challenges	
1.	Initial investment and capital cost	(Skibniewski, 2024; Hatem et al., 2018; Hamadneh et al., 2021; Yang et al., 2021)
2.	Uncertainty in estimating financial benefits of smart technologies	(Ahn et al., 2023 ; Hamadneh et al., 2021; Hewavitharana et al., 2021; Yang et al., 2021)
3.	High maintenance cost	(Skibniewski, 2024; Affonso et al., 2024; Viana et al., 2022)
	Organisation challenges	
4.	Organisation size	(Suprun and Stewart, 2015; Silverio and Eng, 2019)
5.	Organisation data privacy and IT security	(Merschbrock and Munkvold, 2015; Alaloul et al., 2020; Soman and Whyte, 2020; Tanga et al., 2022)
6.	Skill shortages and training gaps	(Skibniewski, 2024; Shafiq and Afzal, 2020; Hwang et al., 2022; Wolf et al., 2022; Daniel et al., 2024)
7.	Organizational and structural adoption	(Ghansah et al., 2020; Lee et al., 2021; Liu et al., 2023)
	Technological challenges	
8.	Impact of poor network connectivity	(Zhong et al., 2015; Hwang et al., 2022)
9.	Environmental condition	(Stock et al., 2018; Hamadneh et al., 2021; Hwang et al., 2022; Ofori et al., 2022)
10.	Outdated and ineffective regulatory frameworks for smart technologies	(M. Reza et al., 2015; Ghansah et al., 2020; Chen et al., 2022; Hwang et al., 2022)
11.	Difficulties in attaining effective interoperability	(Costin and Eastman, 2019; Mazars and Francis, 2020; Yang et al., 2021)

Table 2.3: Summary of Challenges of Implementing Smart Technologies

Ref	Challenges	Sources
12.	Existing system interrupt and clash with new smart technologies	(Qi et al., 2019; Alaloul et al., 2020)
	Societal challenges	
13.	Personal privacy and cybersecurity concerns	(Häikiö et al., 2020; Lee et al., 2021; Hwang et al., 2022; Nnaji et al., 2023)
14.	Reluctance to adoption and changes	(Ogunrinde et al., 2020; Liu et al., 2024)
15.	Workforce dynamics	(Lee et al., 2021; Soto et al., 2022)
	Implementation challenges	
16.	Complexity of smart technologies	(Sacks et al., 2020; Perera et al., 2022)
17.	Sustainability integration gap	(Alireza et al., 2017; Olawumi and Chan, 2018; Stock et al., 2018)
18.	Gap between theoretical research and practical implementation	(Jia et al., 2019; Chen et al., 2022)
19.	Fragmented integration	(Woodhead et al., 2018; Riazi et al., 2020))
	Data management challenges	
20.	Data management	(Zhong et al., 2017; Reja and Varghese, 2019; Ofori et al., 2022)

2.9 Strategies In Adopting Smart Technologies In Construction Project Management

2.9.1 Government Support And Financial Incentives

Government should provide monetary incentives or other forms of assistance to promote the adoption of novel practices or technologies in construction project management. By providing financial incentives, such as subsidies and tax breaks, to reduce the costs associated with implementing new technologies, national governments can promote the diffusion of innovation in the construction industry (Suprun and Stewart, 2015). Oesterreich and Teuteberg (2016) emphasized that financial incentives are crucial for overcoming barriers to the adoption of Fourth Industrial Revolution (4IR) technologies. In addition to encouraging businesses to test and implement cutting-edge technologies, financial incentives also drive R&D efforts, resulting in additional technological breakthroughs and competitive advantages (Hwang et al., 2022).

Governments can be instrumental in the adoption of smart technologies by offering incentives with funding, tax benefits, and other regulatory arrangements that shall encourage innovation. Public policy would encourage sustainable, smart technologies applied in construction through relevant policies (Ozorhon and Oral, 2017).

2.9.2 Leverage Strategic Incentives

The successful implementation of smart technologies in construction project management is strongly influenced strategic incentives, which create a compelling framework for adoption. Strategically, adopting technologies like Building Information Modeling (BIM) and the Internet of Things (IoT) can significantly enhance a firm's competitive edge by improving project quality, reducing errors, and enhancing client satisfaction. These improvements are crucial in a market where differentiation is key, and firms that leverage these technologies are better positioned to win contracts and retain (Hu et al., 2025). Additionally, for construction firms that are unsure about integrating smart devices, this framework provides the necessary assurance to confidently proceed with long term adoption. It helps organizations understand the factors that drive their operations and competitiveness, including the role of technological advancements in increasing efficiency and reducing costs, which are critical benefits for future company growth (Silverio and Eng, 2019)

2.9.3 Engagement Of Collaborative Stakeholders

For smart technologies to be applied successfully, collaboration across all stakeholders, owners, contractors, architects, and technology vendors, is essential. Stakeholder engagement should be facilitated using platforms like BIM and cloud-based project management systems, which provide real-time updates and transparency (Collinge, 2020). These platforms allow teams to collaborate on designs, share data, and make decisions in real time.

Moreover, the study had shown that early stakeholder involvement mitigates the high incidence of errors and rework and streamlines the process of decision-making. A proper and effective communication method, as shown in a study by Afrizal et al., (2024), improves resource allocation and time management by both project teams and stakeholders on complex construction projects.

2.9.4 Create A Clear Strategy To Implement Smart Technologies

One key strategy to improve the application of smart technologies in construction project management is to provide a comprehensive strategic plan tailored to the unique requirements of smart technologies. This involves assessing existing processes and identifying areas where smart technologies such as the Internet of Things (IoT), Building Information Modeling (BIM), and Construction 4.0 can enhance efficiency and innovation. Developing a clear vision that aligns with the company’s goals is essential, as it helps integrate new technologies and streamline workflows across the project lifecycle. A robust strategic plan should also address barriers such as high initial costs, human resource needs, and the need for Research and Development (R&D) investment to ensure successful implementation (Ghansah et al., 2020).

For construction companies ready to incorporate smart technologies, a practical framework can facilitate this transition. This framework comprises two main components: the implementation framework, which provides a structured approach to integrating smart devices into existing practices, and the persuasion framework, which helps manage stakeholder acceptance and overcome resistance to change (Silverio and Eng, 2019). These elements provide an assurance that the strategic plan is well-implemented and that operational practices are aligned to long-term goals of company while adopting smart technologies.

2.9.5 Provide Training And Education For Employee

Improving employee education and training increases technological awareness and makes smart device deployment easier (Silverio and Eng, 2019). Providing training is crucial to ensure that the workforce is equipped to use the technologies effectively in their tasks and becomes more open to adopting smart technologies (Hwang et al., 2022). For example, (Pan and Pan, 2020) draws attention to the role that academic institutions and professional associations play in professional training and research and development (R&D) pertaining to construction robotics. It implies that these establishments are essential for promoting the information and abilities required for using smart technologies, especially in the building industry. Sepasgozar and Davis (2018) then highlighted the importance of top management to facilitate training for adoption of smart technologies in construction project management. The notion that organizational procedures are essential for enabling and accelerating technological advancement is reinforced by the fact that investing in staff training aids companies in more effectively integrating and utilising new innovations (Suprun and Stewart, 2015).

2.9.6 Raising Decision-Maker Awareness On Current Technological Advances

It's critical to raise awareness of decision-makers about the benefits of smart devices if new smart technologies are being adopted in the construction industry. Demonstrating a case study in which smart technologies have been skillfully incorporated into a building project can effectively inspire decision-makers to consider and endorse novel technological endeavors (Silverio and Eng, 2019). Besides, acquiring knowledge about the most recent developments in IoT technology is essential for staying up to date on technological developments. To create a more favorable market environment, they can also raise awareness among industry stakeholders and stimulate demand for new techniques (Suprun and Stewart, 2015) through workshops, seminars, and industry conferences where the latest developments are presented, and practical applications discussed (Hu et al., 2025). An organization's capacity to obtain and apply pertinent information determines how well the organisation will be able to adopt and apply innovations from outside sources. The organization's awareness of technological advancements is also improved by managers who actively track and disseminate information about new materials, products, technologies, and market demands. This promotes the effective adoption of innovations within the organization.

2.9.7 Shift Company's Organisation Culture To Embrace Smart Technologies

Increasing leadership relies on enrolling the decision makers into embedding smart devices in the operational processes of the organisation (Asif et al., 2024). Creating a shift in organisational culture towards embracing smart technologies is vital to improving the adoption of these technologies in construction project management. This cultural change involves fostering a more open and collaborative environment where innovation is encouraged, and smart technologies is seen as a strategic tool for enhancing efficiency. According to (Nguyen and Watanabe, 2017), alignment of goals, contractor commitment, and focus on workers' roles are crucial cultural elements that lead to improved performance in construction projects. Similarly, Asif et al., (2024) highlight that a culture of mutual trust, open communication, and leadership support contributes to more effective project management practices, particularly when adopting new technologies.

2.9.8 Change Individual Attitudes Towards Smart Technologies

Individual attitudes toward adopting new technology can be unpredictable and should be assessed through re-education. In this research, "re-education" means altering staff perspectives to make them more open to embracing new technologies (Silverio and Eng, 2019). In the study carried by Suprun and Stewart (2015), the personnel participation factor scored highly, at 4.36. Even though the industry is criticized for having a lack of qualified workers and for having issues with its educational system, this strategy is still useful for fostering innovation. Employing experienced workers is advantageous, according to those surveyed; however, recent graduates are frequently more flexible, ready to adopt new ideas, and skilled in utilizing contemporary IT tools and techniques. Hence, by encouraging academic institutions to implement smart technologies within their construction management programs, it will be able to enable a new generation of professionals who are well-versed these tools, further driving industry adoption (Hwang et al., 2022).

2.9.9 Optimize Cost For Smart Technologies Adoption

The key to improve the application of smart technologies systems in construction projects is by adjusting their cost. By carefully balancing the costs, construction firms can justify the initial investment by highlighting the long-term operational savings and efficiency gains that smart technologies bring. For instance, smart technologies like Building Information Modelling, drones and IoT-based monitoring systems have already proved to reduce construction delays by properly managing resources involved in the construction process, thus reducing the overall project cost of construction (Jelodar and Shu, 2021). Additionally, leveraging low-cost digitization tools provides an affordable entry into smart technologies, allowing even smaller firms to adopt essential digital solutions without substantial financial strain (Ghansah et al., 2020). This strategy will foster incremental adoption of smart technologies at various project phases.

2.9.10 Boost Collaboration Between Industry And Academia

Boost communication and cooperation between business and academia. Academic researchers can learn about real-world problems and application requirements by forming partnerships, and professionals in the industry can take advantage of new developments in theory (Jia et al., 2019). They can also validate research findings and develop fresh approaches to problems that impede adoption and further development (Suprun and Stewart, 2015). Many academic studies and pilot projects have been conducted with the integration of smart technologies, such as BIM, GIS or IoT, to help industries in the adoption process.

2.9.11 Develop A Data Management Plan

As smart technologies continue to pervade in construction project management, cybersecurity becomes a major issue. In the construction process, sensitive data such as designs of projects, financial records, and information of clients, are stored in the cloud platforms and therefore are prone to cyber-attacks. Therefore, it is necessary to implement advanced encryption technologies, user authentication, and blockchain for enhanced data security (Tanga et al. 2022). Furthermore, by limiting exposure to the information required for each stakeholder, this strategy helps protect privacy by preventing data from being indiscriminately dispersed (Jia et al., 2019).

For example, Celik et al. (2024) found that data leakage led to expensive delays and in some cases even litigation. Hence, blockchain technology is going to help the construction project management process dimension a tamper-proof record of all transactions in such a way that transparency and traceability from data handling are achieved.

2.9.12 Integrate Smart Technologies With Existing System

It is essential to ensure seamless integration with existing processes for the successful adoption of smart technologies in construction project management. Developing customized solutions that work with existing workflows, and introducing these technologies in bits, will help not to disrupt operations (Hwang et al., 2022). For example, when BIM is combined with traditional tools for project management, it becomes easier to transition and gain faster acceptance from the workforce (Hu et al., 2025). The benefits will become evident once they can experience them firsthand.

Pilot projects and incremental implementation are effective strategies for adopting smart technologies in construction project management. By initially deploying these technologies on a smaller scale, construction firms can evaluate the benefits and challenges before committing to a full-scale rollout and adjustments can be made after feedback and insights from the pilot phase. Hence, it reduces risks from full-scale implementation and allows firms to identify any problems that may exist early on to fine-tune their strategies.

Table 2.4: Strategies to Implement Smart Technologies in Construction Project Management

Ref	Strategies	Sources
1.	Government support and financial incentives	(Suprun and Stewart, 2015; Ozorhon and Oral, 2017; Hwang et al., 2022)
2.	Leverage strategic incentives	(Hu et al., 2025 ; Silverio and Eng, 2019)
3.	Engagement of collaborative stakeholders	(Azlin et al., 2024; Collinge, 2020)
4.	Create a clear strategy to implement smart technologies	(Silverio and Eng, 2019; Ghansah et al., 2020)
5.	Provide training and education for employee	(Suprun and Stewart, 2015; Sepasgozar and Davis, 2018; Silverio and Eng, 2019; Pan and Pan, 2020; Hwang et al., 2022)
6.	Raising decision-maker awareness on current technological advances	(Hu et al., 2025 ; Suprun and Stewart, 2015; Silverio and Eng, 2019)
7.	Shift company's organisation culture to embrace smart technologies	(Asif et al., 2024 Zhang et al., 2023 ; Nguyen and Watanabe, 2017)
8.	Change individual attitudes towards smart technologies	(Suprun and Stewart, 2015; Silverio and Eng, 2019; Hwang et al., 2022)
9.	Optimize cost for smart technologies adoption	(Ghansah et al., 2020; Jelodar and Shu, 2021)
10.	Boost collaboration between industry and academia	(Zhong et al., 2015; Hwang et al., 2022)
11.	Develop a data management plan	(Jia et al., 2019; Tanga et al., 2022; Celik et al., 2024)
12.	Integrate smart technologies with existing system	((Hu et al., 2025 ; Hwang et al., 2022)

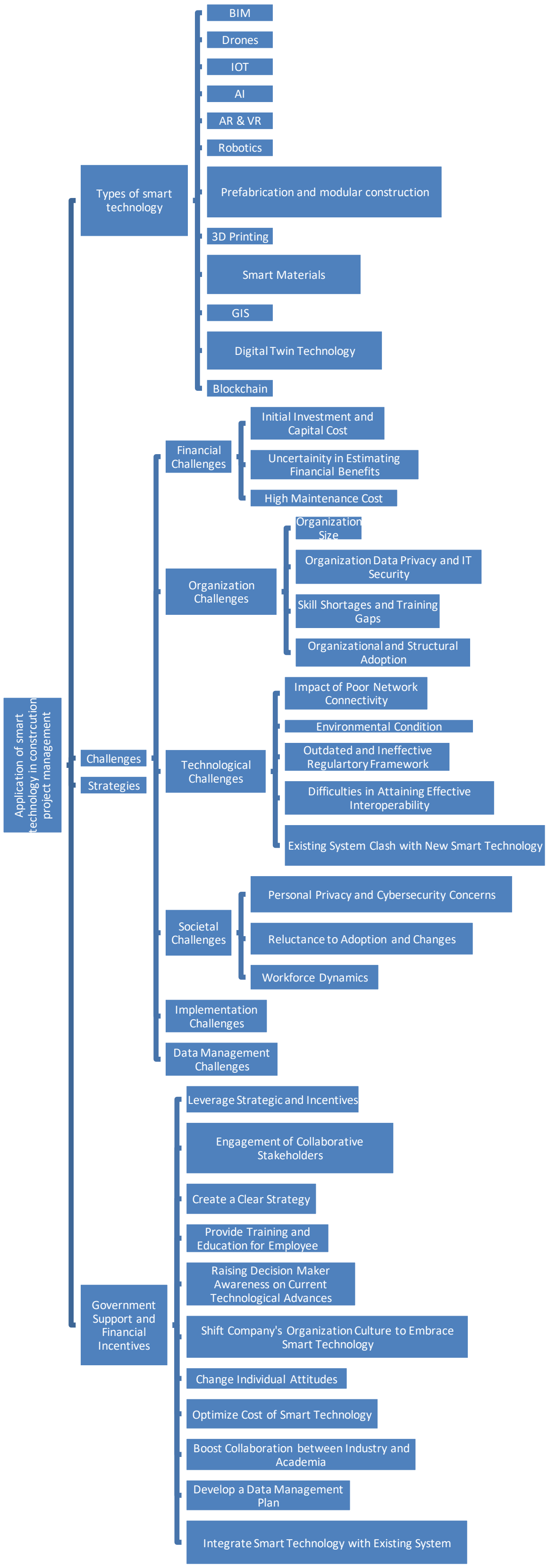

Figure 2.1:Framework of Types of Smart Technologies, Challenges and Strategies to Implement Smart Technologies

CHAPTER 3

RESEARCH METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter primarily discusses the systematic methods used to conduct this research. By applying scientific analysis and techniques to collected data, research can reveal previously unknown insights. As a result, this chapter describes the research methodology used, including the research framework, sampling design, data collection methods, and data analysis strategy.

3.2 Research Methodology

Research methodologies are aimed to understand and improve organisational rules and principles while the method is defined as a deliberate and determined way in which a researcher acts or behaves to achieve a specific goal (Dzwigol, 2022). Research methodology can be classified into three categories which are quantitative approach and qualitative approach. Qualitative approach seeks to gain a deeper understanding of a phenomenon while the quantitative approach uses survey methods to estimate patterns and trends across larger sample sizes. Each approach has its own advantages and disadvantages, making it better suited to address specific questions (Verma, 2019).

Qualitative research focuses on providing a thorough description of a phenomenon, often using methods such as interviews, open-ended questions, or focus groups. Typically, only a small number of participants are involved due to the resource-intensive and time-consuming nature of this research (Borgstede and Scholz, 2021). Interviews can be highly structured with specific open-ended questions or more conversational and flexible. Because of the extensive resources required and the relatively small sample size, findings from qualitative research cannot be generalized to the entire population (Verma, 2019).

The quantitative data collection method aims to analyze a phenomenon across a broad group of participants and allows for summing characteristics and relationships between groups. This involves conducting surveys with a great number of individuals plus applying statistical procedures to establish general patterns and connections.(Borgstede and Scholz, 2021). Surveys may also be done among various groups e.g. comparing mentors who have received training (the experimental group) versus those who have not (the control group); such comparison is significant in evaluating the effectiveness of training. Furthermore, surveys may be repeated at intervals so that researchers can investigate how some aspects like matching may affect specific outcomes including well-being or subsequent success in life (Verma, 2019).

3.2.1 Quantitative Approach

This study is characterized as a quantitative research attempt, as it investigates process revolves around the generation of numerical data through the application of mathematical techniques to assemble information. Using quantitative methods across a large group of individuals allows for generalization, making it a valuable tool for policymaking (Dzwigol, 2022). Quantitative survey methods offer the advantage of gathering data from a larger number of participants, allowing for comparisons across groups and enabling generalization to the broader population (Verma, 2019). The quantitative method adheres to deductive research methodology as it helps develop answers to research questions. Leavy (2017) characterizes the deductive approach as employing a predominantly quantitative methodology to explicate the causal connection between variables. This approach provides numerical or rating information, which is particularly useful for informing policy decisions or establishing guidelines. Additionally, it lends itself to statistical analysis, allowing for the identification of relationships between variables, further supporting evidence-based decisions.

3.3 Research Design

A research design involves organizing the conditions for data collection and analysis with the goal of applying the results from the sample to the broader population (Pandey and Pandey, 2015). A research design will dictate the kind of analysis needed to achieve the intended outcomes. It outlines the study's goals, the methods and techniques to be used to achieve those goals, and serves as a framework for data collection, measurement, and analysis. Essentially, it is the strategy and organisation of the investigation, designed to answer specific research questions (Khanday, 2023).

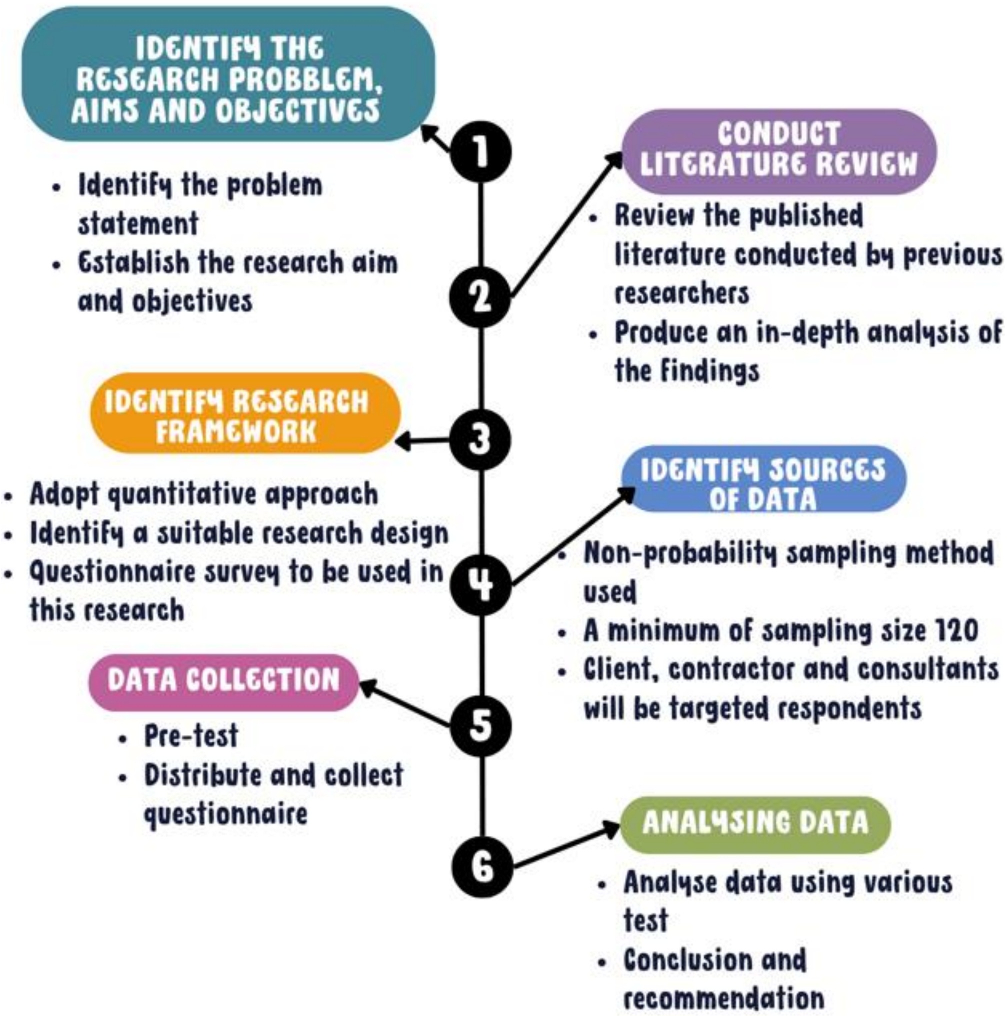

Figure 3.1: Flowchart of Research

3.4 Sampling Design

3.4.1 Sampling Method

Sampling methods are generally categorized into two main types: probability (or random) sampling and non-probability (or non-random) sampling. Before selecting a specific sampling method, it is essential to first determine the overall sampling strategy to be used (Taherdoost, 2016). Probability sampling is a method where every individual in a population has a known and equal chance of being selected for the study. For example, a researcher could first establish a sampling frame and then use a random number generator to select the sample. While this approach minimizes bias and enhances generalizability, it may be the most resource-intensive in terms of time and cost (Taherdoost, 2016). In contrast, non-probability sampling was selected for this research due to its practicality and suitability for targeting specific subgroups within the construction industry, as well as addressing challenges such as time constraints, limited access, and budget limitations.

Several non-probability sampling methods were applied in combination to effectively collect data. Firstly, quota sampling was employed to ensure that the sample reflected key characteristics of the target population. Quotas were set based on criteria such as the participants' position in the construction industry (project managers, site engineers, quantity surveyors and etc.), years of working experience (less than 5 years, 5 to10 years, more than 10 years), and the highest academic qualification (High school, diploma, bachelor’s degree and etc.). This allowed the researcher to gather a balanced representation of opinions and insights across different professional roles (Sharma, 2017). Secondly, snowball sampling was used to identify and recruit participants from hard-to-reach or specialized groups, such as senior professionals or those involved in confidential or niche projects. Initial respondents were asked to refer colleagues within their professional networks, which facilitated access to participants who were otherwise difficult to reach. Lastly, convenience sampling was utilized to collect data from individuals who were easily accessible and available to participate, such as those met during site visits, training sessions, or via online platforms. This method was particularly useful given the limited time and resources available for the study. Convenience sampling complemented the other methods by allowing a broader and quicker gathering of responses, which helped boost the overall sample size and diversity. (Palinkas et al., 2015). The use of these three methods in combination ensured that the research sample was both diverse and practically achievable within the study's constraints.

3.4.2 Sampling Size

Sampling size refers to the number of participants involved in a study and plays a vital role in ensuring the reliability and validity of research findings. According to Tilaki (2014), an adequate sample size minimizes sampling errors and enhances the generalizability of results. In this study, the Central Limit Theorem (CLT) is used as a guiding principle, suggesting that sample sizes ranging from 30 to 500 are generally sufficient to assume normality in the distribution of sample means (Islaqm & Islam, 2018). For studies involving multiple groups, Bujang et al. (2017) recommend a minimum of 30 participants per group to ensure sufficient statistical power.

In line with the CLT and the Rule of 5, which proposes at least five respondents per variable, a minimum sample size of 100 is considered necessary to conduct factor analysis on the 20 identified challenges in implementing smart technologies (Mohammad, 2018). This ensures the basic statistical requirements are met for extracting reliable factors. Furthermore, Hair et al. (2014) suggest that a sample size between 30 and 100 is acceptable for early-stage or exploratory quantitative research using tools such as SPSS.

Empirical studies in related fields reinforce this sampling range. For example, Mohamad et al. (2022) distributed 100 questionnaires to informal entrepreneurs in Malaysia and obtained 51 valid responses, which were sufficient to generate meaningful insights. Similarly, Misman et al. (2023) employed a sample of 100 respondents to validate their survey instrument before scaling up their study. Rahim et al. (2020) and Yap et al. (2019) also targeted sample sizes exceeding 100, producing reliable data despite moderate response rates.

To further ensure an adequate and justifiable sample size, the Yamane formula was applied. This simplified formula is widely used in survey research to determine an appropriate sample size for a finite population (Adam, 2020). The formula and calculation is expressed as:

$$n = \frac{N}{1 + N(e)^2}$$

where n is the sample size, N is the population size, and e is the acceptable margin of error. Using a total population size of 20,000 and aiming for a sample size of 110 respondents, the actual margin of error achieved is approximately 10%. This falls within the acceptable range for exploratory research.

$$\frac{20{,}000}{1 + 20{,}000(0.10)^2} = 100$$

The application of Yamane's formula has been validated in numerous studies, such as Suleiman et al. (2021), who applied it to determine an appropriate sample size for a finite group of construction professionals in Nigeria, reinforcing its reliability in construction-related research contexts.

Based on these theoretical guidelines, formula-based calculations, and empirical precedents, this study adopts a target sample size of 110 respondents, with an approximate distribution of 30 to 40 respondents each from the developer, consultant, and contractor groups. This stratified approach ensures data accuracy, statistical validity, and the potential for meaningful generalizations in the context of structured questionnaire research in the construction industry. For planning purposes, response rate estimates are also considered. Yap et al. (2019) reported a 33.4% response rate from 117 completed surveys out of 350 distributed e-surveys. Similarly, Yap and Skitmore (2018) distributed 1,100 questionnaires and obtained 338 valid responses (including pilot data), resulting in a response rate of 29.4%. Therefore, to achieve at least 110 valid responses, it is estimated that between 280 to 350 questionnaires need to be distributed, assuming a response rate between 31% and 39%.

3.4.3 Targeted Respondents

This research will target professionals working in the construction industry in Malaysia, including engineers, architects, quantity surveyors, and others within contractor's firm, consultant's firm, and client's company. These individuals possess firsthand experience and a deep understanding of the construction industry, making them well-equipped to provide insights on the problems being faced and potential solutions. By tapping into their expertise, this research aims to produce highly accurate and relevant findings that reflect the true needs and desires of those directly involved in construction.

3.5 Data Collection Method

Once the target population, sampling frame, sampling method, and sample size have been determined, the subsequent step is to collect the data (Taherdoost, 2016). In this research, data collection was conducted through a structured questionnaire distributed both physically during site visits, as well as electronically via email and professional platforms. This approach ensured efficient and broad reach within the available time and resources. Before full deployment, the questionnaire underwent a pilot test with a small group of industry professionals to ensure clarity, relevance, and reliability of the questions. Feedback from the pilot test was used to refine the instrument, enhancing the accuracy of the data collected. Data collection was carried out systematically to obtain accurate and reliable information, which is essential for the validity of the research findings (Bryman, 2016). The choice of a primarily quantitative data collection method was aligned with the research objectives of examining challenges in implementing smart technologies, while allowing some qualitative input through open-ended questions to capture deeper insights (Huyler & McGill, 2019).

3.5.1 Questionnaire Design

A questionnaire is a research instrument consisting of a series of questions designed to gather information from respondents. It is widely used in quantitative research to collect standardized data that can be analysed statistically (Krosnick and Presser, 2009). The importance of questionnaires lies in their ability to efficiently collect large amounts of data from a significant number of respondents, making them particularly valuable in survey research where the goal is to generalize findings to a larger population (Bryman, 2016). In order to conduct a questionnaire effectively, the questions must be designed carefully to ensure clarity, relevance, and neutrality, thereby minimizing bias and maximizing the accuracy of the responses.

At the beginning of the questionnaire, the background of the research was presented, along with a detailed explanation of the research topic and its three primary objectives. The questionnaire was then divided into four sections. Section A aimed to gather general information about the respondents, including their background in the construction industry, organisational type, job role, working experiences, knowledge of smart technologies, and the types of projects they have been involved in. This section was designed to better understand the respondents' professional context. From Section B through Section D, a five-point Likert scale was utilized, allowing respondents to express their opinions with options ranging from 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree) to 5 (strongly agree). Section B focused on the application of smart technologies in construction project management, assessing whether respondents were familiar with these technologies, if their companies implemented them, and whether the company had perceived any benefits from their application (12 items). Section C provided 20 options for respondents to rate the challenges associated with adopting smart technologies in their construction projects. Additionally, an open-ended question was included to allow respondents to share their opinions on the challenges they face. Finally, Section D asked respondents to rate the effectiveness of various strategies for implementing smart technologies in construction companies, evaluating whether they believe these strategies would be successful in practice.

3.5.2 Pre-Test

Pre-test data collection is an essential phase in research, serving as a preliminary assessment to refine the methodology and ensure the validity and reliability of the data collection instruments. According to Johanson and Brooks (2010), conducting a pre-test allows researchers to make necessary adjustments before the main study, thereby enhancing the overall quality of the research. In this study, the pre-test was sent to a group of experts, including three lecturers of Quantity Surveying's course and five construction industry professionals, to evaluate the accuracy, reliability, and quality of the questionnaire. This expert review helped identify potential issues and ensured that the questions were appropriately designed. Additionally, Hazzi and Maaldaon (2015) argue that a well-conducted pre-test can uncover unforeseen problems, such as misunderstandings in the instructions or the difficulty level of the questions, which, if unaddressed, could compromise the validity of the study. Therefore, conducting a pre-test is crucial in ensuring that the data collection process is both effective and efficient, ultimately leading to more reliable research outcomes.

3.6 Data Analysis

Once the questionnaires were completed by a sufficient number of respondents, the subsequent steps involved preparing, analysing, and interpreting the data as part of the data analysis process. This analysis was conducted using statistical methods to uncover meaningful evidence that could benefit the study and aid in drawing conclusions. The collected responses were processed and analyzed using the Statistical Package for the Social Sciences (SPSS), a widely used software suite designed for data management, statistical analysis, and graphical representation in social science research. Developed to handle a range of statistical tests and procedures, SPSS offers researchers the ability to process large datasets and perform complex analyses with ease (Beddo and Kreuter, 2019). The method chosen for analysing the collected data are listed below:

i. Normality test – Shapiro Wilk Test
ii. Cronbach's Alpha Reliability Test
iii. Mean Score and Standard Deviation
iv. Kruskal-Wallis Test
v. Spearman's Correlation Test
vi. Exploratory Factor Analysis

3.6.1 Normality Test – Shapiro-Wilk Test

The Shapiro-Wilk test is a commonly utilized statistical tool for evaluating whether a dataset follows a normal distribution. First introduced by Shapiro and Wilk in 1965, this test is particularly suited for small to medium-sized samples, making it one of the most effective tests for assessing normality (Mohd and Yap, 2011). The test functions by comparing the sample's order statistics to the expected values under a normal distribution, producing a W statistic. A W value near 1 suggests that the data are normally distributed, while a W value significantly lower than 1 indicates a deviation from normality (Ghasemi and Zahediasl, 2012).

3.6.2 Cronbach's Alpha Reliability Test

Cronbach's Alpha is a prevalent statistical method used to evaluate the internal consistency of a set of items within a scale or questionnaire. Originally proposed by Lee Cronbach in 1951, this measure assesses how well the items within a test are correlated, reflecting the reliability of the instrument (Tavakol and Dennick, 2011). Essentially, Cronbach's Alpha helps determine whether the items are consistently measuring the same underlying construct. In this research, Cronbach's Alpha is utilized to assess the reliability of the scale associated with the three objectives. A Cronbach's Alpha value exceeding 0.7 is necessary to ensure that all variables related to the three objectives exhibit acceptable internal consistency, are reliable and are correctly measured.

An Alpha coefficient of 0.900 or higher signifies excellent internal consistency, suggesting that the items are highly reliable. Values between 0.800

and 0.899 are considered good, reflecting a high level of consistency among items. An Alpha in the range of 0.700 to 0.799 is deemed acceptable, indicating that the items generally measure the same construct, though there is room for improvement. Scores between 0.600 and 0.699 are classified as questionable, suggesting that the reliability of the items might be insufficient. Alpha values from 0.500 to 0.599 are labeled poor, and values below 0.500 are regarded as unacceptable, indicating a significant issue with the internal consistency of the test items.

Table 3.1: Table of Conbrach's Alpha Reliability Coefficient

Cronbach's Alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$\alpha < 0.5$	Unacceptable

3.6.3 Mean Score and Standard Deviation

The mean is a statistical tool used to compare the central tendency of variables across three objectives in a questionnaire. By calculating and comparing the mean values, variables among the three objectives can be determined which one is most prioritized. Mean ranking is used to identify the relative importance of variables by assessing their average scores. When comparing means across different variables, those with higher or lower mean values (depending on the context) can be identified as the most significant or prioritized. When comparing variables with similar mean values, the one with the lowest standard deviation is generally considered more consistent and may be prioritized higher due to its reliability. Thus, the mean provides a measure of central tendency, while the standard deviation offers insights into the variability of responses, both of which are crucial in determining the priority of variables among the objectives (Field, 2012; Montgomery, 2014).

3.6.4 Kruskal-Wallis Test

The Kruskal-Wallis Test is a non-parametric statistical method used to determine if there are significant differences between the medians of three or more independent groups which are client, consultant and contractor. The Kruskal-Wallis Test is particularly useful when the data do not meet this assumption or when dealing with ordinal data (Fitzgerald et al., 2001). The test ranks all the data points from all groups together and then compares the sum of ranks between the groups. A significant Kruskal-Wallis statistic indicates that at least one group differs significantly from the others, though it does not specify which groups are different. Post-hoc tests are often required to identify where these differences lie (Bakker et al., 2019). The test is widely applied in social sciences, medicine, and other fields where researchers are interested in comparing distributions across multiple independent samples without assuming normality.

Two hypotheses are proposed which the null hypothesis (H0) posits that there is no significant variation in the acceptance of blockchain technology across different age groups or educational levels. Conversely, the alternative hypothesis (H1) suggests that significant differences do exist in how blockchain technology is accepted among various age groups and educational backgrounds. This framework aims to determine whether the acceptance of blockchain is influenced by these demographic factors.

3.6.5 Spearman's Correlation Test

Spearman's correlation test is a non-parametric statistical method used to measure the strength and direction of the association between two ranked variables. Unlike Pearson's correlation, which assumes that the data is normally distributed, Spearman's correlation is based on the ranks of the data rather than their raw values, making it suitable for ordinal data or when the assumptions of parametric tests are not met. Spearman's correlation test to explore the relationship between the challenges and strategies faced in implementing smart technologies. This is to understand how the severity of implementation challenges correlates with effectiveness of different strategies employed.

The test calculates the Spearman's rank correlation coefficient, denoted as ρ (rho), which ranges from -1 to 1. A ρ value of 1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation, and 0 indicates no correlation (Dancey and Reidy, 2020). The procedure for conducting Spearman's correlation begins by ranking the data points of each variable, followed by calculating the differences between the ranks of each pair of data points. These differences are then squared and summed to compute the Spearman's rank correlation coefficient. The significance of the correlation is then tested using a t-test or by comparing the ρ value to critical values in a Spearman's correlation table (Puth et al., 2015).

Table 3.2: Correlation degree between variables (Adopted from Yan et al., (2019)

Grading Standards	Correlation Degree
$\rho = 0$	No correlation
$0<\|\rho\|\leq 0.19$	Very weak
$0.2\leq\|\rho\|\leq 0.39$	Weak
$0.4\leq\|\rho\|\leq 0.59$	Moderate
$0.6\leq\|\rho\|\leq 0.79$	Strong
$0.8\leq\|\rho\|\leq 1.00$	Very strong
1.00	Monotonic correlation

3.6.6 Exploratory Factor Analysis (EFA)

According to Yap et al. (2019), factor analysis is a statistical method used to explore and uncover underlying latent variables within a dataset. Factor analysis is divided into two types: exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). EFA is used when researchers do not have predefined expectations or theories about the factors or underlying structure of the data. It is often applied in the early stages of research to explore the potential factor structure by identifying the number and nature of latent variables (factors) that explain the correlations among observed variables. Hence, in this study, EFA is employed to categorize 20 challenges to smart technologies adoption, which aids in understanding the relationships between variables and in developing more effective measurement tools (Ul Hadia et al., 2016).

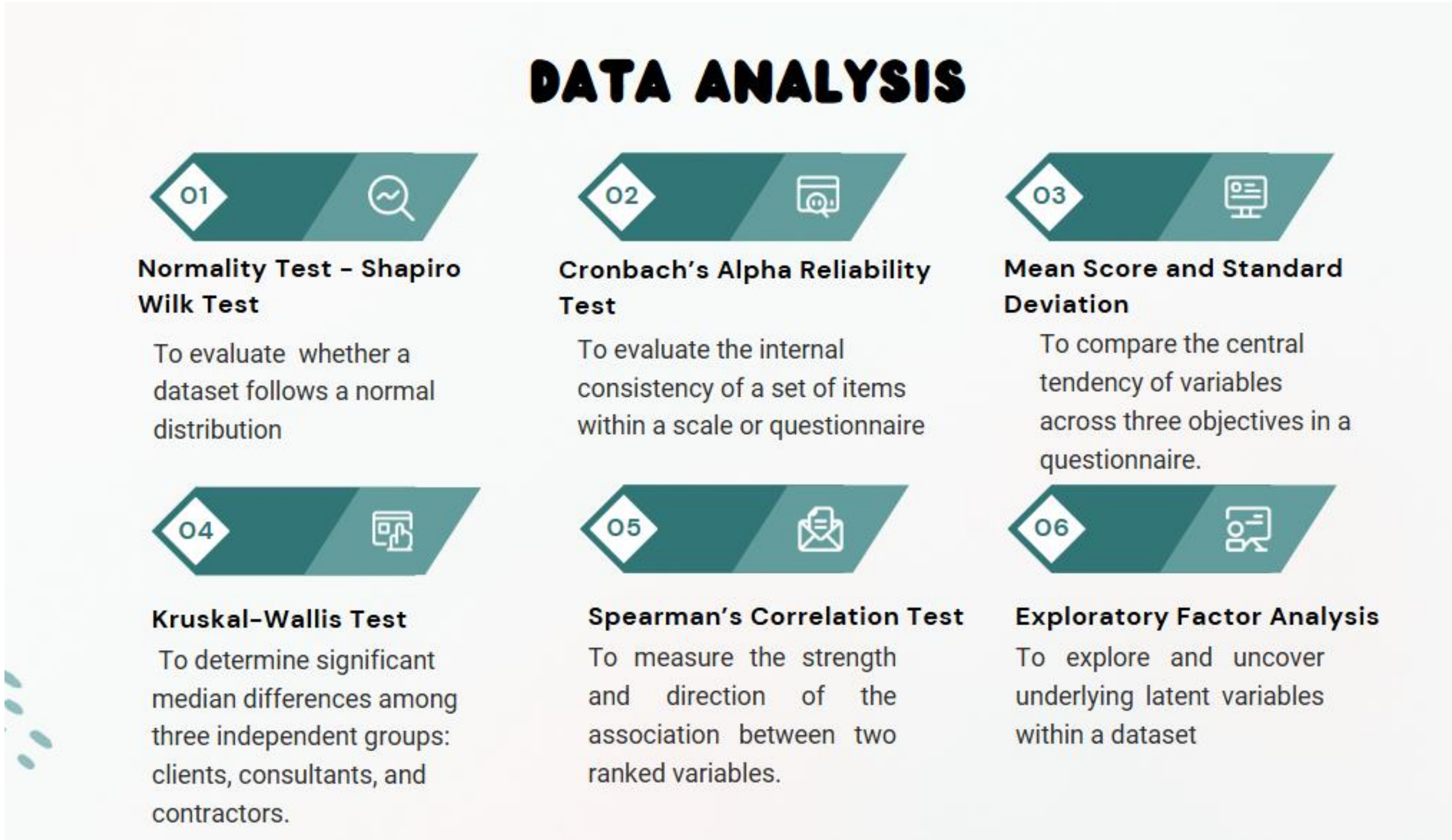

Figure 3.2: Summary of Data Analysis

CHAPTER 4
RESULT AND DISCUSSION

4.1 Introduction

This chapter highlights the outcomes derived from the quantitative data collection. The findings were analysed to uncover their significance in deepening the understanding of both the causes and impacts of construction disputes within private sector projects. These insights were then linked to the overall research objectives. All gathered data were systematically refined, analysed, and presented in tables using SPSS software.

4.2 Outcome of Pre-test

The pre-test phase involved eight participants, including five professionals from the construction industry and three academic lecturers. Their insights were instrumental in evaluating the questionnaire's quality. Based on their input, only minor adjustments were made to a few questions. Overall, the feedback confirmed that the questionnaire was clear, relevant, and easy to interpret. The positive outcomes of the pre-test suggest that the survey instrument is appropriately structured and reliable for use in the main study.

4.3 Questionnaire Response Rate

After receiving positive feedback from the pre-test, the finalized survey was disseminated to targeted participants through email and social media platforms, including WhatsApp, Facebook and Instagram. In addition, professional networking sites such as LinkedIn and JobStreet were utilized to identify and reach out to individuals working in the construction industry. A total of 320 questionnaires were distributed to employed professionals within the Klang Valley region. Over a six-week period, 110 completed responses were collected, resulting in a response rate of 34.43%. As noted by Yap et al. (2020b) and Livingston and Wislar (2017), a response rate exceeding 30% is generally considered acceptable for conducting valid statistical analysis and is sufficient to support accurate model estimation.

4.4 Respondent's Profile

The demographic profile of the respondents (Table 4.1) reflects a balanced and diverse representation from the construction industry. In terms of organisation type, the distribution was nearly equal among developers (33.6%), consultants (33.6%), and contractors (32.7%), indicating a well-rounded input from all major stakeholders. Professionally, the majority were Quantity Surveyors (34.5%), followed by Architects (18.2%) and M&E Engineers (15.5%), suggesting a strong representation from cost and design-related roles. Regarding company positions, a significant portion of the respondents held executive (31.8%) and management-level roles (Director/Top Management, Manager, Senior Manager), accounting for approximately 74.5% of the total. This highlights that the survey captured the perspectives of experienced decision-makers. In terms of working experience, while a notable portion had more than 20 years of experience (20%), the largest group consisted of professionals with less than five years of experience (39.1%), indicating a mix of seasoned experts and younger professionals. Most respondents possessed a Bachelor's degree (67.3%), with an additional 23.6% holding postgraduate qualifications, ensuring that the data collected came from academically qualified individuals capable of providing informed insights. Furthermore, a total of 118 (98.2%) respondents agreed that smart technologiessuch as Building Information Modeling (BIM), Artificial Intelligence (AI), the Internet of Things (IoT), robotics, and automation will contribute to improvements in construction projects, while only 2 (1.8%) disagreed as shown in Figure 4.1. Overall, the respondent profile enhances the credibility and relevance of the study findings.

Table 4.1: Demographic Profile of Respondents.

Parameter	Categories	Frequency	Percentage (%)
Type of Organisation	Developer	37	33.6
	Consultant	36	33.6
	Contractor	36	32.7
Profession	Quantity Surveyor	38	34.5
	Architect	20	18.2
	M&E Engineer	17	15.5
	C&S Engineer	16	14.5
	Construction Management	15	13.6
	Others	4	3.60
Position in Company	Executive	35	31.8
	Top Manager	29	26.4
	Manager	19	17.3
	Senior Manager	15	13.6
	Others	12	10.9
Working Experience	> 20 Years	22	20.0
	15-20 Years	13	11.8
	11-15 Years	16	14.5
	5-10 Years	16	14.5
	< 5 Years	43	39.1
Highest Academic Qualification	Bachelor's Degree	74	67.3
	Postgraduate Degree (PhD, master)	26	23.6
	Diploma	8	7.30
	High School	2	1.80

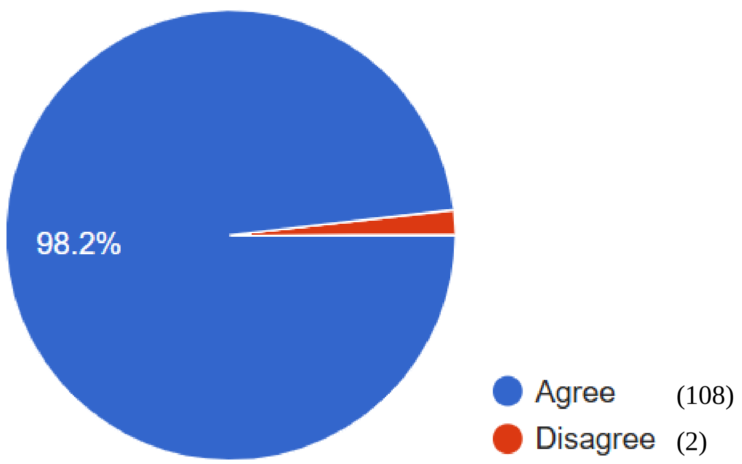

Figure 4.1: Result Agreement on Smart Technologies Improving Construction

4.5 Normality Test – Shapiro Wilk Test

The SPSS normality test returned a p-value of 0.01, which is below the standard significance threshold of 0.05. This result led to the rejection of the null hypothesis (H_0), indicating that the data does not follow a normal distribution. Although the sample size was below 300, normality is not determined solely by sample size. As noted by Ghasemi and Zahediasl (2015) and Mishra et al. (2019), normality tests in small samples may lack power, while in large samples, they can be overly sensitive to minor deviations. Given the non-normal nature of the data, non-parametric methods were applied. The Kruskal-Wallis test was used to rank the mean importance of variables, enabling comparison across groups. To examine the relationship between variables, Spearman's rank correlation was employed, specifically to explore the associations between 20 identified challenges in implementing smart technologies and 12 proposed strategies to overcome them. Additionally, exploratory factor analysis (EFA) was conducted on the 20 challenge items to identify underlying factor structures. While factor analysis is ideally suited for larger samples, it was cautiously applied in this study to provide preliminary insight into the dimensionality of the challenge variables.

4.6 Reliability Test – Cronbach's Alpha

To evaluate the reliability and internal consistency of the questionnaire data, the Cronbach's Alpha reliability test was conducted. The computed Cronbach's Alpha coefficients for the various categories of variables are presented in Table 4.2. Based on the results, it was found that all categories achieved alpha values greater than 0.70, indicating an acceptable level of reliability according to Spiliotopoulou (2009). In particular, variables related to challenges of smart technology adoption recorded alpha values 0.905, which signifies excellent reliability as suggested by Nawi et al. (2020). Some categories attained alpha values 0.866, reflecting good internal consistency. These findings imply that respondents' answers were consistently aligned across related items, thus ensuring the dependability of the data collected for further analysis. Therefore, it can be concluded that the survey instrument used in this study demonstrated strong reliability.

Table 4.2: Cronbach's Coefficient Alpha Values for Reliability Test

Category of variables	Number of items	Cronbach's alpha
Impact of Smart Technologies on Construction Project Success	12	0.928
Perceived Organizational Need for Smart Construction Technologies	12	0.925
Challenges of Implementing Smart Technologies	20	0.905
Strategies of Implementing Smart Technologies	12	0.866

4.7 Adoption of Smart Technologies in Construction Industry Malaysia

4.7.1 Mean Score and Standard Deviation of Impact of Smart Technologies on Construction Project Success

Based on the analysis of smart technologies used in construction as shown in table 4.3, the five highest-ranked technologies in terms of overall mean score are Building Information Modeling (BIM), Prefabrication and Modular Construction, the Internet of Things (IoT), Artificial Intelligence (AI), and Drones/Smart Materials. These technologies have been prioritized by industry professionals due to their proven ability to improve time, cost, quality, safety, and productivity in construction project delivery.

Building Information Modeling (BIM) ranks the highest with an overall mean score of 4.19. BIM is widely valued across all respondent categories, developers, consultants, and contractors because it enables comprehensive project visualization, clash detection, and better coordination among stakeholders (Alotaibi et al., 2024). Contractors, in particular, ranked BIM the highest, as it significantly reduces rework and delays on site by identifying design conflicts early. Developers and consultants also see BIM as essential for improving communication and ensuring cost efficiency throughout the project lifecycle (Sholeh et al., 2020).

Prefabrication and Modular Construction is ranked second overall with a mean of 4.10. This technology allows building components to be manufactured in controlled environments and assembled on-site, which shortens the construction timeline and minimizes site disruptions (Anjum and Ayuns, 2024). Developers and consultants both ranked it first, highlighting its value in accelerating project completion and maintaining consistent quality (Raul, 2023). Developers particularly favor prefabrication because it leads to faster project turnover and earlier returns on investment, while consultants appreciate the reduction in on-site risks and easier quality control (Lakhani, 2024).

The Internet of Things (IoT) holds the third position with a mean of 3.96. IoT technology provides real-time data through sensors and connected devices that monitor site activities, track equipment usage, and support asset management (Elrifaee et al., 2024). Contractors placed a strong emphasis on IoT, ranking it second, as it directly enhances site safety and operational efficiency. Developers also benefit from IoT through post-construction asset tracking and maintenance, although consultants ranked it slightly lower, likely due to their limited direct involvement in on-site monitoring (Khan et al., 2024).

Artificial Intelligence (AI), with a mean of 3.93, is ranked fourth overall. AI applications in construction include predictive analytics for risk management, automated scheduling, and decision-making support. Developers ranked AI highly, recognizing its potential for financial forecasting and project optimization. Contractors and consultants also see the benefits of AI, especially in planning and project control, though its adoption is still in the early stages compared to more established technologies like BIM (Abioye et al., 2021).

Lastly, Drones and Smart Materials are tied in fifth place, both with a mean score of 3.91. Drones are increasingly used for site surveying, aerial inspections, and progress monitoring (Yıldız et al., 2021). Developers rank drones relatively high, valuing their ability to provide clear, visual updates for project stakeholders. Contractors also benefit from drones through improved safety and efficient site logistics. Smart Materials, on the other hand, offer innovative properties such as self-healing, thermal responsiveness, and enhanced durability. These materials contribute to the long-term performance and sustainability of buildings, which explains their consistent ranking across all stakeholder groups (Choi et al., 2023).

The differences in rankings among developers, consultants, and contractors can be attributed to their distinct roles and priorities within the construction process. Developers prioritize technologies that accelerate completion and maximize return on investment, such as prefabrication and AI. Consultants focus on design coordination and compliance, which explains their emphasis on BIM and prefabrication. Contractors favor technologies that directly impact site execution and safety, such as IoT and drones. These variations reflect how each stakeholder group evaluates smart technologies based on their specific responsibilities and project involvement.

4.7.2 Kruskal – Wallis Test of Impact of Smart Technologies on Construction Project Success

The Kruskal-Wallis Asymptotic Significance values presented in the Table 4.3 reveals that all p-values are greater than 0.05, indicating there is no statistically significant difference in how developers, consultants, and contractors ranked the various smart technologies Zhu et al. (2022). This finding suggests a general consensus across stakeholder groups regarding the perceived importance and usefulness of these technologies in the construction industry. Despite the different roles each group plays, developers focusing on investment and time efficiency, consultants emphasizing design and compliance, and contractors prioritizing on-site performance, there appears to be a shared understanding of which technologies are most beneficial Hamamurad et al. (2022). For example, technologies that support digital collaboration, automation, and real-time monitoring tend to be rated highly across all groups, reflecting common goals such as improving productivity, quality, and safety. The absence of significant disagreement also implies a maturing awareness and acceptance of smart technologies across the industry, regardless of specialization. This alignment may facilitate smoother technology implementation in future projects, as similar priorities are shared among key decision-makers.

Table 4.3: Mean Score, Standard Deviation and Kruskal Wallis Test Impact of Smart Technologies on Construction Project Success

Smart Technologies	Overall (N=110)			Developer (N=37)			Consultant (N=37)			Contractor (N=36)			Chi square	Asymp. sig
	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank		
Building Information Modeling (BIM)	4.19	0.818	1	4.22	0.712	1	4.11	0.843	2	4.25	0.906	1	1.047	0.592
Prefabrication and modular constructions	4.10	0.834	2	4.14	0.713	2	4.16	0.800	1	4.00	0.986	3	0.324	0.850
Internet of Things (IoT)	3.96	0.765	3	4.05	0.743	5	3.81	0.877	4	4.03	0.654	2	2.079	0.354
Artificial Intelligence (AI)	3.93	0.945	4	4.11	0.875	3	3.76	0.955	6	3.92	0.996	5	2.928	0.231
Drones	3.91	0.873	5	4.05	0.664	6	3.78	0.947	5	3.89	0.979	7	1.493	0.474
Smart Materials	3.91	0.924	6	3.92	1.010	9	3.89	0.966	3	3.92	0.806	4	0.128	0.938
Geographic Information System (GIS)	3.88	0.906	7	4.03	0.763	4	3.73	1.071	7	3.89	0.854	6	1.074	0.584
Robotics	3.81	0.914	8	3.97	0.799	7	3.62	0.861	9	3.83	1.056	10	3.553	0.169
3D Printing	3.81	0.991	9	3.84	1.143	12	3.73	1.018	8	3.86	0.798	9	0.599	0.741
Augmented Reality/Virtual Reality (AR/VR)	3.77	0.955	10	3.97	0.928	8	3.49	0.932	10	3.86	0.961	11	5.689	0.058
Digital Twin	3.76	0.938	11	3.92	0.894	10	3.49	0.961	11	3.89	0.919	8	5.635	0.060
Blockchain	3.72	1.068	12	3.92	1.010	11	3.43	1.168	12	3.81	0.980	12	4.210	0.122

4.7.3 Mean Scores and Standard Deviation of Perceived Organisational Need for Smart Construction Technologies

The analysis of perceived organisational need for smart construction technologies (Table 4.4) reveals that Building Information Modeling (BIM), Augmented Reality/Virtual Reality (AR/VR), Artificial Intelligence (AI), Robotics, and Prefabrication & Modular Construction are the top five technologies most valued across the construction industry. These technologies are highly rated because they offer practical and measurable benefits to organisations, such as improving project coordination, reducing human error, enhancing visualization, and increasing productivity. BIM, ranked first overall, provides a collaborative platform that allows for better design integration and communication among stakeholders, which is essential for reducing conflicts and rework. AR/VR is highly appreciated for its ability to support immersive design presentations and effective on-site training, particularly useful for stakeholder engagement and safety management. This aligns with findings from Li et al. (2018), who showed that AR/VR applications enhance worker understanding and improve hazard identification on construction sites. AI and Robotics are recognized for their role in automating repetitive tasks, improving data-driven decisions, and addressing the skilled labor shortage, especially on construction sites (Vaidya et al.,2022). Prefabrication, on the other hand, is valued for its potential to shorten project timelines, minimize waste, and increase construction precision by shifting work to a controlled environment.

Interestingly, the preference for smart technologies varies among developers, consultants, and contractors due to their differing roles and priorities in a construction project. Developers place higher importance on technologies like Digital Twin and AI, which support long-term asset performance monitoring and cost prediction, reflecting their focus on investment efficiency and lifecycle management (Boje et al., 2020). Consultants favor BIM and AR/VR as these tools help them with design accuracy, clash detection, and client communication, aligning with their responsibility to ensure design compliance and coordination. Meanwhile, contractors highly rate technologies like AI, BIM, and Robotics, which directly contribute to faster execution, better site safety, and reduced on-site labor dependency key concerns during the construction phase. These differences show that although the same technology may be used by all parties, its perceived value depends on how it supports specific organisational functions.

Comparatively, technologies like Blockchain and 3D Printing were rated the lowest, possibly due to their limited implementation in current projects, lack of industry familiarity, or perceived risk. While Blockchain offers secure data transactions, its benefits may not yet be seen as essential at the operational level (Perera et al., 2020). Similarly, 3D Printing is often considered experimental and may not be cost-effective or suitable for mainstream construction at this stage. In contrast, technologies like BIM and AI are widely adopted, supported by established software, and provide visible returns, making them more favorable choices (Gibson et al., 2015).

In conclusion, the top-rated smart technologies reflect a combination of technological maturity, ease of adoption, and clear contribution to organisational goals such as cost control, quality assurance, and project efficiency. The variation in stakeholder perspectives further highlights the need for tailored implementation strategies that consider the specific functions and challenges faced by developers, consultants, and contractors. Understanding these preferences helps guide more effective decision-making in adopting digital technologies in the construction industry.

4.7.4 Kruskal – Wallis Test of Perceived Organizational Need for Smart Construction Technologies

The Kruskal-Wallis test (Table 4.4) was employed to examine whether there are statistically significant differences in the perceived organisational need for various smart construction technologies among developers, consultants, and contractors. Based on the results, most smart technologies such as BIM ($p = 0.348$), AR/VR ($p = 0.175$), AI ($p = 0.330$), Robotics ($p = 0.467$), Prefabrication ($p = 0.786$), IoT ($p = 0.747$), Smart Materials ($p = 0.464$), GIS ($p = 0.167$), and 3D Printing ($p = 0.203$) show Asymp. Sig. values greater than 0.05, indicating no statistically significant difference in how these technologies are perceived among the three stakeholder groups. This suggests that despite having different roles in a construction project, developers, consultants, and contractors generally share similar views regarding the importance of these technologies. The reason for this consistency could be due to the industry's increasing adoption of collaborative platforms like BIM, which helps improve coordination and reduce rework. AR/VR also supports more effective stakeholder engagement through immersive visualization and site training applications (Li et al., 2018). Moreover, AI tools are being used to optimize scheduling and enhance decision-making, improving overall project productivity (Vaidya et al., 2022). On the other hand, three technologies, Digital Twin ($p = 0.010$), Drones ($p = 0.033$), and Blockchain ($p = 0.002$), have p-values less than 0.05, indicating a statistically significant difference in perception among the groups. These differences may stem from the varying levels of understanding, implementation readiness, and practical exposure across the roles.For example, Digital Twin technology is often valued by developers for its use in lifecycle management and predictive maintenance (Boje et al., 2020). Blockchain is gaining interest for its role in secure transactions and smart contract automation, particularly among consultants and developers (Perera et al., 2020). In contrast, drones are more commonly used by contractors for site inspections and safety monitoring (Abdullah et al., 2024), which explains the higher ranking among that group.

Table 4.4: Mean Score, Standard Deviation and Kruskal Wallis Test of Perceived Organizational Need for Smart Construction Technologies

Smart Technologies	Overall (N=110)			Developer (N=37)			Consultant (N=37)			Contractor (N=36)			Chi Square	Asymp. sig
	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank		
Building Information Modeling (BIM)	4.34	0.838	1	4.43	0.928	1	4.16	0.843	2	4.42	0.841	1	2.113	0.348
Augmented Reality/Virtual Reality (AR/VR)	4.24	0.801	2	4.41	0.897	2	4.03	0.932	4	4.28	0.815	3	10.932	0.175
Artificial Intelligence (AI)	4.21	0.930	3	4.32	0.986	3	4.03	0.955	5	4.28	0.974	4	7.344	0.330
Robotics	4.16	0.862	4	4.11	0.994	7	4.11	0.861	1	4.28	0.849	2	10.154	0.467
Prefabrication and modular constructions	4.11	0.817	5	4.19	0.815	5	4.05	0.800	3	4.08	0.937	6	0.495	0.786
Digital Twin	4.06	0.770	6	4.38	0.855	4	3.86	0.961	7	3.94	0.754	10	10.943	0.010
Internet of Things (IoT)	4.05	0.917	7	4.14	1.064	8	3.92	0.877	6	4.11	0.919	5	0.583	0.747
Drones	3.99	0.981	8	4.24	1.038	6	3.76	0.947	9	3.97	1.134	8	4.028	0.133
Smart Materials	3.96	0.918	9	4.08	1.058	9	3.78	0.966	8	4.03	0.774	7	1.535	0.464
Geographic Information System (GIS)	3.94	0.951	10	4.19	1.127	5	3.7	1.071	10	3.92	0.874	11	3.582	0.167
3D Printing	3.88	1.090	11	3.86	1.116	12	3.65	1.018	11	4.14	0.867	9	6.547	0.203
Blockchain	3.86	0.953	12	4.3	1.096	3	3.49	1.168	12	3.81	0.889	12	11.995	0.002

4.7.5 Key Benefits of Smart Construction Technologies

The data offers a comprehensive and organized overview of how different smart construction technologies contribute uniquely to various project objectives as shown in figure 4.2. For enhancing coordination and collaboration, Building Information Modelling (BIM) emerges as the most effective with 65 responses (13.5%). Its centralized data platform facilitates seamless interdisciplinary interaction, significantly outperforming drones, which received only 20 indications (5.6%) due to their narrower function in site surveillance. Augmented and Virtual Reality (AR/VR), with 55 responses (14.7%), and Artificial Intelligence (AI), with 60 mentions (12.1%), also provide support, but BIM's strength in centralizing and visualizing complex project data offers it a distinct edge for overall coordination.

In terms of cost estimation and financial control, prefabrication and modular construction lead with 60 responses (24%), delivering tangible savings through off-site production, minimized waste, and process standardization. AI follows with 70 indications (14.1%) by enabling predictive financial planning, while Blockchain, with 55 selections (19.3%), contributes through its support of financial transparency. AR/VR, however, receives only 20 responses (5.3%), reflecting its limited relevance to direct cost management. This pattern reinforces the idea that technologies that physically transform the construction process tend to generate the most cost efficiencies (Perera et al., 2020).

When evaluating speed and operational efficiency, robotics stand out with 85 selections (28.3%) due to their ability to automate labor-intensive tasks. 3D printing also performs well, securing 60 responses (24%) for its rapid component fabrication. On the other hand, Blockchain earns just 25 mentions (8.8%), highlighting that tools focused on documentation and security contribute less to direct on-site productivity. This contrast demonstrates that tangible automation plays a far greater role in boosting efficiency compared to purely digital solutions (Seyman and Kismet, 2023).

In the area of project monitoring and data acquisition, Geographic Information Systems (GIS) lead with 90 responses (30%) because of their superior spatial tracking capabilities. Internet of Things (IoT), with 85 responses (19.8%), and drones, with 75 mentions (21.1%), also show strong performance, emphasizing the growing reliance on real-time data for effective project oversight. In contrast, 3D printing (25 mentions, 10%) and Blockchain (20 responses, 8%) rank significantly lower. The top-performing technologies in this category are purpose-built for sensing and data integration, making them essential tools in contemporary construction monitoring (Akindele et al., 2023). Regarding quality enhancement, smart materials dominate with 75 responses (30%) due to their ability to improve durability, sustainability, and performance. 3D printing follows closely with 70 selections (28%), while BIM contributes with 90 mentions (18.8%), showing how innovation in materials and design coordination can elevate project standards. Blockchain, receiving only 20 responses (7%), plays a lesser role in this area. These findings illustrate that both physical and digital innovations are necessary to ensure superior construction outcomes.

For stakeholder engagement, AR/VR proves most influential with 80 mentions (21.3%), offering immersive, easily understood visualizations that help non-technical participants grasp complex concepts. BIM (70 responses, 14.6%) and cloud computing (25 responses, 6.3%) also support communication, but AR/VR stands out for its clarity and user engagement. Digital Twin technology is the least selected, with just 10 mentions (3.3%), highlighting the need for user-friendly presentation in data-driven platforms (Wen & Gheisari, 2020).

In the domain of sustainability, Blockchain leads with 65 responses (22.8%) by providing robust traceability and documentation that facilitate compliance with environmental standards. AI contributes with 55 mentions (11.1%) by enabling optimization, while smart materials (15 responses, 6%) offer direct, though more limited, environmental benefits. Robotics receive only 5 mentions (1.7%), suggesting potential trade-offs between automation and energy consumption. These results indicate that sustainable outcomes often rely more on data tracking and transparency than on construction speed (Rodrigo et al., 2020).

To summarize, each smart technology demonstrates particular strengths aligned with distinct project goals:

- Coordination and collaboration: BIM (65 responses, 13.5%)
- Cost estimation and management: Prefabrication and modular construction (60 responses, 24%)
- Speed and efficiency: Robotics (85 selections, 28.3%)
- Quality improvement: Smart materials (75 responses, 30%)
- Stakeholder communication: AR/VR (80 mentions, 21.3%)
- Sustainability: Blockchain (65 responses, 22.8%)

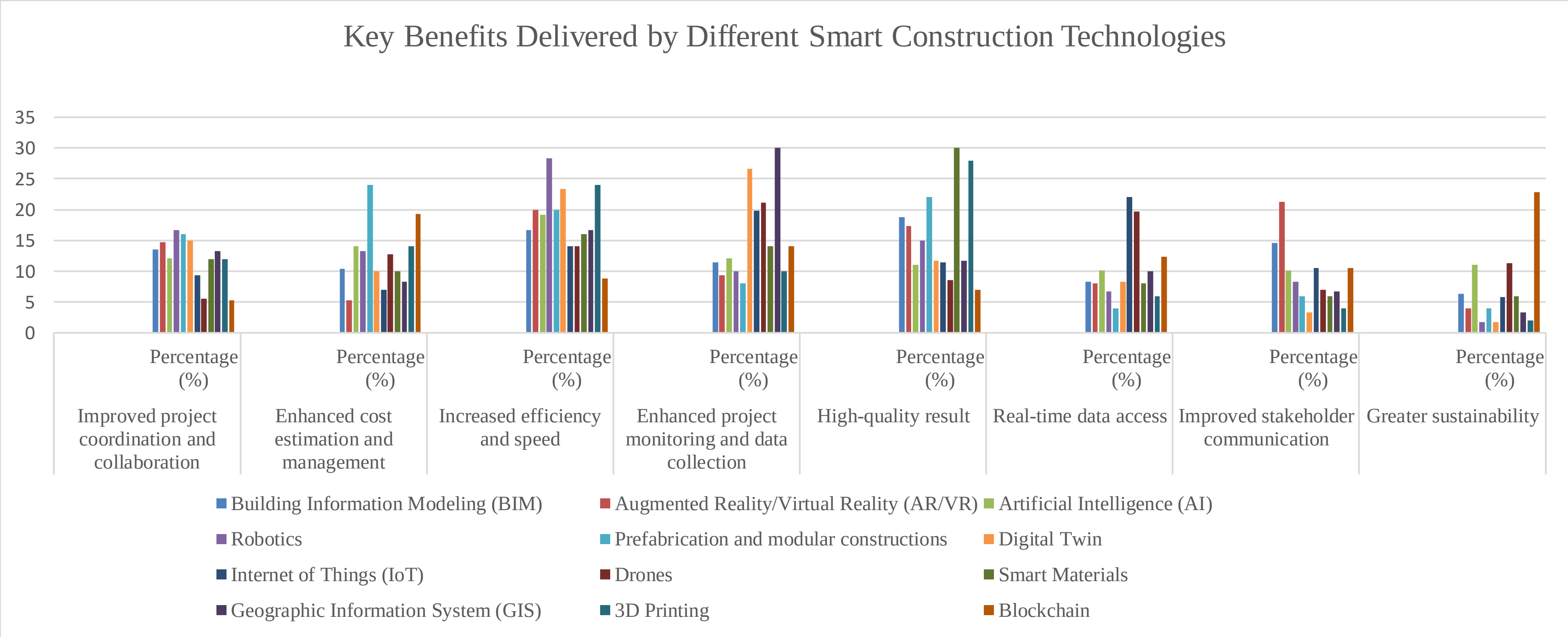

Figure 4.2: Key Benefits Delivered by Different Smart Construction Technologies

4.8 Challenges of Implementing Smart Technologies in Construction Project Management

4.8.1 Mean Score and Standard Deviation

Table 4.5 presents the main challenges in adopting smart technologies in construction, ranked by mean scores from developers, consultants, and contractors. The top five challenges identified are high initial investment and capital cost, organisation size, skill shortages and training gaps, high maintenance cost, and organisational and structural adoption. These reflect common concerns over financial constraints, workforce readiness, and internal capacity for change. Although all stakeholder groups agree that high investment cost is the most critical issue, differences in rankings highlight how each group's priorities vary based on their roles in the project.

The most significant challenges in implementing smart technologies in construction projects is the high initial investment and capital cost. This issue is consistently emphasized by all three key stakeholders in the industry. Developers rate this as their top challenge (Mean = 4.51), closely followed by contractors (Mean = 4.28) and consultants (Mean = 4.22). The adoption of smart technologies requires substantial upfront costs for hardware procurement, software systems, training, and infrastructure upgrades. Smaller firms, especially small- and medium-sized enterprises (SMEs), are particularly affected due to limited financial resources. According to a study published in *Sustainability* by MDPI, SMEs often lack not only capital but also technical expertise and personnel, making them less likely to adopt ICT and smart innovations compared to larger firms (Maqbool et al., 2019). This financial barrier creates a significant hurdle that delays or entirely prevents the implementation of smart technologies in construction (Maqbool et al., 2019).

Another key challenge closely linked to the financial aspect is the organisation size. Developers (Mean = 4.29) and consultants (Mean = 4.24) rank it as the second most important obstacle. Larger organizations typically possess the structured processes and financial capability to manage technological transformation, whereas smaller firms may lack the scale necessary to implement and sustain such changes. Again, the MDPI study (2019) supports this by highlighting that SMEs struggle with adopting ICT due to a combination of limited resources, absence of technical know-how, and lower innovation capacities. This point is reinforced in Maqbool et al.'s study, which shows how smaller firms often lag due to constraints in technical capacity and lower adaptability. Skill shortages and training gaps represent another prominent barrier, particularly for consultants who perceive this as the greatest challenge (Mean = 4.30), followed by developers (Mean = 4.24). Contractors, however, assign it a lower rating (Mean = 3.86), likely because they are more focused on day-to-day operations rather than long-term human capital development. The shortage of skilled workers capable of handling digital tools, BIM systems, AI, and other smart technologies remains a serious concern across the industry. A recent report by Autodesk and Deloitte (2024) revealed that 42% of construction firms in Asia Pacific cited lack of digital skills among employees as the primary barrier to technology adoption. This digital skills gap not only slows down adoption but also impacts productivity and industry competitiveness on a wider scale.

In addition to skill gaps, the high cost of maintenance associated with smart systems poses another significant challenge. Contractors rate this issue as their second-highest concern (Mean = 4.29), while developers (Mean = 4.00) and consultants (Mean = 4.08) also recognize its impact. Maintenance of smart systems includes not just routine servicing, but also system updates, cybersecurity, and sometimes specialized repair work. According to Energy Savings Lab (n.d.), although smart building systems bring efficiency and predictive capabilities, they also involve substantial ongoing maintenance costs that can strain operational budgets. For firms already cautious about capital expenditures, the added long-term financial commitment becomes a deterrent.

Lastly, the challenge of organisational and structural adoption is noted by both developers (Mean = 4.16) and consultants (Mean = 4.11), but contractors rate it relatively lower (Mean = 3.75). This reflects the fact that developers and consultants are more involved in strategic and administrative functions that demand structural alignment when adopting smart systems. The reconfiguration of internal processes, overcoming resistance to change, and encouraging collaboration across departments are essential for successful implementation. A review by Neuroject (2024) explains that the conservative nature of the construction industry, hierarchical decision-making, and slow digital transition contribute to resistance among stakeholders when trying to integrate smart technologies into everyday operations.

In comparing the three stakeholders, it is evident that while all parties are aligned in recognizing the burden of initial and maintenance costs, their views differ significantly in other areas. Developers and consultants, often operating at higher levels of planning and decision-making, are more concerned with issues like organization size, structural adjustments, and skill development. Contractors, meanwhile, are more focused on tangible, short-term challenges such as maintenance expenses and possibly show less emphasis on training and restructuring. This variation in perspective highlights the need for customized solutions that cater to the priorities and limitations of each stakeholder group. For example, policy incentives and training programs may be more impactful for developers and consultants, whereas subsidized maintenance schemes and ready-to-use smart platforms might be more effective for contractors (Neuroject, 2024).

In conclusion, successful adoption of smart technologies in the construction industry requires a multifaceted approach that addresses financial limitations, upskills the workforce, and promotes organizational flexibility. Recognizing the differing concerns among developers, contractors, and consultants allows for more targeted strategies to be developed, ultimately leading to a smoother transition toward smart and digital construction practices

4.8.2 Kruskal – Wallis

The significant difference in perception regarding "Organizational and structural adoption" among developers, consultants, and contractors (Chi-square = 6.180, $p = 0.046$) may be attributed to their distinct responsibilities and perspectives in the project lifecycle. Developers often oversee high-level business strategies and resource allocation, making them more sensitive to changes in organizational frameworks. Consultants, on the other hand, play a role in advising and designing processes, and may encounter resistance from rigid organizational structures when implementing smart technologies. Contractors typically focus on execution and may experience direct operational disruptions due to structural misalignment or unclear responsibilities during technology integration. This divergence aligns with findings by Liao et al. (2020), who emphasize that organizational readiness and internal structural support are critical for the successful adoption of digital innovations. Their studies suggest that without alignment between management strategies and operational practices, smart technology adoption is likely to face barriers, particularly if stakeholder roles and communication channels are unclear or inconsistent. Therefore, the statistically significant difference found in this study highlights the need for customized change management strategies that consider the unique positions of each stakeholder group within construction organizations.

Table 4.5: Mean Score, Standard Deviation And Kruskal Wallis Of Challenges In Adopting Smart Technologies In Construction

Challenges	Overall (N=110)			Developer (N=37)			Consultant (N=37)			Contractor (N=36)			Chi-square	Asymp. sig
	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank		
Initial investment and capital cost	4.30	0.654	1	4.51	0.607	1	4.22	0.75	3	4.28	0.566	1	4.353	0.113
Organization size	4.14	0.807	2	4.29	0.732	3	4.24	0.723	2	3.89	0.919	10	4.058	0.131
Skill shortages and training gaps	4.14	0.807	3	4.24	0.641	4	4.30	0.740	1	3.86	0.961	13	4.857	0.088
High maintenance cost	4.12	0.687	4	4.00	0.707	7	4.08	0.682	4	4.29	0.659	2	3.185	0.203
Organizational and structural adoption	4.01	0.783	5	4.16	0.688	5	4.11	0.516	5	3.75	0.841	15	6.166	0.046
Organization data privacy and IT security	4.00	0.888	6	4.16	0.764	6	3.97	0.986	9	3.86	0.899	11	2.083	0.353
Uncertainty in estimating financial benefits of smart technologies	3.99	0.684	7	3.95	0.468	8	4.03	0.687	6	4.00	0.862	5	0.853	0.653
Complexity of smart technologies	3.93	0.798	8	3.84	0.727	13	4.11	0.774	7	3.83	0.878	8	2.520	0.284
Gap between theoretical research and practical implementation	3.90	0.801	9	3.84	0.688	14	4.00	0.882	8	3.86	0.833	12	1.161	0.560
Workforce dynamics	3.87	0.791	10	3.81	0.660	15	3.92	0.862	10	3.99	0.854	4	0.804	0.669
Reluctance to adoption and changes	3.85	0.862	11	3.78	0.750	16	4.03	0.897	11	3.75	0.937	14	2.366	0.306
Fragmented integration	3.84	0.736	12	3.89	0.699	10	3.81	0.811	14	3.81	0.710	9	0.412	0.814
Existing system interrupt and clash with new smart technologies	3.84	0.830	13	3.84	0.688	12	3.97	0.928	12	3.69	0.656	7	2.628	0.269

Sustainability integration gap	3.81	0.760	14	3.81	0.701	17	3.84	0.764	13	3.78	0.832	6	0.026	0.987
Outdated and ineffective regulatory frameworks for smart tech	3.78	0.861	15	3.84	0.764	11	3.97	0.833	15	3.53	0.841	17	4.868	0.088
Difficulties in attaining effective interoperability	3.75	0.792	16	3.97	0.645	9	3.76	0.830	16	3.53	0.845	18	5.324	0.07
Environmental condition	3.72	0.879	17	3.70	0.878	18	3.81	0.811	17	3.64	0.961	16	0.452	0.798
Impact of poor network connectivity	3.72	0.930	18	3.70	0.878	19	3.86	0.887	18	3.58	1.025	19	1.144	0.798
Data management	3.70	0.693	19	3.92	0.640	10	3.78	0.712	19	3.83	0.737	3	0.836	0.658

4.9 Strategies of Implementating Smart Technologies in Construction Project Management

4.9.1 Mean Score and Standard Deviation

Table 4.6 ranks the top strategies to overcome challenges in adopting smart technologies in construction, based on input from developers, consultants, and contractors. The top five strategies are financial incentives, training and education, clear implementation strategies, cost optimization, and strategic incentives. All groups emphasize financial support and workforce training, though their rankings differ based on roles: developers prioritize financial incentives, consultants focus on planning and collaboration, and contractors highlight practical implementation and skill development. This reflects the varying needs and concerns of each stakeholder group in technology adoption

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The overall ranking of strategies to overcome challenges in smart technology adoption reveals a strong emphasis on addressing financial constraints and enhancing workforce readiness. Government support and financial incentives emerged as the most recommended approach, with a mean score of 4.49, reflecting the universal importance of financial assistance in overcoming the high initial costs associated with adopting smart technologies. Developers, in particular, highlighted the critical role of financial incentives, ranking them highest (M = 4.59), as these incentives can significantly mitigate the capital burden and make adoption more feasible. Sepasgozar et al. (2019) emphasize that government support plays a pivotal role in driving digital technology adoption in resource-constrained firms in the construction sector (Sepasgozar et al., 2019). Additionally, Ogunlana et al. (2020) suggest that government-funded initiatives can be crucial for overcoming financial barriers, particularly for small and medium enterprises (SMEs).

The second-ranked strategy, training and education (mean = 4.42), underscores the need to bridge the skills gap within the workforce. Contractors, who are directly involved in the operational aspects of projects, placed the highest emphasis on this strategy (M = 4.39), highlighting concerns about the practical competencies required to implement digital tools on-site. Consultants also rated training highly (M = 4.54), recognizing its importance in ensuring that the workforce is adequately prepared for the integration of smart technologies. According to Lee et al. (2020), training programs specifically designed to upskill workers in smart technologies can improve implementation rates and efficiency in construction projects.

Creating a clear strategy (M = 4.33) was ranked third, pointing to the necessity of a well-structured roadmap for technology implementation. This strategy was highly valued by consultants and contractors, who are responsible for planning and execution, although developers were slightly less enthusiastic about it (M = 4.06), likely due to their reliance on consultants and technology providers for planning. Dufresne et al. (2021) argue that a clear implementation strategy is crucial for ensuring that all stakeholders understand the technological integration process and align their efforts accordingly.

Optimizing the cost of adoption (M = 4.28) was particularly important for contractors, who are tasked with controlling project budgets during execution. Contractors emphasized the importance of managing adoption costs to ensure the technology remains within budget. Lastly, leveraging strategic incentives, such as tax breaks or public-private partnerships (M = 4.21), ranked fifth, reflecting the value placed on aligning technology adoption with broader business goals. While engagement of collaborative stakeholders and boosting academia-industry collaboration ranked sixth and seventh overall, consultants rated these strategies more highly, reflecting their role in facilitating collaboration among various project stakeholders. According to Chen and Zhang (2019), incentives such as tax breaks can significantly lower the financial risk associated with smart technology investments, thus encouraging widespread adoption.

This analysis demonstrates that a tailored, multi-stakeholder approach is essential for the successful adoption of smart technologies in construction projects, where developers focus on financial support and cost optimization, consultants emphasize planning and collaboration, and contractors prioritize practical implementation and workforce readiness.

4.9.2 Kruskal-Wallis test

The Kruskal-Wallis test results (Table 4.6) reveals important insights about how different stakeholder groups prioritize strategies for smart technology adoption. The analysis shows statistically significant differences in only one strategy - shifting organizational culture to embrace smart technologies ($\chi^2 = 0.016$, $p < 0.05$). Consultants ranked this strategy significantly higher (mean = 4.38) compared to developers (4.19) and contractors (4.06), reflecting their professional focus on facilitating organizational change management for clients. This finding aligns with consultants' typical role in driving cultural transformation during technology implementations (Cao et al.,2025).

For all other strategies, the test results showed no statistically significant differences between groups (p-values ranging from 0.201 to 0.812), indicating remarkable consensus across stakeholders. Government support and financial incentives emerged as the top priority overall (mean = 4.49), with similarly high ratings from all three groups (developers = 4.59, consultants = 4.46, contractors = 4.42). This consistency underscores the universal importance of financial mechanisms in enabling technology adoption. Similarly, providing training and education for employees was consistently ranked second overall (mean = 4.42), with particularly strong emphasis from consultants (4.54) (Sepasgozar et al., 2019).

The lack of significant differences for most strategies suggests that, despite their different professional roles, developers, consultants and contractors share fundamentally similar views about the relative importance of various approaches to implementing smart technologies. The single exception regarding organizational culture highlights how professional orientation shapes strategic priorities - consultants, whose work revolves around change management, naturally place greater emphasis on cultural factors compared to the other groups. These findings have important implications for collaborative projects, indicating that stakeholders can generally find common ground in strategy selection, while needing to pay special attention to cultural alignment when consultants are involved. The results support a unified approach to smart technology implementation, with some customization needed for cultural change management aspects. This finding aligns with Dufresne et al. (2021), who argued that change management is a critical component of smart technology adoption.

Table 4.6: Mean Score, Standard Deviation And Kruskal Wallis Of Strategies In Adopting Smart Technologies in Construction

Strategies	Overall (N=110)			Developer (N=37)			Consultant (N=37)			Contractor (N=36)			Chi square	Asymp. sig
	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank		
Government support and financial incentives	4.49	0.632	1	4.59	0.551	1	4.46	0.650	2	4.42	0.692	2	1.209	0.546
Provide training and education for employee	4.42	0.641	2	4.14	0.713	4	4.54	0.605	1	4.39	0.599	1	2.145	0.342
Create a clear strategy to implement smart technologies	4.33	0.622	3	4.06	0.829	3	4.35	0.676	4	4.36	0.543	3	0.417	0.812
Optimize cost for smart technologies adoption	4.28	0.665	4	4.27	0.652	2	4.32	0.709	6	4.17	0.737	6	1.173	0.556
Leverage strategic incentives	4.21	0.665	5	4.32	0.709	6	4.24	0.597	8	4.25	0.692	4	0.587	0.746
Engagement of collaborative stakeholders	4.18	0.719	6	4.03	0.763	7	4.32	0.709	7	4.14	0.593	5	2.276	0.320
Boost collaboration between industry and academia	4.18	0.68	7	3.92	0.722	5	4.32	0.530	5	4.03	0.845	10	2.164	0.339
Change individual attitudes towards smart technologies	4.15	0.675	8	4.00	0.624	9	4.24	0.683	9	4.19	0.710	7	3.21	0.201
Raising decision-maker awareness on current technological advances	4.13	0.756	9	4.35	0.538	10	4.19	0.660	11	4.17	0.845	8	1.255	0.534
Shift company's organization culture to embrace smart technologies	4.12	0.713	10	4.19	0.616	12	4.38	0.594	3	4.06	0.754	9	8.292	0.016
Integrate smart technologies with existing system	4.09	0.643	11	4.00	0.667	8	4.16	0.602	12	4.08	0.692	11	0.787	0.675
Develop a data management plan	4.05	0.689	12	4.03	0.645	11	4.11	0.699	10	4.06	0.715	12	0.471	0.790

4.10 Spearman's Correlation Test of Challenges and Strategies in Implementing Smart Technologies

The Spearman's correlation table presents crucial insights into how specific strategies align with the challenges encountered in implementing smart technologies in construction projects. The "Total Sig" row at the bottom of the table highlights how many statistically significant relationships each strategy has with the listed challenges. Among the twelve strategies, S1 (Government support and financial incentives) and S12 (Integration with existing systems) record the highest total significant values, both at 15, indicating their broad applicability in tackling a wide range of obstacles across financial, organizational, and technological domains.

Starting with S1, its strong correlation with C6 (Skill shortages and training gaps, $\rho = 0.445$) and C3 (High maintenance cost, $\rho = 0.35$) shows that government support goes beyond just initial funding, it indirectly enables upskilling and better preparedness for long-term operational expenses. Government incentives can fund not only hardware acquisition but also capacity-building programs, bridging the gap between technological potential and human readiness. Furthermore, it moderately correlates with C1 (Initial investment cost, $\rho = 0.398$), a common barrier in technology adoption. This suggests that financial strategies play a foundational role, acting as enablers for subsequent adoption steps like employee training, integration, and organizational culture change (Sepasgozar et al., 2019).

In comparison, S12 deals more with technical integration and compatibility. Its correlation with C15 (Workforce dynamics, $\rho = 0.354$) and C17 (Sustainability integration gap, $\rho = 0.382$) emphasizes that technological fit is essential for maintaining workforce stability and aligning with environmental goals. While S1 removes financial resistance, S12 ensures the smooth operational absorption of new technologies, making them both complementary. It also correlates with C16 (Complexity of smart technologies, $\rho = 0.251$), showing how system integration can reduce perceived complexity and resistance from employees (Sepasgozar et al., 2019).

Among all relationships, the strongest correlation is found between C6 and S10 (Boost collaboration between industry and academia, ρ = 0.466), a standout insight. This implies that academic partnerships are not just supportive, but transformative, especially in developing skilled human capital. In contrast to S1 and S12, which broadly affect multiple barriers, S10 shows depth of impact on one of the most critical long-term barriers: workforce capability. This makes it strategically unique. In scenarios where labor market readiness is the main barrier (especially in emerging markets), S10 might outperform both S1 and S12 in effectiveness (Lee et al., 2020).

A comparison of S1 vs. S12 vs. S10 reveals a strategic hierarchy:

- S1 is a financial enabler that initiates the adoption process by removing capital constraints.
- S12 is a technical harmonizer, making sure that smart technologies can blend into existing practices.
- S10 is a human capital enhancer, addressing future sustainability of the smart workforce.

Interestingly, some strategies like S3 (Engagement of stakeholders) and S7 (Shifting company culture) show relatively low total significant values (5 and 4 respectively), despite being theoretically important. This could indicate that cultural and stakeholder barriers may be less quantifiable, or their influence is indirect and context-dependent, requiring long-term efforts not captured through short-term correlations (Dufresne et al., 2021).

In conclusion, the data shows that while S1 and S12 are versatile and should be prioritized for immediate action, S10 provides strategic depth and is crucial for long-term success. A well-rounded smart technology implementation plan should integrate all three approaches: financial readiness, system compatibility, and workforce development. This nuanced understanding allows policymakers and industry leaders to design targeted interventions based on specific challenge profiles.

Table 4.7: Correlation between Challenges and Strategies in Implementing Smart Technologies in Construction Project Management

Strategies / Challenges	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	Total Sig
C1	0.398**	0.195*	-	0.293**	0.253**	-	-	-	0.405**	0.255**	-	-	6
C2	0.257**	-	-	0.279**	-	-	-	-	0.260**	0.351**	-	0.226*	5
C3	0.350*	0.289**	0.259**	0.217*	-	-	-	-	-	-	0.207*	0.321**	6
C4	0.211*	-	0.239*	0.293**	-	-	-	0.207*	0.314**	0.300**	0.283**	0.305**	8
C5	-	-	-	0.305**	-	-	-	-	0.244**	0.466**	0.218*	0.271**	5
C6	0.445**	-	-	0.201*	0.335**	-	-	-	0.310**	0.394**	0.280**	0.307**	7
C7	0.219*	-	-	0.246**	0.201*	-	-	-	0.271**	0.396**	0.218*	0.266**	7
C8	0.225*	-	-	-	-	-	-	-	-	-	-	0.197*	2
C9	-	-	0.205*	0.270**	0.228*	-	-	-	-	0.290**	0.270**	-	5
C10	-	-	-	-	-	0.242*	0.239*	-	-	-	-	0.195*	3
C11	0.302**	0.274**	0.279**	0.213*	-	-	-	-	0.245**	-	0.215*	-	6
C12	0.287**	0.193*	-	-	-	-	0.262**	-	0.287**	0.284**	0.214*	0.215*	7
C13	0.222**	-	-	-	-	-	-	-	-	-	-	-	1
C14	0.304**	-	0.188*	0.224*	-	-	-	0.231*	0.301**	0.214*	-	0.354**	7
C15	0.231*	0.212*	0.234*	0.214*	0.236*	0.257**	-	0.349**	0.255**	0.256**	0.314**	0.382**	11
C16	0.150**	-	0.257**	0.214*	-	-	-	0.240*	0.207*	-	0.311**	0.251**	7
C17	-	-	-	-	-	0.193*	-	0.305**	-	-	0.311**	0.197*	4
C18	0.191*	-	0.221*	0.190*	0.241*	0.289**	-	0.353**	0.195*	0.203*	0.262**	0.297**	10
C19	0.245**	-	-	-	-	-	-	0.264**	-	0.196*	-	0.194*	4
C20	-	-	-	-	-	-	-	-	-	0.201*	0.251**	-	2
Total Sig	15	5	8	13	6	4	2	7	12	13	13	15	

4.11 Factor Analysis

4.11.1 Kaiser-Meyer-Olkin (KMO) Test and Bartlett's Test

Factor analysis was utilized to identify the underlying factor structure associated with various previously recognized challenges of implementing smart technologies in construction project management of the Malaysian construction industry. Before performing the factor analysis, data suitability was assessed through the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity, as shown in Table 4.8. In this study, the KMO value for the 20 variables stood at 0.81, surpassing the minimum acceptable threshold of 0.50. Additionally, Bartlett's test of sphericity yielded a value of 1112.721 with a significance level of 0.000, suggesting that the correlation matrix is not an identity matrix and that meaningful inter-correlations exist among the variables (Yap, Low, & Wang, 2017). These findings confirm that the data is appropriate for conducting factor analysis.

Table 4.8: Results of KMO and Bartlett's Tests

Parameter Value	Value
Kaiser-Meyer-Olkin measure of sampling adequacy	0.81
Bartlett's test of sphericity	
Approximate chi-square	1112.721
Degree of freedom	190
Significance	0

4.11.2 Factor Loading, Variance Explained and Scree Plot

Figure 4.3 displays the scree plot for the 20 variables identified earlier. Principal Component Analysis (PCA) was employed to extract the key factors, resulting in five factors with eigenvalues exceeding 1.0. To enhance data interpretability, varimax rotation was applied (Hashim, Said, & Idris, 2019). Table 4.9 reveals that these five components collectively explain 65.669% of the total variance, meeting the acceptable threshold of 60% for extracted variance as recommended by Yap, Low, and Wang (2017). Additionally, all 20 challenges demonstrated factor loadings above 0.40 and were categorized into five distinct dimensions which are implementation challenges, technological challenges, organization challenges, societal challenges and financial challenges.

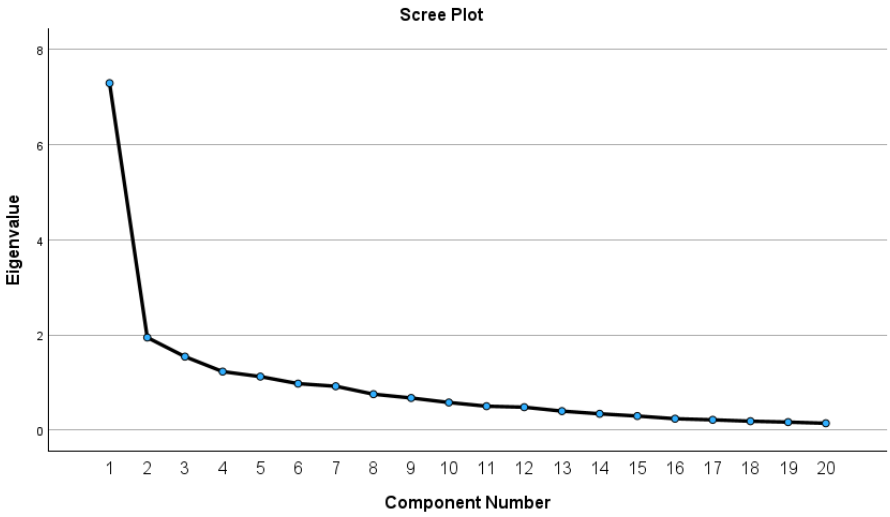

Figure 4.3: Scree plot for 20 variables.

Table 4.9: Factor loading and variance explained.

Challenges of Implementing Smart Technologies	Factor Loading	Variance Explained (%)
Factor 1: Implementation Challenges		19.307
Complexity of smart technologies	0.785	
Reluctance to adoption and changes	0.775	
Workforce dynamics	0.708	
Gap between theoretical research and practical implementation	0.597	
Sustainability integration gap	0.725	
Factor 2: Technological Challenges		15.173
Impact of poor network connectivity	0.775	
Environmental condition	0.767	
Outdated and ineffective regulatory frameworks for smart technologies	0.714	
Difficulties in attaining effective interoperability	0.598	
Existing system interrupt and clash with new smart technologies	0.561	
Factor 3: Organization Challenges		13.408
Organizational and structural adoption	0.818	
Skill shortages and training gaps	0.721	
Organization data privacy and IT security	0.715	
Organization size	0.655	
Factor 4: Societal Challenges		10.784
Fragmented integration	0.580	
High maintenance cost	0.571	
Data Management	0.563	
Personal privacy and cybersecurity concerns	0.513	
Factor 5 : Financial Challenges		6.997
Initial Investment and Capital Cost	0.735	
Uncertainty in estimating financial benefits of smart technologies	0.767	
Cumulative variance explained		65.669

4.11.3 Discussion of Factor Analysis Result

4.11.3.1 Factor 1: Implementation Challenges

The grouping of these five variables under "Implementation Challenges" is well-justified as they all pertain to site-level practicalities, readiness issues, and transitional hurdles that emerge when attempting to integrate smart technologies into the construction process. At its core, implementation involves the translation of strategic goals and technological innovation into real-world actions. Yet, even when the technology is available and theoretically beneficial, execution can fail due to a complex mix of technical, behavioral, and operational issues (Ghobakhloo, 2018).

One of the most prominent challenges, the complexity of smart technologies, directly impacts implementation success. Advanced technologies such as Internet of Things (IoT), Artificial Intelligence (AI), and Building Information Modelling (BIM) often require not only new hardware and software systems, but also new ways of thinking, working, and collaborating. As observed by Li et al. (2019), the inherent complexity of these systems often leads to hesitation among stakeholders, who may not fully understand their function or long-term benefits. This challenge is compounded by the reluctance to adoption and changes, a behavioral and cultural barrier that has consistently been identified in innovation literature. Resistance to change is deeply rooted in construction culture, which traditionally prioritizes risk aversion, low-cost practices, and well-established procedures (Hosseini et al., 2018). Therefore, the resistance is not only technical but also psychological and institutional, reinforcing the difficulty of actual implementation.

Adding to these difficulties is the challenge of workforce dynamics, including issues such as age diversity, varying levels of tech proficiency, and unionized work environments. As digital transformation accelerates, there is a clear divide between “digital natives” and older construction professionals, with the latter often struggling to adapt (Sacks et al., 2020). These dynamics reduce the effectiveness of implementation strategies unless they are accompanied by structured change management and upskilling programs. The workforce issue here also serves as a bridge between the human and operational sides of implementation, showing that resistance can stem from either skill gaps or organizational inertia.

Another critical implementation issue is the gap between theoretical research and practical application. While smart technologies are widely researched in academia, these findings often do not translate directly to the field. Research prototypes may be developed in controlled environments, but their implementation in complex construction sites is a different challenge altogether. Whyte (2019) highlights that even mature technologies may face resistance or fail due to misalignment between academic solutions and practical requirements such as project timelines, budget constraints, and stakeholder expectations. This disjunction delays or even deters implementation. In this sense, the challenge can be compared to the “last mile problem” in logistics, where the most difficult and costly part of a journey is the final stage. Smart technologies may be well-developed in theory and supported at the organizational level, but still fail to be embedded in actual practice due to real-world friction.

Finally, the sustainability integration gap serves as a bridge between strategic goals and operational constraints. While many construction firms publicly support sustainable development, integrating smart technology specifically for sustainability purposes, such as energy efficiency monitoring, carbon tracking, or adaptive systems, remains low in practice. This gap exists because sustainability features are often seen as “add-ons” rather than core project components, especially when short-term project costs are the focus (Lin et al., 2024). Therefore, even when sustainable smart technologies are technically available, their implementation is often deprioritized.

4.11.3.2 Factor 2: Technological Challenges

This factor with 15.173% of variance explained encompasses four key challenges: impact of poor network connectivity, environmental condition, outdated and ineffective regulatory frameworks, and difficulties in attaining effective interoperability, with a fifth, existing system interrupt and clash with new smart technologies, rounding out the group. These challenges are all inherently technical in nature, relating to the core infrastructure, system compatibility, environmental interfaces, and regulatory ecosystem required to support smart technologies. Grouping them under a common “Technological Challenges” factor is both statistically sound and conceptually coherent.

One major challenge is the impact of poor network connectivity, which is a foundational barrier in the deployment of smart technologies. Many such technologies, like IoT sensors, cloud-based platforms, and AI-driven analytics, require constant, real-time data exchange. Inadequate network coverage, particularly in remote or high-rise construction sites, can disrupt data flow, making technologies unreliable or completely unusable. As noted by Perera et al. (2020), the success of smart systems in construction is directly dependent on robust ICT infrastructure. This variable naturally groups with the broader theme of technological infrastructure limitations.

Closely related is the issue of environmental conditions, such as extreme temperatures, humidity, dust, or vibration, which can compromise the functionality of smart devices and sensors. Construction sites are open, dynamic, and often harsh environments where devices designed for controlled indoor settings might underperform. These environmental challenges demand ruggedization of technology, which not only increases cost but limits the selection of usable tools (Zhao et al., 2021). This problem reinforces the "technological challenge" grouping, as it reflects a contextual barrier to technology performance rather than a human or organizational one.

The inclusion of outdated and ineffective regulatory frameworks may at first appear to be a policy or governance issue, but in the context of this factor, it directly relates to how regulations either enable or restrict the use of smart technologies. For instance, if building codes or industry standards fail to accommodate digital construction tools, or if data governance laws are ambiguous, it becomes difficult to implement technological solutions legally or ethically. This reflects what Whyte (2019) refers to as institutional inertia, where lagging regulatory structures fail to keep pace with innovation. The result is a technical barrier rooted in external systems, hence its fit in the technological category.

Another critical component is interoperability, the ability of different systems and devices to communicate and work together. Construction projects often involve multiple stakeholders, each using different digital platforms (e.g., AutoCAD, Revit, Primavera). When these systems cannot synchronize data or workflows, fragmented information flow leads to errors, inefficiencies, and rework. Interoperability challenges are deeply embedded in the technical design of software and data standards, and are widely cited in the literature as one of the leading barriers to smart technology adoption.

The final element in this group is the clash between existing systems and new technologies. This refers to the legacy system barrier, where current infrastructure, equipment, or digital tools cannot support the integration of newer, more advanced technologies. Often, construction firms have invested heavily in traditional systems, and replacing them would require not just capital, but a total redesign of workflows. This leads to compatibility conflicts that are technical at their core, highlighting the rigidity of construction's digital ecosystem. As highlighted by Bandi & Thomas (2021), the path-dependency of older systems creates a technological lock-in, making integration difficult.

4.11.3.3 Factor 3: Organisation Challenges

The third factor with 10.387% of variance explained includes the following variables: lack of incentives or motivations to adopt smart technologies, insufficient top management support, high cost of implementation, and lack of awareness about the benefits of smart technologies. These are challenges that originate from within the organization, specifically in terms of leadership commitment, strategic priorities, and internal resource allocation. Grouping these variables under "Organizational Challenges" is logical because they all involve decision-making, resource planning, and cultural readiness core aspects of organizational behavior and management.

The first issue, lack of incentives or motivations, reflects an absence of internal or external driving forces that encourage organizations to invest in or adopt smart technologies. In the absence of competitive pressure, policy mandates, or economic benefits, construction firms may not see a strong "business case" for change. As highlighted by Pan and Zhang (2021), firms often require clear return-on-investment indicators before embracing innovation. When such incentives are not evident, smart technologies are viewed as optional luxuries rather than necessities, stalling their adoption.

Closely tied to this is the lack of top management support. Strategic initiatives such as digital transformation require sponsorship and active backing from top executives, who must allocate budgets, authorize structural change, and communicate vision. Without such leadership, even well-intentioned technology pilots often fade out or remain siloed. According to Davies et al. (2015), leadership support is a critical success factor in innovation diffusion. This challenge is deeply embedded in organizational dynamics, where decisions about technology are not made by engineers or IT teams, but by those holding financial and strategic authority.

The high cost of implementation is another key deterrent. While smart technologies can offer long-term benefits in terms of productivity, quality, and safety, their upfront costs, hardware, software, training, and integration, can be daunting, especially for small and medium-sized enterprises (SMEs). Organizations may lack the financial capacity or risk appetite to make such investments. This reflects an organizational constraint on capital planning and cost-benefit analysis. As indicated by Ghaffarianhoseini et al. (2017), perceived high cost is one of the most cited barriers in smart technology adoption.

The fourth challenge, lack of awareness about the benefits, further reinforces the organizational theme. This variable reflects a knowledge gap at the institutional level. When decision-makers are not fully informed about what smart technologies can do, or how they align with project goals, they are unlikely to prioritize investment. This also suggests a communication breakdown between technology developers and industry leaders. The issue goes beyond individual ignorance, it’s often the result of insufficient internal knowledge-sharing, weak vendor engagement, and poor dissemination of success stories across projects or departments (Abubakar et al., 2020).

Together, these variables represent a strategic readiness deficit within construction organizations. They highlight how internal dynamics, culture, leadership, financial strategy, and knowledge management, play a pivotal role in enabling or resisting technological change. In contrast to Factors 1 and 2, which deal with execution and infrastructure, Factor 3 deals with organizational willpower, the very foundation of innovation adoption.

4.11.3.4 Factor 4: Societal Challenges

This factor with 7.627% of variance explained includes three interconnected challenges: lack of expertise and knowledge among construction practitioners, lack of proper training and education programs, and resistance to change among the workforce. These variables are grouped together as they all reflect a human capital deficiency, the absence of necessary skills, awareness, and willingness required for the successful adoption and application of smart technologies in the construction industry.

The first challenge, lack of expertise and knowledge among construction practitioners, is perhaps the most direct indicator of a workforce unprepared for digital transformation. Smart technologies such as BIM, IoT, AI, and drones require new technical and digital competencies. However, construction has traditionally been a labor-intensive sector with limited exposure to such technologies, especially among older professionals. As highlighted by Eadie et al. (2015), the shortage of digital skills among construction professionals has become one of the most significant obstacles to innovation uptake. This skill gap becomes more pronounced when smart technologies are introduced without parallel human development strategies.

The second challenge, lack of proper training and education programs, further explains the persistence of the first. If practitioners are not trained through formal curricula or on-the-job upskilling, they cannot be expected to embrace or master advanced tools. Many universities and technical colleges are only recently updating their syllabi to include smart construction content. Likewise, construction firms often fail to allocate budgets or time for digital skill development. This results in a pipeline of professionals who are underprepared for technology-driven roles. A study by Khosrowshahi and Arayici (2015) emphasized that without proactive education and training programs, BIM and similar technologies remain underutilized due to human resource limitations.

The third variable, resistance to change among the workforce, reflects not just a lack of skills, but a psychological and cultural barrier to learning. Even when training is available, employees may resist adopting new methods due to fear of redundancy, discomfort with technology, or loyalty to traditional practices. Resistance to change is well-documented in change management literature and is particularly pronounced in construction, where workflows and norms have remained stable for decades (Mahamadu et al., 2020). This resistance can stem from generational gaps, lack of confidence, or skepticism about the effectiveness of new systems.

These three variables align strongly under the “human-centered barriers” category. Unlike organizational or technological issues, these are not rooted in strategy or infrastructure, but in people's readiness, adaptability, and learning capacity. They form a self-reinforcing loop: lack of training leads to lack of skills, which increases resistance to change, which in turn reduces the likelihood of training success. This cyclical nature strengthens their grouping into a single factor.

4.11.3.5 Factor 5: Financial Challenges

This factor with 6.434% of variance explained includes two strongly interrelated variables: Initial investment and capital cost, and uncertainty in estimating financial benefits of smart technologies. These challenges are grouped under “Financial Challenges” because they both deal with the economic viability and affordability of implementing smart technologies in construction projects. The statistical grouping is conceptually valid as both items revolve around financial decision-making, budgeting risks, and return on investment (ROI) concerns, key considerations for construction firms when assessing any new innovation.

The first challenge, initial investment and capital cost, is a direct deterrent for many construction companies, especially small and medium-sized enterprises (SMEs), when considering the adoption of smart technologies. These technologies often require substantial upfront spending on hardware (e.g., sensors, drones, RFID devices), software licenses (e.g., BIM platforms, AI tools), training programs, and IT infrastructure upgrades. For firms operating on tight profit margins, these costs can be prohibitive. As highlighted by

Gledson and Greenwood (2017), many construction stakeholders view smart technologies as cost-intensive with uncertain payback, leading to delayed or avoided adoption. The perceived high capital cost becomes even more of a burden in developing countries, where financing and credit support are less accessible.

The second challenge, Uncertainty in estimating the financial benefits of smart technologies, compounds the problem. Even if the investment capital is available, companies may hesitate due to the difficulty in forecasting measurable returns. Smart technologies promise indirect or long-term benefits such as increased productivity, reduced rework, better project control, and safety enhancements, but quantifying these gains in advance is often complex. There is a lack of standardized metrics or industry benchmarks that clearly demonstrate cost-savings over time. According to Olatunji (2020), the inability to model or predict ROI with certainty limits executive confidence in approving smart tech investments. This uncertainty becomes even more critical in competitive bidding environments, where short-term cost efficiency often outweighs long-term innovation.

These two variables form a risk-reward paradox: high costs upfront, but uncertain benefits later. This justifies their grouping as a distinct factor, they are two sides of the same coin. The capital cost represents the risk, and the inability to measure outcomes represents the lack of reward clarity. Both significantly affect the economic feasibility of smart technology adoption.

4.11.4 Comparison among Different Country

The table 4.10 presents a comparative analysis of challenges faced by six different countries, namely Ghana, United Kingdom, Australia, Germany, India, and China, in implementing smart technologies in construction project management. These challenges are grouped into five categories, as derived from the factor analysis test: financial, implementation, technological, societal, and organizational (Ghansah et al., 2020; Ahuja et al., 2020). Ghana, a developing country, primarily struggles with financial, implementation, technological, and organizational challenges, reflecting common issues such as limited funding, inadequate infrastructure, and a shortage of skilled personnel (Abdulai et al., 2023). Despite being developed nations, both the United Kingdom and Australia experience all five categories of challenges, indicating that even advanced economies face obstacles such as societal resistance, integration complexity, and organizational inertia (Oyedira and Oke, 2020; Forsythe, 2022). Germany appears to be the most prepared, facing only organizational challenges. This suggests that while the country has overcome financial and technological barriers, internal structural issues may still hinder full adoption (Marzouk et al., 2022). Meanwhile, India and China, as rapidly developing economies, encounter a mix of implementation, technological, and societal challenges, highlighting common difficulties in digital readiness and public acceptance during transitional development stages (Dharani and Suresh, 2021; Xia et al., 2020).

In comparison, the present study focusing on Malaysia identifies twenty key challenges in implementing smart technologies, which have been categorized through factor analysis and assessed across three main stakeholder groups: developers, consultants, and contractors. Notably, the findings from this research reveal that, unlike previous studies conducted in other countries which often highlight challenges limited to only a few specific categories, Malaysia is the only context where challenges span across all five major categories of barriers, namely technological, organizational, environmental, individual, and project-related. This indicates a broader and more complex spectrum of implementation issues, including inefficiencies in execution, inadequate technological infrastructure, and societal resistance associated with digital literacy and workforce adaptation. These findings highlight the urgent need for comprehensive strategic planning, active stakeholder engagement, and robust policy support to ensure the successful integration of smart technologies. Positioned uniquely between developing and developed economies, Malaysia is well placed to draw insights from both contexts and apply a balanced and context-sensitive approach to effectively address these multifaceted challenges.

Table 4.10: Comparison with Previous Studies from Different Countries

Countries	Challenges	C1	C2	C3	C4	C5
	Journal / Author	Financial Challenges	Implementation Challenges	Technological Challenges	Societal Challenges	Organization Challenges
Ghana	(Ghansah et al., 2021)	x		x		x
United Kingdom	(Shojaei and Burgess, 2022)		x	x	x	x
Australia	(Chaaya et al., 2025)	x			x	x
Germany	(Schnell et al., 2022)		x			x
India	(Prasad et al., 2023)		x	x		
China	(Zhang et al., 2023)	x	x		x	

4.12 Summary

This study examined smart technology adoption in Malaysia's construction sector through survey responses from 110 professionals (34.43% response rate). Statistical analysis using Shapiro-Wilk tests confirmed non-normal data distribution ($p=0.01$), prompting the use of non-parametric methods, while Cronbach's alpha verified strong internal consistency ($\alpha>0.7$) across all measures. The findings reveal distinct technological specializations, with BIM emerging as the coordination backbone (65 votes, 13.5%), prefabrication/modular construction leading in cost management (60 votes, 24%), robotics dominating efficiency (85 votes, 28.3%), GIS excelling in monitoring (90 votes, 30%), and AR/VR optimizing stakeholder communication (80 votes, 21.3%). Three primary adoption barriers were identified: financial constraints (initial costs), organizational factors (company size), and workforce limitations (skill gaps), which correlate strongly ($\rho=0.35$-0.42) with recommended solutions including government incentives, training programs, and strategic implementation plans. Factor analysis further categorized 20 challenges into five key dimensions: implementation, technological, organizational, societal, and financial barriers. These results demonstrate that while smart technologies offer specialized benefits, their successful implementation requires addressing multidimensional challenges through targeted financial support, workforce development, and organizational readiness initiatives tailored to Malaysia's construction ecosystem. The consistent patterns across analytical methods - from mean rankings to correlation and factor analysis - strengthen the validity of these findings for both practitioners and policymakers seeking to accelerate digital transformation in construction.

CHAPTER 5
CONCLUSION

5.1 Introduction

This chapter concludes the study by summarizing the findings in relation to the previously stated research aim and objectives. It also discusses the implications and limitations of the research. Finally, the chapter offers several recommendations to guide and enhance future studies on related topics.

5.2 Conclusion

In summary, the integration of smart technologies marks a critical turning point in the transformation of the global construction industry. While global leaders such as China, the U.S., and the U.K. have demonstrated rapid progress in adopting Construction 4.0 tools, Malaysia's adoption rate remains relatively low despite ongoing policy support and increasing investments in infrastructure. Although initiatives like the National Construction Policy 2030 signal a national ambition to modernize the sector, the actual implementation of smart technologies in local projects is still limited in scale and effectiveness.

The slow uptake in Malaysia can be attributed to a combination of financial, technical, and human capital barriers. High initial investment costs continue to be a major deterrent for many industry players, especially small and medium-sized firms. Additionally, a shortage of skilled labor and inadequate training have made it difficult to fully utilize smart technologies even when available. Integration challenges with legacy systems, lack of awareness, and organizational resistance to change further complicate the transition process.

Addressing these issues requires a comprehensive and multi-pronged strategy. First, financial incentives and government-backed support programs are essential to reduce entry barriers and encourage broader industry participation. Second, structured training and capacity-building initiatives must be implemented to develop a digitally literate construction workforce capable of handling emerging technologies. Third, creating clear and realistic implementation roadmaps can provide the necessary guidance for firms navigating the complex shift from conventional to digital practices. Long-term collaboration between academia and industry also plays a pivotal role in generating local expertise and fostering innovation tailored to the Malaysian context.

Ultimately, while Malaysia's construction industry shows great potential for digital advancement, realizing this potential will depend on how effectively stakeholders can overcome these systemic challenges. Strategic alignment between government policies, private sector readiness, and workforce development will be key to ensuring that smart technology adoption becomes not just a trend, but a standard in the country's construction landscape.

A thorough literature review was conducted, leading to the identification of 12 potential smart technologies, 20 challenges, and 12 strategies. Based on these findings, a structured questionnaire was developed as the primary data collection instrument for a field survey. This survey targeted construction professionals across various disciplines, developers, consultants, and contractors within the region of Malaysia. A total of 110 valid responses were collected and analysed using suitable statistical methods. Each variable was then ranked and prioritized according to its mean score. Last but not least, the study successfully fulfilled its research objectives, which are summarized below.

Objective 1:

The first objective of this study was to investigate the application of smart technologies in the management of time, cost, and quality in construction projects. The findings confirm that challenges related to time delays, cost overruns, and quality defects remain critical concerns in the Malaysian construction industry. These issues are consistent with global industry trends, where projects often suffer from poor planning, inaccurate budgeting, and inadequate quality control. The analysis of respondent feedback revealed that all twelve identified smart technologies achieved mean scores above 3.5, indicating widespread agreement among professionals that these tools hold considerable potential to improve project outcomes. Among the technologies assessed, Building Information Modeling (BIM) emerged as the most highly rated across all three stakeholder categories, developers, consultants, and contractors, demonstrating strong consensus regarding its value. BIM is recognized for its ability to integrate design, scheduling, and cost data into a centralized platform, which enhances coordination, reduces errors, and supports real-time decision-making throughout the project lifecycle. This comprehensive functionality makes BIM especially effective in addressing the “iron triangle” of project constraints, time, cost, and quality. The strong alignment across the different professional groups further validates BIM's practical relevance and applicability in the Malaysian context. Therefore, this objective confirms that while challenges remain, the adoption of smart technologies, particularly BIM, represents a viable solution to improve construction project performance.

Objective 2:

The second objective of this study was to explore the challenges in implementing smart technologies in construction project delivery. Through the analysis of twenty identified challenges, it became evident that a range of financial, organizational, and technical barriers influence stakeholders’ willingness and ability to adopt smart technologies. Among these, financial constraints emerged as the most significant, with high initial investment costs and capital requirements consistently ranked at the top. This finding reflects a well-known concern within the Malaysian construction industry, where tight budgets, limited cash flow, and risk aversion, particularly among SMEs, often hinder the pursuit of technological innovation.

To gain deeper insights, a factor analysis was conducted to categorize the 20 challenges into broader thematic groups based on patterns in the responses. This analysis revealed five key challenge categories: financial challenges, societal challenges, implementation challenges, technological challenges, and organizational challenges. Each group represents a cluster of interrelated barriers that shape industry stakeholders’ adoption decisions. Notably, the financial factor was the most dominant, reinforcing that cost-related issues form the most pressing concern for the industry. The technological and implementation challenges such as integration complexity, lack of technical expertise, and compatibility issues were also significant, indicating the need for both funding and technical support.

These findings are crucial as they not only identify the most influential obstacles but also provide a structured understanding of the challenge landscape, enabling more targeted and strategic interventions. By revealing the underlying factors behind low adoption rates, the study equips policymakers and industry leaders with a clearer direction for promoting smart technologies such as introducing financial aid programs, improving digital infrastructure, and fostering collaboration with technology providers and academia. In conclusion, understanding and categorizing these challenges is a necessary step toward overcoming them, paving the way for a more technologically advanced and competitive construction sector in Malaysia.

Objective 3:

The third objective of this study was to recommend strategies for adopting smart technologies in the construction industry, particularly in response to the challenges identified earlier. Among all proposed strategies, "Government support and financial incentives" emerged as the most critical and effective, especially in addressing the industry's most significant barrier, the high initial investment cost and capital requirement. The results reinforce that without strong financial backing, many construction firms in Malaysia, particularly SMEs, are unlikely to adopt smart technologies despite understanding their long-term benefits. Government grants, tax reliefs, and public-private partnerships could serve as powerful enablers to ease the financial burden and encourage digital transformation across the sector.

Furthermore, the Spearman's correlation analysis revealed that both "Government support and financial incentives" and "Integration with existing systems" had the highest number of significant correlations with the identified challenges. This finding is important because it reflects not only the financial dimension but also the technical practicality of technology adoption. Integration with existing systems helps reduce resistance to change and minimizes operational disruptions, making the transition to smart technologies more feasible and less risky. It ensures that new technologies are not only affordable but also compatible with the current workflow, improving acceptance among contractors and consultants.

These results demonstrate that a dual focus on financial enablers and technical compatibility is key to overcoming adoption barriers. Therefore, any national or organizational strategy aimed at accelerating smart technology implementation should prioritize these two areas. With targeted support and thoughtful system integration, Malaysia's construction industry can move toward a more innovative, productive, and sustainable future.

5.3 Research Implication

This research makes a significant theoretical contribution by enhancing the understanding of smart technology adoption within the context of construction project management in Malaysia. It extends existing frameworks such as the Innovation Diffusion Theory and the Technology Acceptance Model by applying them to the Malaysian construction industry, thereby validating their relevance in a developing country context. Through empirical data, the study offers new insights into how technological, organizational, and environmental factors interact to influence adoption behavior among construction stakeholders. By identifying the perceived benefits, challenges, and strategic considerations associated with various smart technologies, the research also contributes to the development of an integrated model that future scholars can build upon when studying digital transformation in the construction sector.

From a managerial perspective, the study offers practical guidance for construction professionals and decision-makers. It highlights the specific smart technologies that are currently associated with improved project performance, such as enhanced coordination, better cost estimation, and increased operational efficiency. These findings can inform investment decisions and help firms prioritize the adoption of technologies that align with their organizational goals.

Additionally, by revealing the main barriers to adoption, including limited technical expertise, budget constraints, and resistance to change the research equips managers with the knowledge needed to develop targeted strategies for successful implementation. This can include actions such as investing in workforce training, engaging in pilot projects, or collaborating with technology providers.

Overall, this study contributes meaningfully to the construction industry by providing a foundational understanding of the current landscape of smart technology adoption in Malaysia. It offers both theoretical and empirical insights that can guide the development of more responsive and effective digital strategies. The findings can assist construction firms in benchmarking their current practices, aligning their technological efforts with industry trends, and supporting the broader goal of advancing Malaysia's construction sector towards greater innovation and digitalization in line with national development agendas.

5.4 Research Limitation

This research provides timely and valuable insights into the application of smart technologies in construction project management. However, like any study, there are certain limitations that may influence the depth and generalizability of the findings. These limitations do not undermine the value of the research but rather highlight areas for further exploration in future studies. The data collection was conducted using a structured quantitative approach via Google Forms. While this method enabled broad participation from professionals across various regions in Malaysia, it may not fully capture the underlying reasons behind stakeholder perceptions or the contextual nuances of technology adoption. To complement the strengths of the quantitative approach, future research may consider incorporating qualitative methods such as interviews or focus group discussions. This would allow for a deeper understanding of real-world experiences, organizational culture, and decision-making dynamics.

Another consideration is the breadth of the study scope. The research examined multiple types of smart technologies and involved various professional groups including developers, consultants, and contractors. While this broad perspective offers a comprehensive overview of the current landscape, a more focused investigation on a specific technology or stakeholder group could provide more detailed and practical insights. For example, future studies might focus solely on Building Information Modeling (BIM) or the Internet of Things (IoT), or explore implementation strategies among small and medium-sized firms.

In addition, the study did not segment responses based on factors such as company size, project type, or market specialization. These factors may influence the readiness, capability, and approach of organizations in adopting smart technologies. Future research that includes such segmentation could provide a clearer understanding of the specific challenges and opportunities faced by different categories of firms.

Furthermore, the study did not explicitly examine which phases of the project management lifecycle such as design, planning, execution, monitoring, or closure would benefit most from smart technology implementation. This could have provided more targeted insights into where specific technologies have the greatest impact. Addressing this gap would help construction firms allocate resources more strategically during different stages of a project.

Finally, the research represents a cross-sectional snapshot of current practices and perceptions. As technology adoption is a dynamic and evolving process, a longitudinal study design could offer greater insight into how adoption patterns develop over time. This would be especially useful for evaluating the long-term effects of national policies and digital transformation initiatives in the Malaysian construction industry.

In summary, while this study contributes meaningfully to the understanding of smart technology adoption, future research could enhance its impact by adopting a more diversified methodology, a narrower scope, and a more segmented and longitudinal approach. These enhancements would further support the ongoing development of strategies and policies that promote innovation in the construction sector.

5.5 Recommendations for Future Work

This research offers valuable insights into the application of smart technologies in construction project management in Malaysia. Based on the findings, several recommendations can be made to improve current practices and support more effective implementation of smart technologies across the industry.

Firstly, project managers should prioritize the integration of smart technologies that directly address recurring project challenges such as delays, cost overruns, and poor coordination. Tools like Building Information Modeling (BIM), real-time monitoring systems, drones, and Internet of Things (IoT) applications have demonstrated significant benefits in improving project coordination, enhancing cost control, and increasing efficiency. Project managers are encouraged to embed these technologies into their project workflows early in the planning and design stages to maximize impact.

Secondly, organizations should invest in training programs to build digital capabilities among their project teams. Resistance to change and lack of technical knowledge were found to be key challenges in technology adoption. By equipping professionals with the necessary skills and knowledge, project managers can ease the transition and foster a culture that embraces innovation. Thirdly, construction firms should develop a structured implementation strategy that includes stakeholder engagement, clear digital transformation goals, and alignment of smart technologies with project-specific objectives. Project managers play a key role in bridging the gap between technical teams and organizational leadership. Strong leadership in change management is essential to ensure smooth integration and minimize disruptions.

In addition, collaboration with technology providers and government bodies should be strengthened. Project managers should advocate for participation in public-private initiatives that offer funding support, shared resources, or pilot programs. Leveraging such support mechanisms can help reduce financial burdens and facilitate smoother adoption, particularly for small and medium-sized firms.

Moving forward, future studies can expand upon this research to further enhance its practical applicability. Although this study gathered quantitative data from a diverse group of practitioners across Malaysia, incorporating qualitative methods such as interviews or focus group discussions would provide deeper insights into stakeholder experiences and organizational behaviors. A mixed-methods approach would allow researchers to better understand how and why decisions around smart technology adoption are made. Future research could also narrow the scope to focus on specific technologies or project objectives. By doing so, it would be possible to conduct more detailed analyses and generate tailored recommendations for different segments of the industry. For instance, examining the role of automation in cost control or the impact of BIM on coordination could yield practical implementation models.
Segmenting the data by company size, project type, or market specialization could also uncover unique challenges and opportunities. Small firms may experience different barriers than larger ones, and identifying these variations would enable more targeted support strategies. Future studies should investigate which specific stages of the project management cycle (e.g., design, execution, monitoring) most require smart technology intervention. This can help firms deploy the right tools at the right time, improving resource efficiency and maximizing project outcomes.

Lastly, a longitudinal research design is recommended to observe the evolution of smart technology adoption over time. This would be especially useful in tracking the effectiveness of government policies like the National Construction Policy 2030 and assessing the maturity of digital transformation in the sector.

In summary, this study offers a foundation for improving smart project management practices in Malaysia. Through strategic adoption, continuous training, and strong leadership, project managers can drive digital transformation and enhance construction performance. At the same time, future research should aim to deepen the understanding of implementation dynamics and develop more targeted, context-sensitive solutions for the industry.

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APPENDIX : Questionaaire

Application of Smart Technologies in Construction Project Management

Dear Sir or Madam,

Good day to you, I am Chua Kah Ling, a final year student of Bachelor of Science (Hons) Quantity Surveying, from Lee Kong Chian Faculty of Engineering and Science (LKC FES) of Universiti Tunku Abdul Rahman (UTAR). I am conducting a research for my Final Year Project which titled " Application of Smart Technologies in Construction Project Management", with the supervision of Ir. Ts. Dr. Jeffrey Yap Boon Hui.

Criteria need to be fulfilled to participate in this survey:
i. Currently working in the Construction Industry

The objectives of this research are:

i. To investigate the application of smart technologies in the management of time, cost, and quality in construction projects.
ii. To explore the challenges in implementing smart technologies in construction project delivery.
iii. To recommend strategies in adopting smart technologies in the construction industry.

This questionnaire consists of four sections and is designed to be completed within 15 minutes.
Section A: Demographic Information

Section B:

Assessment of Awareness, Implementation, and Benefits of Smart Technologies in Construction Project Management
Section C: Challenges in Adopting Smart Technologies in Construction Projects
Section D: Strategies for Effective Implementation of Smart Technologies in Construction Companies

Your participation is highly appreciated. Your responses will be kept confidential and used for academic purposes.
If you have any questions about this survey, please do not hesitate to contact me at chuakahling@1utar.my through email.
Thank you for your kind corporation and participation.

Regards,
Chua Kah Ling

Section A

Demographic Information

1. 1. Which of the following best classifies your organisation?

Mark only one oval.

- ⬭ Developer/Client
- ⬭ Consultant
- ⬭ Contractor

2. 2. Which of the following best described your profession?

Mark only one oval.

- ⬭ Architect
- ⬭ Civil & Structural Engineer
- ⬭ Mechanical & Electrical Engineer
- ⬭ Quantity Surveyor
- ⬭ Construction Management
- ⬭ Other: ____________________

3. 3. What is your position in your organisation?

Mark only one oval.

- ⬭ Executive
- ⬭ Manager
- ⬭ Senior Manager
- ⬭ Director / Top Management
- ⬭ Other: ____________________

4. 4. How many years of working experience do you have in the construction industry?

Mark only one oval.

- < 5 years
- 5 - 10 years
- 11-15 years
- 15 - 20 years
- > 20 years

5. 5. What is your highest academic qualification?

Mark only one oval.

- High School (e.g. SPM, STPM)
- Diploma
- Bachelor's Degree
- Postgraduate Degree (PhD, Master's Degree)

6. 6. Do you believe the adoption of smart technologies (such as Building Information Modeling (BIM), Artificial Intelligence (AI), Internet of Things (IoT), robotics, and automation) will contribute to improvements in construction projects?

Mark only one oval.

- Agree
- Disagree

Section B

Assessment of Awareness, Implementation, and Benefits of Smart Technologies in Construction Project Management

7. 1. Have you encountered any of the following issues in your previous construction projects? (You may select more than one option)

Check all that apply.

- [ ] Project Delay
- [ ] Cost Overruns
- [ ] Quality Issues

8. 2. How frequently have you encountered any of the following issues in your projects?

Mark only one oval per row.

	Never	Rarely	Occasionally	Frequently	Always
Project Delay	◯	◯	◯	◯	◯
Cost Overruns	◯	◯	◯	◯	◯
Quality Issues	◯	◯	◯	◯	◯

9. 3. In your opinion, how impactful is the adoption of smart technologies in improving construction project management?

Mark only one oval.

◯ Not at all impactful
◯ Slightly impactful
◯ Moderately impactful
◯ Very impactful
◯ Extremely impactful

10. 4. In your opinion, how significant are the benefits of smart technologies to the overall success of construction projects?

Mark only one oval per row.

	Not critical at all	Slightly critical	Moderately critical	Very critical	Extremely critical
Building Information Modeling (BIM)	⬭	⬭	⬭	⬭	⬭
Drones	⬭	⬭	⬭	⬭	⬭
Internet of Things (IOT)	⬭	⬭	⬭	⬭	⬭
Artificial Intelligence (AI)	⬭	⬭	⬭	⬭	⬭
Augmented Reality and Virtual Reality (AR and VR)	⬭	⬭	⬭	⬭	⬭
Robotics	⬭	⬭	⬭	⬭	⬭
Prefabrication and modular constructions	⬭	⬭	⬭	⬭	⬭
3D Printing	⬭	⬭	⬭	⬭	⬭
Smart Materials	⬭	⬭	⬭	⬭	⬭
Geographic information system	⬭	⬭	⬭	⬭	⬭
Digital Twin	⬭	⬭	⬭	⬭	⬭
Blockchain	⬭	⬭	⬭	⬭	⬭

12. 6. In your opinion, do smart construction technologies significantly provide advantages to your current project?

Mark only one oval per row.

	Building information modeling (BIM)	Drones	Internet of things (IOT)	Artificial intelligence (AI)	Augmented reality (AR) and virtual reality (VR)	Robotics	Prefabrication and modular construction	3D printing	Smart materials	Geographic information system (GIS)	Digital twin	Blockchain
Improved project coordination and collaboration												
Enhanced cost estimation and management												
Increased efficiency and speed												
Enhanced project monitoring and data collection												
High-quality results												
Enhanced monitoring and control in project quality												
Real-time data access												
Accurate cost and schedule prediction												
Improved stakeholder communication												
Accelerating progress by replacing manual labor												
Greater sustainability												
Increased design flexibility and precision												
Enhanced durability of materials												
Streamlined contract management with smart contracts												

13. 1. In your opinion, what is your level of agreement on the following challenges hampering the safety technology adoption in construction projects?

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Initial investment and capital cost					
Uncertainty in estimating financial benefits of smart technologies					
High maintenance cost					
Organization size					
Organization data privacy and IT security					
Skill shortages and training gaps					
Organizational and structural adoption					
Impact of poor network					

Environmental condition					
Outdated and ineffective regulatory frameworks for smart technologies					
Difficulties in attaining effective interoperability					
Existing system interrupt and clash with new smart technologies					
Personal privacy and cybersecurity concerns					
Reluctance to adoption and changes					
Workforce dynamics					
Complexity of smart technologies					

Sustainability integration gap					
Gap between theoretical research and practical implementation					
Fragmented integration					
Data management					

Section D :

Strategies for Effective Implementation of Smart Technologies in Construction Companies

14. 1. In your opinion, do you agree that the mentioned strategies are effective for implementing smart technologies in construction projects?

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
Government support and financial incentives	⬭	⬭	⬭	⬭	⬭
Leverage strategic incentives	⬭	⬭	⬭	⬭	⬭
Engagement of collaborative stakeholders	⬭	⬭	⬭	⬭	⬭
Create a clear strategy to implement smart technologies	⬭	⬭	⬭	⬭	⬭
Provide training and education for employee	⬭	⬭	⬭	⬭	⬭

Raising decision-maker awareness on current technological advances	⬭	⬭	⬭	⬭	⬭
Shift company's organization culture to embrace smart technologies	⬭	⬭	⬭	⬭	⬭
Change individual attitudes towards smart technologies	⬭	⬭	⬭	⬭	⬭
Optimize cost for smart technologies adoption 1 2 3 4 5	⬭	⬭	⬭	⬭	⬭
Boost collaboration between industry and academia	⬭	⬭	⬭	⬭	⬭
Develop a data management plan	⬭	⬭	⬭	⬭	⬭
Integrate smart technologies with existing system	⬭	⬭	⬭	⬭	⬭