EXPLORING THE IMPLEMENTATION OF SMART TECHNOLOGIES IN THE CONSTRUCTION INDUSTRY

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EXPLORING THE IMPLEMENTATION OF SMART TECHNOLOGIES IN THE CONSTRUCTION INDUSTRY

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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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APPROVAL FOR SUBMISSION

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ABSTRACT

As urbanisation continues to surge, the construction industry is grappled with an array of unprecedented economic, environmental, and social challenges. With a heightened awareness of these challenges, the construction industry is compelled to overhaul its current operations by incorporating smart technologies. In spite of this, there has been a paucity of research investigating about the application and adoption level of smart technologies, drivers as well as barriers of its adoption in Malaysian construction industry. As such, this study aims to uncover the potentials of incorporating smart technologies in the Malaysian construction industry. The objectives of this study are to determine the adoption level of smart technologies as well as drivers and challenges influencing its adoption. 10 types of smart technologies, 12 drivers and 13 challenges were identified from literature review. A quantitative approach was employed for this study, whereby online questionnaires were disseminated to the construction practitioners in Selangor and Wilayah Persekutuan Kuala Lumpur (WPKL). 175 responses were collected and analysed using Cronbach's Alpha Reliability Test, Arithmetic Mean, Friedman Test, Spearman's Correlation Test and Kruskal-Wallis Test. The findings revealed that Cloud Computing is highly adopted in Malaysia construction industry. Additionally, the study highlighted that organisational drivers are the primary impetus and economic challenges are the main hindrance to the successful implementation of smart technologies in their projects. Spearman's Correlation test demonstrated that the major drivers and challenges influencing the adoption of smart technologies are associated with organisational aspects. Moreover, this study unveiled that respondents' prioritisation of drivers and challenges associated with the adoption of smart technologies varies based on their social demographics, which includes company business activities, organisational position, working experience and company size. The outcomes of this research serve as a guideline to the policymakers, government agencies, and professional bodies in devising a digital transformation roadmap for the Malaysian construction industry.

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LIST OF SYMBOLS / ABBREVIATIONS

n	sample size
z	z-scores of the desired confidence level
p	the proportion of the population with attributes understudy
q	1-p
e	margin of error

3D Printing	Three-dimensional Printing
3DCP	Three-dimensional Concrete Printing
4IR	Fourth Industrial Revolution
AI	Artificial Intelligence
ANN	Artificial Neural Network
AR	Augmented Reality
B-DAPP	Big Data Accident Prediction Platform
BIM	Building Information Modelling
CIDB	Construction Industry Development Board
CLT	Central Limit Theorem
CO2	Carbon Dioxide
COBie	Construction Operations Building Information Exchange
GDP	Gross Domestic Product
IFC	Industry Foundation Classes
IoT	Internet of Things
ML	Machine Learning
NCP 2030	National Construction Policy 2030
PAM	Persatuan Arkitek Malaysia
PEM	Project Evaluation Model
RFID	Radio-Frequency Identification
SMEs	Small and medium-sized enterprises
SPSS	Statistical Practices for Social Sciences
UAE	United Arab Emirates
UAVs	Unmanned Aerial Vehicles
URL	Uniform Resource Locator
VR	Virtual Reality

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CHAPTER 1

INTRODUCTION

1.1 Introduction

A brief overview of this research is presented, which covers background of study, problem statement, research aim, research objectives, research methods, and research scope.

1.2 Background of Study

Over the decades, the construction industry has been one of the fundamental pillars of a country's economic growth due to its significant contribution to the national Gross Domestic Product (GDP). As reported by the Department of Statistics Malaysia (2022), the construction industry accounted for 3.6% of Malaysia's GDP in the first quarter of 2022. Although the construction industry constitutes less than 5% of the economy, its importance to economic growth cannot be underestimated due to its forward and backward linkages with other sectors (Alaloul, et al., 2021). Despite being the primary stimulus to the country's GDP, the construction industry has lagged behind other industries in terms of quality, productivity, and sustainability (Lee and Park, 2022; Balasubramanian, et al., 2021).

In tandem with burgeoning urbanisation, the exponential growth of the construction activities has swamped the construction industry with a myriad of interrelated economic, environmental, and social issues. Owing to the economic downturn induced by the Covid-19 outbreak, the inconsistent performance of Malaysia's construction sector has brought devastating ripple effects on the nation's economy (Jalil, 2022). Simultaneously, the construction industry has been criticised for activities that precipitate an alarming increase in environmental degradation, waste generation, harmful gas emissions, and depletion of natural resources (Stanitsas and Kirytopoulos, 2021; Bathrinath, et al., 2022). According to Lima, et al. (2021), the construction industry is accountable for 35% of the carbon dioxide (CO2) emissions and 30% of the greenhouse gas emissions globally. Irrespective of the fact that construction operations entail a substantial portion of dicey tasks, the construction industry typically disregards occupational safety and health, rendering it one of the most accident-prone industries (Goel, Ganesh and Kaur, 2019). Over the first quarter of 2022, Singapore's construction industry had the highest incidence of workplace fatalities and injuries, with 10 cases and 84 incidents respectively (The Star, 2022). With heightened awareness of these contemporary challenges, the construction industry is spurred to revamp its operations to be more competitive by leveraging smart technologies.

As Industry 4.0 progresses, the emergence of smart technologies, which range from automated construction to high-level digitisation that integrates virtual space and real construction projects has spawned novel avenues for digitalisation in the construction industry. This is attributed to the innate capability of smart technologies to autonomously oversee, structure, and perform designated tasks (Hwang, Ngo and Teo, 2022). The incorporation of these cutting-edge innovations across all facets of the construction industry will significantly enhance the efficiency of the industry that has been maligned over decades for being sluggish, inefficient, and risky for working. Simultaneously, Forcael, et al. (2020) advocated that digitalisation brought by Industry 4.0 has overcome the construction industry's reliance on human resources and addressed a multitude of dilemmas in the construction industry. In Malaysia, National Construction Policy 2030 (NCP 2030) is established to guide for the local practitioners in adopting smart technologies in their current workflow and process to be more sustainable and competitive (CIDB, 2022).

Since digitalisation facilitates the attainment of competitive advantage, the adoption of smart technologies is regarded as a major turning point in the construction industry. The primary rationale behind this is that smart technologies possess the potential to augment the project outcomes and devise solutions for various longstanding encumbrances, including cost overruns, poor waste management, and high injuries rate, thereby enabling a more effective response to both present and future demands (Gehlot and Shrivastava, 2021). In spite of this, the construction industry is notoriously lethargic in embracing smart technologies (Kissi, Aigbavboa and Kuoribo, 2022). In consideration of the fact that technological innovation is the primary driver of an industry's transition, this research intends to examine in depth the application of smart technologies in the Malaysia's construction industry.

1.3 Problem Statement

Since smart solutions are regarded as the enablers for construction transformation, there is a proliferation of literatures on optimising the construction industry by deploying smart technologies. Olawumi and Chan (2020b), Franco, et al. (2022) and Li, et al. (2022) have provided an overview of leveraging smart technologies, including the definition, applications, prospects and contribution to the industry. Besides, multiple studies have demonstrated that the application of smart technologies spawned by Industry 4.0, such as Building Information Modelling (BIM), Internet of Things (IoT), digital twin, and Three-dimensional (3D) printing will accelerate the construction industry's transition (Schamne, Nagalli and Soeiro, 2022; Ghosh, Edwards and Hosseini, 2021; Sepasgozar, 2021; Valente, Sibai and Sambucci, 2019). These studies indicate that the deployment of smart technologies has a favourable impact on the performance and development of the construction industry. Nevertheless, the scope of these literatures is limited to the adoption of a single technology.

Concomitantly, several studies have been undertaken worldwide to evaluate the implementation of smart technologies in the construction industry. For instance, Olawumi and Chan (2022b) presented a comparison of the adoption of smart technologies in Nigeria and Hong Kong construction industry and established a project evaluation model (PEM) for its implementation. While Balasubramanian, et al. (2021) demonstrated the applicability and usability of Construction 4.0 Sustainability Framework in the United Arab Emirates (UAE) construction industry. Simultaneously, the effectiveness of smart technologies application in the construction industry of China, South Korea, Australia and India was presented in the studies by Zhou, et al. (2023), Choi, Lee and Kim (2021), Teisserenc and Sepasgozar (2021) as well as Bhattacharya and Momaya (2021). Whereas Oke, et al. (2021) have highlighted the advantages of adopting smart technologies to encourage the implementation by Nigerian construction practitioners. Based on these studies, it is notable that the application of smart technologies has been conducted extensively worldwide but not in Malaysian construction industry.

Despite the growing interest in the application of smart technologies in construction industry, there has been a paucity of research investigating about the application and adoption level of emerging smart technologies, drivers as well as challenges of its adoption in Malaysian construction industry. Consequently, this circumstance will hinder the local construction practitioners from maximising smart technologies for resolving the issues that dominate the Malaysian construction sector. In order to bridge the research gap, this research aims to determine the viability of incorporating various types of smart technologies in Malaysian construction industry. As a consequence, it will be capable of maximising the use of smart technologies, while simultaneously advancing toward the goal of smart construction industry.

1.4 Research Aim

This study aims to uncover the potential of incorporating smart technologies in the Malaysian construction industry.

1.5 Research Objectives

In an effort to attain the research aim stated above, the following research objectives are formulated:

1. To explore the adoption level of smart technologies used in the construction industry.

2. To ascertain the drivers of adoption of smart technologies in the construction industry.

3. To discover the challenges of adoption of smart technologies in the construction industry.

1.6 Research Methodology

This study employed a quantitative methodology. A questionnaire was created in Google Forms and circulated to potential construction practitioners using digital means such as email, social media platforms, and LinkedIn in an attempt to enhance the survey's response rate. The data collected was analysed and tabulated using five statistical test, namely Cronbach's Alpha Reliability Test, Arithmetic Mean, Friedman Test, Spearman's Correlation Test and Kruskal-Wallis Test.

1.7 Research Scope

This study was conducted in the states of Selangor and Wilayah Persekutuan Kuala Lumpur (WPKL), Malaysia. Besides, this study was confined to construction practitioners, without constraints on the company business activities, profession, working experience, position, and company size.

1.8 Chapter Outline

This research is divided into five main chapters and the outlined as follows:

As the introductory part of the entire research, Chapter 1 presents a concise overview of the study, including the background of study, problem statement, research aim and objectives, research methodology, research scope, as well as outline of the chapter.

Chapter 2 thoroughly reviews the the literature, synthesising previous research conducted by other researchers. It delves into the elemental definition of the research area and evaluates the potentials of incorporating smart technologies in the Malaysian construction industry.

Chapter 3 outlines the research methodology to accomplish the research aim and objectives. It encompasses the research method and its selection rationale, sampling design, approaches to data collection, and data analysis techniques.

Chapter 4 demonstrates the interpretation of the data acquired from questionnaires survey and the outcomes of the corresponding analysis. The findings are then evaluated with respect to the research aim and objective to accomplish the overarching research goal.

Chapter 5 sums up the overall research findings, covering the realisation of research objectives and research contributions. Further, the limitations confronted throughout the research are acknowledged and conceivable recommendations for future research are provided.

1.9 Summary of Chapter

To summarise, a research gap is identified subsequent to an in-depth review of the research area’s background. The research gap emphasises the significance of conducting research aimed at assessing the adoption level of smart technologies, as well as identifying the drivers and challenges of leveraging smart technologies in the Malaysian construction industry. Further, the research aim and research objectives are formulated to bridge the research gap. In addition, the methodology employed, the scope of research, and the chapter outline were discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter examines existing literatures and previous research undertaken by other researchers. It begins with a brief introduction to smart technologies and benefits of leveraging smart technologies in the construction industry. By reviewing the previous related studies, the type of smart technologies used as well as its adoption level in the construction industry are explored and discussed. Furthermore, this chapter entails the drivers and challenges of smart technologies adoption in the Malaysian construction industry.

2.2 Smart Technologies in the Construction Industry

In recent years, the construction industry has undergone significant technological advancement driven by the Fourth Industrial Revolution (4IR). This revolution is distinguished by the emergence of smart technologies that possess the capacity to revolutionise conventional construction practices. According to Kozlovska, Klosova and Strukova (2021), smart technologies is defined as a sophisticated set of information and communication technologies (ICT) that enables the collection, storage, computation, presentation, communication and integration of data. Besides, smart technologies is positioned at the heart of technological innovation due to their ability to transform the existing construction workflows (Kissi, Aigbavboa and Kuoribo, 2022). As a result, smart technologies possess a vast array of applications that facilitate their fusion with diverse processes throughout the project life cycle.

In general, smart technologies can be sorted into five distinct categories based on their respective functions, namely data acquisition technologies, data analytics technologies, data visualisation technologies, communication technologies, and construction automation technologies (Chen, et al., 2022). Initially, the smart technologies that facilitate data acquisition comprise IoT, Drones, Radio-Frequency Identification (RFID), Photogrammetry, and so forth. These smart technologies have effectively addressed compromised precision and time lags associated with conventional data acquisition techniques for monitoring and tracking construction progress (Silverio-Fernández, et al., 2021). Given the construction sector's data-intensive nature, the deployment of smart technologies such as Artificial Intelligence (AI) and big data is crucial for effective data analytics due to their capacity to handle vast amounts of data (Munawar, et al., 2022). This will improve the ability to handle data effectively, enabling the construction stakeholders to make real-time and informed decisions.

Moreover, BIM, Augmented Reality (AR), and Virtual Reality (VR) are classified as technologies that support data visualisation. To clarify further, these smart technologies provide a more comprehensive overview of the construction process in a simulated environment (Ibrahim, et al., 2022). This will facilitate the stakeholders in acquiring a more profound understanding of the project, specifically in the project planning and design stages. As a means to optimise the efficiency of planning, designing, and monitoring process, there is a growing trend to integrate visualisation technologies either with each other or with data acquisition technologies (Chen, et al., 2022). In addition, cloud computing serves as an instance of technology for communication that facilitates collaboration of project teams both on-site and off-site. This is exemplified by its ability to resolve coordination and communication issues arise during the Covid-19 pandemic where physical meetings and site visits were restricted (Elrefaey, et al., 2022).

Last but not least, robotics and three-dimensional concrete printing (3DCP) are examples of smart technologies that automate construction processes. These smart technologies has the potential to substantially alter existing construction techniques, particularly in terms of workers extent, and processes (Kim, et al., 2022). This will improve the performance on-site, which will ultimately result in the optimization of worker safety, the improvement of construction operation efficiency, and the deliverance of exceptional outcomes. Nevertheless, the current application of automation technologies in the construction industry is relatively nascent in comparison to other categories of smart technologies (Chen, et al., 2022).

2.3 Benefits of Using Smart Technologies in the Construction Industry

In essence, smart technologies serve as a catalyst to instigate the construction industry’s transformation. This stems from the fact that smart technologies have the ability to provide a multitude of benefits for various facets of the construction industry, spanning from time management, cost management, communication management, safety management, and quality management.

First and foremost, smart technologies are pivotal in optimising project time management. Time management is vital to avert dire outcomes such as liquidated damages. During the project planning stage, smart technologies have the ability to generate an automated schedule that entails the creation of construction tasks, calculation of activity durations and application of sequencing rules (Chen, et al., 2022). This timeline permits for the estimation of project duration and the allocation of project resources. Subsequently, material estimation may be derived from the digital model, allowing just-in-time purchasing and inventory optimization (Zhu, et al., 2022). Consequently, the project is anticipated to be completed within the scheduled timeline and with minimal wastage of materials.

Besides, cost management, which is the primary focus of the entire project can be enhanced. With the availability of a digital model and design alternatives developed by smart technologies, it is feasible to estimate the project budget during the inception phase. In view of this, Zhu, et al. (2022) have posited that the vast amount of data garnered through smart technologies has the potential to augment the accuracy of budget planning and cost estimation. This will in turn enhance the efficiency of cost consultants as it reduces the time required to prepare project cost estimates compared to conventional methods. Further, Balasubramanian, et al. (2021) revealed that smart technologies will enable designers to simulate multiple eventualities. This has significantly reduced the likelihood of costly design modifications and rework in subsequent project phases. Indeed, smart technologies can monitor cost overruns and ensure projects are completed within budget.

Moreover, the adoption of smart technologies will result in a refinement in communication and collaboration between stakeholders, which is crucial for construction projects that have multi-party nature (Silverio-

Fernández, et al., 2021). Chen, et al. (2022) highlighted that smart technologies could foster digital collaboration between on-site workers and office personnel by offering an open platform for efficient sharing of files, data, and information. This implies that the entire project team can monitor and control the construction process in real-time, regardless of their physical location (Ibrahim, et al., 2022). Consequently, the likelihood of conflict will reduce as valuable project information is exchanged effectively from time to time over the project lifecycle.

Furthermore, the deployment of smart technologies is imperative for enhancing the construction industry's health, safety and risk management. According to Bai, et al. (2020), implementing smart technologies will culminate in a transition from labor-intensive processes to innovation-supported operations. This will eliminate high-risk tasks and expedite up the building process, facilitating the project's timely completion. Further, smart technologies can provide hazard identification and alerts as well as real-time monitoring at dynamic and complex construction site environments (Turner, et al., 2021). As a result, the fatality rate will reduce, as hazards may be detected promptly, and safety managers can make informed decisions in situations of imminent danger. Hence, regular health, safety, and risk monitoring can reduce construction site downtime caused by injuries or fatalities, shifting the construction industry from a high-risk to a low-risk industry.

Apart from that, smart technologies are able to augment project quality management. In construction projects, quality control is essential for preventing defects that incur costly replacement costs, such as wall deformation and cracks in the deliverables. Luo, et al., (2022) averted smart technologies can facilitate the detection and evaluation of quality defects while compensating for the fallibility of human judgement based on visual observation. In a similar vein, Zhu, et al. (2022) contended that smart technologies have the capability to predict potential quality issues, such as defects, and identify the underlying causes of these problems to enhance quality control. Consequently, quality issues can be addressed in a timely and precise manner, resulting in a construction project that adheres to the client's requirements with minimal quality-related problems.

In short, it is evident that the construction industry has profoundly benefited from technological advancement. Specifically, the incorporation of smart technologies has offered untapped possibilities to enhance the functionality, efficiency, and productivity of the construction industry which has encountered a decline in efficiency over the past few decades. Nevertheless, the worldwide construction sector has yet to fully embrace smart technologies, which is partly attributed to the industry's fragmented nature (Hwang, Ngo and Teo, 2022). Thus, considerable efforts are necessary from all construction stakeholders, both external and internal, to maximise the adoption of smart technologies.

2.4 Types of Smart Technology Used in the Construction Industry

In the following subsections, the smart technologies that are commonly adopted in the construction industry are elucidated extensively.

2.4.1 Building Information Modelling (BIM)

BIM, also known as n-D modelling, is a digital simulation process that provides the physical and functional attributes of a building (Hyarat, Hyarat and Kuisi, 2022). The building information model includes precise geometry and pertinent data relevant to all stages of construction, thereby serving as a basis for well-informed decision making (Begić and Galić, 2021). Besides, the fundamental essence of BIM pertains to the facilitation of information integration and collaboration among the various stakeholders involved in a construction project (Ahmed, 2019). Thus, BIM has offered the construction stakeholders with a greater insight to plan, design, execute and oversee a project in an efficient manner, leading to an escalation of the their productivity and work quality.

Several researchers have recently demonstrated that BIM may facilitate construction processes (Reizgevičius, et al., 2018; Santos, et al., 2019; Al-Hattab, 2021; Olanrewaju, et al., 2022). As a visualisation tool, BIM empowers unparalleled project visibility amongst project stakeholders during the planning stage (Eldeep, Farag and El-hafez, 2022). As such, potential issues such as design deficiencies, faulty schedules and unrealistic budgets can be detected and rectified prior to the actual execution of the work on-site.

Further, BIM's capabilities are enhanced by adding multidimensional capacities, which enable the execution of an endless number of models. Srivastava, et al. (2022) asserted that seven-dimensional (7D) BIM comprises the incorporation of pertinent sustainable designs and practices in building projects to minimise carbon footprint, whereas eight-dimensional (8D) BIM strives to provide construction site safety and security. Alternatively, Sepasgozar, et al. (2022) alluded that five-dimensional (5D) BIM model can be utilised to monitor, anticipate and regulate the project cost throughout the project life cycle. Undoubtedly, BIM is capable of enhancing efficiency across the various phases of a construction project.

2.4.2 Blockchain

Blockchain is a distributed database containing interconnected blocks of data that are cryptographically safeguarded against tampering (Sanka, et al., 2021). The application of blockchain in the construction industry is commonly observed in the realm of cost management, with the intent of streamlining the transactions among diverse entities engaged in the industry. The unique attributes of blockchain technology comprise decentralisation, security, immutability, disintermediation, auditability, transparency and traceability (Perera, et al., 2020). With these capabilities, blockchain has the potential to address the issues regarding trust, transparency, data traceability, and record-keeping throughout the project lifecycle.

Primarily, the adoption of smart contracts, which are automated contracts that operate on blockchain technology in a decentralized manner, has the potential to reduce the expenses associated with the formulation, negotiation, and enforcement of construction project agreements as well as requirement of trusted intermediaries (Li, Greenwood and Kassem, 2019). This will translate into substantial cost savings and eradicate the necessity for printed documentation, thereby reducing resource consumption. Further, Oke, et al. (2022) adduced that blockchain-based payment automation through smart contracts has the potential to streamline payment process in construction projects. This can be achieved by facilitating periodic payments to contractors based on pre-established terms and conditions for the work completed. As such, this will enhance the transparency of stakeholders and reduce the possibility of payment-related controversies among construction professionals that may compromise the achievement of project objectives. Moreover, the ability of smart contracts to streamline duties across disciplines enables all project stakeholders to concur on construction-related contract processes, which in turn improve collaboration (Celik, Petri, Barati, 2023). Indeed, smart contracts play an important role in expediting the automation of the construction process.

2.4.3 Cloud Computing

Cloud computing is defined as a framework that allows on-demand remote access to a common pool of resources with the availability of high-speed Internet (You and Feng, 2020). Unlike the conventional storage model, cloud computing outsources data storage and processing to eliminate the dependency on local hardware (Srivastava, et al., 2022). As such, the user has real-time access to the data stored over the internet from any device with minimum administrative effort. Google Drive, Microsoft 365, and Dropbox are instances of cloud computing that are extensively utilised in the construction industry for various purposes such as communication, data management, data syncrhonisation and file sharing.

Through the capabilities facilitated by a cloud-based system, the project stakeholders from different physical locations can collaborate seamlessly on a shared task by exchanging information and making real-time decisions (Newman, et al., 2021). This will significantly enhance the efficiency of the project stakeholders, while fostering greater coordination and cohesion among the team members. In addition, the application of cloud computing does not necessitate substantial up-front costs, as sophisticated software and hardware are not required (Kissi, Aigbavboa and Kuoribo, 2022). Simultaneously, cloud computing offers economical and adaptable means to facilitate business operations through the pay-per-use pricing model, which determines payment based on the actual utilisation of cloud storage (Kineber, et al., 2022). Apart from that, Bello, et al. (2021) has collated the effectiveness of present cloud computing applications in construction waste minimisation, safety, energy management, supply chain management and project management. As such, the future of the construction industry greatly depends on cloud computing since cost reduction, time savings, better data-driven decision making, and profit margin expansion may be realised.

2.4.4 Three-dimensional Concrete Printing (3DCP)

As the name implies, 3DCP is a sort of additive manufacturing that fabricates physical structures from digital models by depositing successive layers of cementitious mixture (Mohan, et al., 2022). This implies that 3DCP has higher geometric flexibility than conventional reinforced concrete construction, which is sculpted by formwork (Batikha, et al., 2022). Therefore, 3DCP can fabricate structures with customised and complex designs, such as curved shapes, as well as enable the construction of buildings in a single phase. Undoubtedly, 3DCP will offer architects and engineers novel design possibilities.

Numerous studies have demonstrated the significance of leveraging 3DCP in the construction industry. For conventional reinforced concrete (RC) construction, Paul, et al. (2018) revealed that the overall cost of formwork materials and labour accounted for more than 50% of the project costs. In contrast, adopting 3DCP will result in substantial construction cost savings as it does not require conventional formworks and utilises fewer resources (Han, et al., 2021). Apart from that, 3DCP has also led to a radical shift in labour structures and an improvement in the health and safety of site personnel owing to the automation in construction processes (Rouf, et al., 2022; Kaszyńska, Skibicki and Hoffmann, 2020). This will in turn lead to time savings, improved productivity, and an enhancement in the final product's quality. Additionally, several studies asserted that the adoption of 3DCP will minimise material waste in the form of excess cement and aggregates (Olsson, et al., 2021). This is due to the fact that 3DCP allows for the recycling of materials in the subsequent iterations of additive construction. Evidently, 3DCP has offered infinite economic, environmental, and social advantages, making it as a viable alternative to conventional RC.

2.4.5 Internet of Things (IoT)

IoT appertains to internetworking of devices that transmit, share and, exploit data from the physical environment to the digital realm (Srivastava, et al., 2022). Primarily, IoT comprises three core components, including sensors and actuators for data gathering, internet and other communication systems for connectivity, as well as a processor for data processing (Starr, et al., 2021). To date, IoT has brought added value to the construction industry, by enabling access to real-time data and facilitating ad hoc decision-making, which has resulted in substantial cost and time savings.

In view of the prevalence of workplace injuries and fatalities, IoT devices such as sensors can be incorporated into site machinery and equipment to automate the real-time safety monitoring and hazard identification of construction sites (Tabatabaee, et al., 2022; Yeo, Yu and Kang, 2020; Wang, et al., 2022; Zhou, Yang and Yang, 2019). Srivastava, et al., (2022) further propounded that sensors can also identify severe settings or hazardous areas and set alarms for taking the necessary action. This will enable prompt alerts of potential on-site hazards, thereby enhancing construction site safety by reducing on-site accidents. Moreover, Chung, et al. (2020) asserted that an IoT-based safety model that runs on sensors can result in a 78% cost reduction compared to the conventional manual safety system. This will alleviate the economic strain experienced by small and medium-sized entreprises (SMEs) with limited budgets and constrained liquidity. Apart from that, wireless monitoring devices that rely on IoT sensors can evaluate environmental pollutants produced by construction sites by acquiring real-time data on resource consumption, energy efficiency, and waste management (Paudel and Neupane, 2021; Ghosh, Edwards and Hosseini, 2021). Indeed, the diverse applications of IoT in the construction sector have led to a range of benefits.

2.4.6 Big Data

Big data is characterised as vast quantities of structured and unstructured data that exhibit five distinct attributes, namely volume, value, variety, velocity, and veracity (Maroufkhani, et al., 2022). The process of utilising big data entails four essential steps, including data acquisition, storage, sorting, and refinement (Munawar, et al., 2022). In view of the swift pace of data generated from smart technologies, Srivastava, et al. (2022) averred that big data analytics represents a viable approach for managing voluminous amounts of information from a variety of sources and formats, which standard data mining and handling techniques cannot accomplish. Consequently, this will enhance the process of forecasting and decision- making across various construction phases.

Since profitability and cost reduction are indicators of economic success, Bilal, et al. (2019) has developed a project analytics approach in which big data is utilised to comprehend the current and future profitability performance of various types of construction project. This approach mitigates the risk of budgetary overruns and underspending in project budgets by proactively anticipating potential cost-related uncertainties. Moreover, Munawar, et al. (2022) advocated the utilisation of big data to formulate safety plans and management strategies. Similarly, Ajayi, et al. (2019) proposed Big Data Accident Prediction Platform (B-DAPP) as a means of identifying the underlying factors contributing to safety issues and supporting decision-making processes aimed at reducing occupational hazards in construction sites. Apart from that, several researchers have proven the capabilities of big data in construction waste management (Chen and Lu, 2017; Sepasgozar, et al., 2021; Xu, et al., 2020; Yuan, Lu and Xue 2021). To clarify further, Lu, et al. (2018) claimed that big data analytics can reveal concealed patterns, obscure connections, and other valuable insights that can aid in making informed decisions regarding the efficient management of construction waste.

2.4.7 Artificial Intelligence (AI)

AI is an advanced area of computing that enables machines and computers to execute complex tasks that ordinarily require human intellect (Adel, Elhakeem and Marzouk, 2022). This is achieved through the utilisation of a knowledge database to generate judgements, predictions, or classifications. To put it another way, AI is the artificial replication of human intelligence. Intermittently, AI and its subfields, such as machine learning (ML) have the capabilities to enhance profitability, efficiency, productivity, safety, and sustainability within the construction industry.

Due to the inherent inaccuracies of conventional cost-estimating approaches, various AI-based cost-estimation tools have been developed to provide swift and accurate construction cost estimates (Matel, et al., 2019; Turner, et al., 2021; Mahmoodzadeh, Nejati and Mohammadi, 2022). This is exemplified by the findings of Smith and Wong, (2022), who demonstrated that the inaccuracies in predicting construction costs have been decreased by 20% using artificial neural networks (ANN). Consequently, the risk of cost overruns and subsequent project delay can be mitigated. Further, AI may excel in areas such as facilitating environmental monitoring, optimising energy consumption and production as well as optimising transport system (Yigitcanlar and Cugurullo, 2020; Koyamparambath, et al., 2022; Lin, et al., 2021). In response to the high accident fatality rate in the construction industry, Kim, et al. (2022) created an accident prediction model at the construction site on the basis of a deep learning algorithm owing to significant predictive ability, whereas Abbasianjahromi and Aghakarimi (2021) presented a safety performance evaluation model by applying decision tree algorithm. This will lead to a reduction in on-site accidents, thereby fostering a safe and secure working environment. Indeed, the contributions of AI and its subsets in diverse project domains cannot be overlooked.

2.4.8 Drones / Unmanned Aerial Vehicles (UAVs)

Drones, also known as UAVs are remotely piloted aeronautical platforms that can be outfitted with a variety of sensors to autonomously gather data such as video and images (Yildiz, Kivrak and Arslan, 2021). In other words, drones are capable of operating without human intervention. The construction industry is progressively utilising drones due to their versatile operational capabilities and mobility, as well as their ability to access hard-to-reach areas and cover wide-ranging construction sites (Hammad, et al., 2021). These characteristics make drone technology ideally suited for data collection, mapping, and visual surveillance throughout all stages of construction.

As illustrated by Elmeseiry, Alshaer and Ismail (2021), the deployment of drones on construction sites has led to significant reductions in both time and costs associated with task completion. In this regard, Onososen, et al. (2023) expounded that drone-based technologies are capable of generating highly precise aerial visual data, which can significantly enhance decision-making processes. Moreover, significant cost savings can be achieved by eliminating labour, heavy machinery, and costly logistical requirements like specialized elevating platforms for site inspection (Li and Liu, 2019).

Additionally, drones can alleviate work safety concerns by replacing humans to conduct periodic inspections of the site areas that pose substantial danger, such as foundation pits, which pose a risk of inadvertent collapse (Martinez, et al., 2021; Wu, et al. 2021). Without a doubt, this will expedite the site inspection process as drones can furnish the person in charge with real-time data, while minimizing the potential for accidents. In the sphere of construction waste management, Filkin, et al. (2021) divulged that drones are utilised to detect unlawful dumping, topographic mapping of waste disposal locations, and the planning of environmental protection measures.

2.4.9 Construction Robotics

Construction robotics is a manipulator that can be configured to execute diverse operations in the construction industry by means of pre-programmed motions (Yahya, et al., 2019). Potentially, robots can outperform humans in terms of endurance and productivity since they can operate for more extended periods and handle greater workloads at a faster pace. In an effort to address the physically demanding and repetitive tasks that hinder productivity, construction companies have incorporated a range of single-purpose and general-purpose robots, such as bricklaying, concreting, rebar-tying, and welding robots (Kim, et al., 2021).

In essence, the primary contribution of robotics to construction is the improvement of worker safety and the provision of safer working environment. Muhammad, et al. (2021) discovered that employing robotic systems on construction sites significantly lowers the threats associated with performing dangerous tasks such as manipulating heavy and hazardous construction materials and working on high-rise buildings. Thus, this can decrease the fatalities resulting from accidents and greatly improve the safety of workers. Additionally, the application of construction automation and robotics can result in a wide range of economic benefits, hence facilitating the attainment of economic gains. As utilising robots and automated processes will reduce the number of workers on sites, Bhattacharya and Momaya (2021) claimed that substantial labour cost savings are conceivable. Moreover, Delgado, et al. (2019) explicated that construction robotics can drastically reduce the average time required for construction tasks, while improving output quality and productivity. Further, Balasubramanian, et al. (2021) unveiled that the deployment of robotics for panel installation and plastering has the capacity to minimise waste and rework resulting from errors. Hence, this will eradicate the possibility of project delays that could lead to additional expenses, resulting in indirect economic benefits.

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

Generally, there are two primary categories of enhanced digital reality, namely AR and VR. AR is described as the augmentation of the physical environment by superimposing virtual information to specific locations known as markers, whilst VR entails the creation of a fully immersive virtual environment that mimics a physical setting (Srivastava, et al., 2022). Owing to their versatile capabilities, AR and VR are well-suited for a range of construction applications, including site inspection, defect identification, staff training simulations, and design evaluations.

In an effort to mitigate occupational risks and fatalities, AR and VR can be utilised for safety training in the construction industry. According to Zhang, et al. (2022), Wang, et al. (2018) and Nassereddine, et al. (2022), the utilisation of AR and VR in training workers on the operation of construction equipment, such as cranes and excavators, has been proven to improve the workers' proficiency in specific construction tasks. By means of interactive and immersive representation, participants can be acquainted with hazardous behaviours and associated risks present at construction sites, while simultaneously acquiring practical skills without subjecting themselves to potential threats (Ahmed, 2019). Undoubtedly, AR and VR-based safety training is substantially more effective than the conventional construction training.

Additionally, AR and VR can provide an intuitive overview of a project prior to its construction. Thus, AR and VR can be utilised for preconstruction planning by simulating realistic conditions. Through an AR-based platform, Akyazi, et al. (2020) contended that virtual architectural designs and BIM models can be imposed on actual construction sites, presenting users with a holistic comparison of the as-planned and as-built form of the project at early design stages. Thus, it can eradicate the necessity for design changes in the later stage of construction since the users can alter the design depending on their needs and preferences based on the visual output provided (Marino, et al., 2021). This will in turn minimise the additional costs associated with post-contract modifications, omissions, reworks, and defects, resulting in long-term cost savings. Despite the significant upfront costs associated with implementing AR and VR technologies, their advantages in enhancing project efficiency over the long run are irrefutable.

2.5 Drivers for Adoption of Smart Technologies in the Construction Industry

Drivers are perceived as external or internal forces that inspire adoption of the smart technologies in the construction industry. In this study, the drivers can be divided into three distinct categories, namely external, organisational, and technological drivers.

2.5.1 External Drivers

External drivers are the factors that are beyond the dominance of an organisation but have the potential to induce a shift in the organisation's internal environment. This driver exerts a significant impact on the adoption of smart technologies in the construction industry due to the construction industry's dependence on diverse external actors, including government and client.

2.5.1.1 Government assistance

As the greatest client of the construction industry, proactive government support is essential for the effective adoption of innovations and new practices. Due to the substantial costs associated with technological change, government assistance in the form of financing and incentive schemes, financial subsidies, as well as tax relief is crucial in facilitating the initial steps of digital transition, particularly the decision to embrace smart technologies (Chen, et al., 2022; Lee and Park, 2022; Zhou, et al., 2022). In particular, Jiang, et al. (2022) explored that the Singaporean government has established BIM Fund to provide subsidies for projects that comply with BIM mandate and implement BIM. Certainly, government financial aid might serve as start-up financing for construction firms by offsetting the costs associated with the preliminary phase of transitioning to digitalisation, particularly for SMEs. This will minimise the project stakeholders' resistance to the application of smart technologies.

Apart from financial assistance, the government can act as an educator, imparting technical support and guidance to construction stakeholders by conducting comprehensive training and educational programs (Jiang, et al.,2022). As a case in point, the government of Singapore has implemented an array of programs encompassing training, mentoring, outreach, and specialized certification courses for stakeholders and students. In spite of this, the government and industry players need to establish robust cooperative measures to address the anticipated disruptions caused by smart technology.

2.5.1.2 Government policy

Government policies, including legislation, regulation, procedure, and administrative action, are viewed as potent instruments for encouraging the construction sector to avail advantage of the untapped potential of digital technologies (Tan, Tan and Ramakrishna, 2022; Marzouk, Elsaay and Othman, 2021). This is owing to the fact that government policies can serve as a benchmark for construction stakeholders, while facilitating informed decision-making by top-level management concerning the deployment of smart technologies (Al-Ashmori, et al., 2022). As such, several previous studies have speculated that government policies exert a significant influence on promoting the uptake of smart technologies in the construction industry (Zulu, et al., 2022; Chen, et al., 2022).

In an effort to promote the adoption of smart technologies, the Malaysian government and its regulatory agencies have formulated several policies including National Construction Policy (NCP) 2030 and Construction 4.0 Strategic Plan. While in Singapore, Hwang, Ngo and Teo (2022) unfolded that the government has developed a Construction Industry Transformation Map that outlines the fundamental principles necessary to facilitate digital transformation. Similarly, the South Korean government has devised a Smart Construction Technology Roadmap, whereas the Japanese government has established I-Construction as a detailed action plan (Lee and Park, 2022). These initiatives serve as a blueprint for integrating smart technologies within their respective construction industry. Therefore, it is evident that numerous nations worldwide have a shared objective of transforming the construction industry.

2.5.1.3 Government enforcement

Government enforcement pertains to the application of punitive measures that obviates the necessity for legal regulations to avert undesirable behaviours (Marzouk, Elsaay and Othman, 2021). Primarily, the government's enforcement efforts are meant to ensure that all parties involved in a project adhere to a predetermined set of rules and regulations established by the government. Darko and Chan (2018) buttressed this further by claiming that government mandate is one of the success factors in promoting a novel approach in the construction industry, as firms will be compelled to implement technological solutions in order to avoid penalties for violations.

In this regard, various nations worldwide have enacted mandates in diverse degrees and with varying mandating requirements for the application of smart technologies (Jiang, et al., 2022; Marzouk, Elssay and Othman, 2021; Yang and Chou, 2018). For instance, countries with a BIM adoption rate higher than 70%, such as the United States, United Kingdom, Singapore, United States, Germany, and France, are more likely to have such mandatory regulations. While in Malaysia, it is mandatory for all public projects with a value of RM100 million or more to adopt BIM (Ariono, Wasesa and Dhewanto, 2022). These efforts have the ability to strengthen external motivation, such as demand from clients and the market. Thus, there appears to be a direct correlation between government enforcement and the probability of a company adopting smart technologies.

2.5.1.4 Client demand and acceptance

Generally, the innovative behaviour of a construction firm can be swayed by the pressure exerted by the client, who acts as a financier and decision-maker (Chen, et al., 2019). For the majority of projects, the project owner or client has the final authority over the contractual budget and the means by which such projects may be executed. Therefore, several researchers have indicated that clients' demand is a primary force driving smart technologies adoption since projects that embrace smart technologies are more costly than conventional ones (Ariono, et al., 2022; Oke, et al., 2022; Olawumi and Chan, 2020b).

Further, Chen, et al. (2019) and Kineber, et al., (2022) clarified that the client acceptance of smart technologies adoption depends on their innovativeness, confidence in the capabilities and perceived benefits of smart technologies to facilitate their projects and satisfy their requirements over existing practices. When clients acceptance increases, they are eager to invest more funds in smart technologies to reap their benefits. This is in line with the interview conducted by Chan, et al. (2019), in which the success rate of past BIM projects, such as higher productivity and timely project completion, will impact client demand and degree of satisfaction. Therefore, construction firms should make concerted efforts to showcase the merits of employing digital technologies for project execution to increase client acceptance.

2.5.2 Organisational Drivers

Organisational drivers are management-related variables, such as management structure and organisational resources that can catapult the effective integration of smart technologies in current operations. In other words, it refers to the internal efforts exerted by organisation's top management and employees.

2.5.2.1 Top management support

Top management support is perceived as the management's commitment to scrutinize the enabling environment and designate the necessary resources to effectively adopt smart technologies through grasping their respective capabilities (Ahmed, et al., 2022). Several authors have affirmed that the commitment and support of top management play a prominent role in effective smart technologies execution in construction projects (Lu and Deng, 2022; Herrera, et al., 2021; Evans, et al., 2021; Ahuja, et al., 2020). The fundamental reason is that the top management level has the authority to determine the financial feasibility of allocating resources toward cutting-edge innovations.

Additionally, Shojaei and Burgess (2022) articulated that the willingness of the top management to implement smart technologies in their organisations is usually contingent on their insight of the advantages of smart technologies and their outlook on digital transformation, that is either technology-driven or human-centred change. Typically, a technology–oriented organisation is more inclined to invest resources in reshuffling their organisational structure and policies, as well as offering training programmes to facilitate the adoption of smart technologies adoption into their operations (Oraee, et al., 2022; Chan, et al., 2019). In addition, the top management may drive the adoption of new technologies by conveying and reaffirming company future development plan (Liu, et al., 2022). Undoubtedly, the support of senior management will impact an organization's inclination to either embrace or reject any new invention or innovation.

2.5.2.2 Practitioners' competency

The advent of digitalisation requires that project teams possess not only core competencies, but also digital competencies, which is a speciliased skillset of using smart technologies to perform tasks (Liu, et al.,2022). In this regard, various studies demonstrated that the effective deployment of smart technologies in the construction industry is contingent on the technical competence of staff with respect to smart technologies (Ghobakhloo, et al., 2022; Zhou, et al., 2022; Yap, et al., 2022; Olawumi and Chan, 2022b). This stems from the fact that digitally savvy project teams are more inclined to adopt smart technologies, along with better suited to administrate and handle technology-related issues (Ahuja, et al., 2020).

Moreover, it is imperative for organisations to establish a baseline level of individual competencies to ensure that employees commence their skills development at an appropriate proficiency level (Shojaei, Oti-Sarpong and Burgress, 2022). This is due to the fact that younger generations exhibit a stronger proclivity towards digital literacy in contrast to their older counterparts (Zulu, Saad and Gledson, 2023). This approach can aid employees in conducting customised training that is more impactful. In response to the ever-evolving industry landscape, the project teams must develop expertise in a broader array of software and smart technologies to remain competitive and avoid the risk of losing their employment.

2.5.2.3 Training and educational program

Every practice in the construction industry is dependent on the quantity of knowledge gained through training, workshops, conference, and educational programmes (Ayarkwa, et al., 2022). Since technological advancements are altering the sorts of skills and abilities required in the workplace, several researchers have underscored the significance of conducting training programmes or workshops to serve as a knowledge foundation for future application (Pan and Pan, 2020; Lu and Deng, 2022; Chan, et al., 2019; Farahaneza, et al., 2018). In this vein, Oke, et al. (2022) supplemented that introducing hands-on experience with smart technologies during training would more effectively bring current employees up to speed in the technological sense and lessen adoption resistance.

Additionally, Ma, et al. (2018) enunciated that continuous upskilling and reskilling is necessary to ensure the acceptance of smart technology and the effectiveness of its adoption. Nevertheless, it is essential to provide technology-specific training as various technologies may have varying skill requirements (Yap, et al., 2022). In other words, the training programme can be designed to provide users with the requisite technical skills for their particular domains, such as design, construction, material supply, and so forth. Indeed, upgrading the project team's and company's skill sets on a regular basis is necessary to eliminate the skills gap and enhance the construction industry's readiness for digital transformation.

2.5.2.4 Organisation culture

According to Ullah, Witt and Lill (2022), an organisation’s culture reflects the attitudes, beliefs, standards, and actions of its employees. In this vein, multiple researchers opined that an organisational culture exhibits flexibility in embracing change, a greater propensity to take risks, and a forward-thinking attitude can significantly influence an organisation's inclination to integrate smart technologies into its existing operations (Aghimien, et al., 2022; Ahmed, et al., 2022; Shojaei, Oti-Sarpong and Burgress, 2022; Ghobakhloo, et al., 2022). In addition to that, Zulu, et al., (2023) postulated that a firm must foster collaborative culture, constructive culture that is receptive to feedback and suggestions, dynamic culture that motivates employees to move beyond their comfort zones as well as training culture when promoting digitalisation in organisation.

Furthermore, Zhou, et al. (2023) asserted that company with a conservative mindset often fall behind or resist incorporating smart technologies, whereas a company that embrace innovative mindset is usually at the forefront of trends in adopting smart technologies. Due to the fact that the decision-makers of a construction firm are made up of elderly professionals, the existence of an old-fashioned mentality will have a knock-on effect on the smart technologies adoption in the industry. Therefore, it is imperative to initiate alterations in the organisational culture to expedite the diffusion of smart technologies.

2.5.2.5 Sufficient financial resources

Cost is a critical factor for the successful application of smart technologies. To this end, several studies pointed out that adequate financial resources allocated to smart technologies are the most apparent driving force behind smart technologies implementation in the construction industry (Chen, et al., 2022; Belay, et al., 2021; Olawumi and Chan, 2020). This is due to the fact that the deployment of smart technologies is accompanied by a variety of expenditures, including the cost associated with the procurement of hardware and equipment, software packages, licences, regular updates, ongoing maintenance fees, training expenses as well as professional fees (Ghobakhloo, et al., 2022; Yeh and Chen, 2018).

Simultaneously, the availability of appropriate financial resources will reflect the readiness of a construction firm to accept new innovations (Chen, et al., 2019). As such, the construction firm should equally allocate financial resources to facilitate the adoption of smart technologies. In an effort to evaluate the cost and advantages of adopting smart technologies, Silverio-Fernández, et al. (2021) alluded to a cost benefit analysis that establishes a specified financial feasibility threshold for a construction company. This approach may particularly advantage SMEs firms that often face financial constraints when making adoption decisions.

2.5.3 Technological Drivers

Technological drivers are directly tied to the technical attributes in catalysing the adoption of smart technologies in the construction industry. It encompasses the components that inspire the construction practitioners to integrate smart technologies into current operations, such as perceived efficacy, awareness and availability of appropriate smart technologies.

2.5.3.1 Proven technology effectiveness

According to Wang, et al. (2022), technology is considered effective when its adoption meets the predetermined criteria and enhances the current project performance. Since the adoption of smart technologies necessitates considerable financial and other resource input, most construction stakeholders are concerned with the effectiveness of technology and return on investment (ROI) to secure their profitability (Olatunji, Olawumi and Awodele, 2017). It is common practice among construction firms to embrace only technology that has already been proven effective, as this indicates minimal uncertainty.

Further, Olawumi and Chan (2020) stressed the significance of presenting clients with empirical evidence of the successful deployment of smart technologies in construction projects to increase their contentment and trust. This is due to the fact that developing relationships based on trust with clients enables reticent clients to recognise the value of smart technologies for their projects (Shojaei, Oti-Sarpong and Bugress, 2022). To put it another way, construction firms are more inclined to embrace smart technologies that have been proven competent and manage to deliver greater benefits than existing technologies or working techniques. This is coherent with the findings of Nguyen, et al. (2021), who discovered that the BIM’s effectiveness will considerably raise stakeholders' adoption intent.

2.5.3.2 Technology awareness

Technology awareness is the degree to which consumers perceive the current status of technology (Silverio-Fernández, et al., 2021). Specifically, it relates to the perceived usefulness, ease of use and vulnerability of smart technologies. According to Ejidike, Mewomo and Anugwo (2022), there are five steps to the process of adopting smart technologies, namely the awareness stage, the conviction stage, the decision-making stage, the execution stage, and the confirmation stage. Due to the ever-changing nature of technology, the awareness stage necessitates the ongoing collection of technological knowledge and information.

Adoption of smart technologies often begins with the professional and owner's awareness of smart technologies and their application in contemporary construction operations (Ejidike, Mewomo and Anugwo, 2022). In the United Kingdom, Awwad, Shibani and Ghostin (2020) proclaimed that increasing BIM awareness at all levels of construction firms appears to be a vital success factor in promoting BIM application since it will assist in altering perception towards BIM. Furthermore, creating case studies that showcase the successful implementation of smart practices in the construction industry is regarded as a direct approach to enhance knowledge and promote awareness (Shojaei, Oti-Sarpong and Burgress, 2022). In light of this, it is essential to enhance the awareness and expertise of project team members through training, conferences, and workshops.

2.5.3.3 Availability of appropriate technology

The execution of smart technologies in construction projects involves the combination of various software and hardware. For instance, 3D printing requires advanced machinery, such as robot printer and gantry printer (Craveiro, et al., 2019). Therefore, the availability of appropriate technological resources is crucial since it signifies a construction firm’s technical readiness to deploy smart technologies in the construction industry (Sinoh, Othman and Ibrahim, 2020). To this end, several researchers articulated that necessary software and hardware investment is a vital approach that led to the effective adoption and usage of BIM (Babatunde, Udeaja and Adekunle, 2021; Darwish, Tantawi and Elbeltagi, 2020; Oluleye, et al., 2021).

Similarly, Pan and Pan (2020) claimed that the availability of robotics technology, such as welding robots, exoskeleton units, collaborative robots, and robotic arms is an influencing factor of automation in Hong Kong construction industry. This is in line with the interview conducted by Awwad, Shibani and Ghostin (2020), who disclosed that it is essential to ensure the availability of relevant software, which will result in better communication between the parties and stakeholders involved in the process. Notably, the construction company should prioritise the preparation and upkeep of hardware and software to maximise the success of smart technology applications.

2.6 Challenges of Adoption of Smart Technologies in Construction Industry

The construction industry has been criticised for being slow in embracing smart technologies due to its fragmented nature. Therefore, evaluating fundamental impediments is essential for determining the success or failure of employing such an application. In the section that follows, the obstacles to the adoption of smart technologies are divided into four distinct categories, namely economic, technological, organisational, and external obstacles.

2.6.1 Economic Challenges

The economic challenges are constraints imposed by financial variables, such as cost, that hinder the desire and ability for organisations to acquire smart technologies. This constraint may pose threats to the organisation, particularly small and medium-sized companies.

2.6.1.1 Extensive upfront investment

The venture into the realm of smart technologies typically incurs substantial initial capital outlays for acquiring the requisite hardware, software, and underlying infrastructure (Babatunde, Udeaja and Adekunle, 2021; Ghobakhloo, et al., 2022). Similarly, several researchers have corroborated that the novel construction approach that integrates smart technologies such as BIM, AI, robotics, drone and 3DCP demands substantial upfront costs as compared to the conventional methods (Vanderhorst, et al., 2022; Abioye, et al., 2021; Olanrewaju, et al., 2020; Yap, et al., 2022; Hwang, et al., 2022). Undoubtedly, this may surpass the financial capabilities of numerous SMEs that comprise the majority of the construction sector.

Further, Regona, et al. (2022) claimed that high initial investment cost is the highest-ranked hurdle of smart technologies adoption in construction industry. This stems from the fact that investment in a novel approach is fraught with risk and uncertainty. Since the construction stakeholders are profit-oriented and risk-averse, most of them perceive the high start-up cost as a deterrent, rather than the considerable long-term cost benefits offered by smart technologies in the latter phases of the project (Wu, et al., 2019). Certainly, the lengthy payback period associated with the smart technologies investment will indirectly diminish their desire to incorporate them in their construction project.

2.6.1.2 Substantial operational and maintenance costs

Apart from start-up investments, Won, Hwang and Samion (2022) indicated that substantial expenses will be associated with the constant need to expand technology capabilities at the operational level. In fact, consistent investment in regular software upgrades and hardware maintenance is necessary to ensure that smart technologies operates at the optimal performance (Kissi, Aigbavboa and Kuoribo, 2022). These hidden costs are likely to inflict a financial strain on a firm as these costs will persist for an extended period. Several researchers have recognized that such hidden long-term expenses are a stumbling block to smart technologies adoption, particularly the SMEs (Demirkesen and Tezel, 2022; Regona, et al., 2022).

Further, several researchers highlighted that ongoing training costs associated with the deployment of smart technologies are a stumbling block to the development of smart practices in the construction industry (Hyarat, Hyarat and Kuisi, 2022; Regona, et al., 2022). This is further supported by Zhou, Yang and Yang (2019), who noted that the high expenses of employing BIM professionals and consultants as well as updating BIM software and hardware are a significant deterrent in China. Therefore, it is essential to identify all cost components that must be assessed in order to determine whether the benefits will eventually outweigh the expenses.

2.6.2 Technological Challenges

Technological challenges are impediments that are inextricably linked to the capabilities of smart technologies, affecting their actual usage and execution. Adoption of smart technologies in the construction sector is significantly influenced by features such as complexity, incompatibility and the availability of internet infrastructure.

2.6.2.1 Technology complexity

Technology intricacy refers to the level of difficulty associated with comprehending and leveraging smart technologies, which exhibits an inverse relationship with the adoption of such technologies. In fact, certain smart technologies may not be user-friendly or easy to operate. Several researchers postulated that it is a significant technical hurdle behind the decision to adopt smart technologies in construction project (Evans and Farrell, 2021; Yap, et al., 2022; Hasan, et al., 2021). This is supplemented by the findings of Chen, et al. (2019), who discovered that the inclination of managers in construction firms to adopt smart technologies will be impacted by the substantial learning curve involved, notwithstanding the benefits they offer.

Owing to the complexity associated with smart technologies adoption, Won, Hwang and Samion (2022) divulged that construction practitioners who are not equipped with information technologies knowledge confront a steep learning curve when intend to incorporate smart technologies into their existing operations at the outset. Under such circumstances, the construction practitioners will perceive that smart technologies adoption is likely to introduce added intricacy to their workflow, rather than streamlining the current operations. As a result, the construction firm may be deterred from adopting a technology that is hard and complicated to operate. Undoubtedly, technological complexity will lead to hesitation and apathy, dissuading construction professionals from deploying smart technologies.

2.6.2.2 Technology interoperability issue

Interoperability issues emerge when smart technologies clash with other existing software and technologies in the construction industry (Zhou, et al., 2023). This will lead to errors and information loss when transmitting data across different applications (Li, Greenwood and Kassem, 2019). For instance, the conversion of AutoCAD drawings to Revit 3D by consultants often leads to the omission of specific components in the resultant drawings when accessed in other BIM software.

In this sense, several studies have recognised the lack of interoperability as a constraint to the widespread adoption of smart technologies in the construction industry (Evans and Farrell, 2021; Hall et al., 2022; Yap, et al., 2022; Hyarat, Hyarat and Kuisi, 2022). This is coincides with the findings of Delgado, et al. (2019), who pointed out that the inability to automatically update BIM models and project schedules from AR and VR systems was impeded by the absence of compatibility between BIM systems and AR and VR models. Moreover, the interoperability issue is aggravated when the SMEs support systems that are broadly substandard or outdated (Munianday, Rahimi and Esa, 2022). Consequently, poor technological interoperability will significantly impact on efficiency, communication, and collaboration among project participants, leading to a range of issues that impede the project's success.

2.6.2.3 Lack of internet infrastructure

Internet connectivity is indispensable to the revolutionary potential of digitalisation as most of the smart technologies such as IoT, big data, BIM and cloud computing required a reliable and stable internet access to operate to their full potential. Besides, Hajj, et al. (2023) stated that the effectiveness of smart technologies is intricately bound to the geographical region in which it is implemented. Typically, the internet connectivity on construction site varies based on location, where site located in rural or underdeveloped areas are likely to have inadequate access to the internet (Kissi, Aigbavboa and Kuoribo, 2022).

For this reason, the recurring intermittent internet connectivity in the construction site appears to be an obstacle that must be resolved sooner than later to enhance the efficacy of smart technologies in construction operations (Hall, et al., 2022; Hasan, et al., 2021; Gamil et al., 2020; Hyarat, Hyarat and Kuisi, 2022). This is clearly evidenced in the study of Abioye, et al. (2021), who demonstrated that unstable internet connectivity has posed a substantial challenge for adopting AI tools on construction sites, where decent internet connectivity and power supply are necessary for optimal functioning. Whereas Li, Greenwood and Kassem (2019) further uncovered that insufficient server capacity has resulted in unstable blockchain technology operations. Under such conditions, it will be incredibly challenging for smart technologies to operate effectively.

2.6.3 Organisational Challenges

Organisational constraints are company-level obstacles that might hinder the successful integration of smart technologies in construction project. These difficulties are typically attributable to the inaction of employees and the top management, which impedes the application of smart technologies.

2.6.3.1 Shortage of expertise

In correspondence with the novelty of smart technologies, the dearth of digitally literate employees will obstruct the deployment of smart technologies in the construction industry (Kissi, Aigbavboa and Kuoribo, 2022; Zhou, Yang and Yang, 2019; Abioye, et al., 2021). This is consistent with the study of Gamil, et al. (2020), who uncovered that the unavailability of required skill sets hinders IoT adoption in Malaysian construction industry. Further, Newman, et al. (2021) propounded that there is a paucity of trained professionals to work with 3DCP, BIM, sensor-based technologies, and IoT in the construction process in the United Kingdom construction industry.

Owing to a lack of expertise, construction workers may experience difficulty and anxiety when confronted with transitory changes in the mode of operation. In line with this, Akinradewo, et al. (2022) averred that finding blockchain experts with knowledge in the construction industry to develop tailored solutions aimed at resolving the numerous issues. Simultaneously, Demirkesen and Tezel, (2022) attested that a dearth of skilled labour leads to poor labour productivity, often resulting in construction delays. The rationale is that such workers exhibit a higher susceptibility to commit errors while performing their duties, thereby necessitating rework (Farouk, et al., 2023). Indeed, the adoption of smart technologies is a mirage in a region where specialists with the necessary competence and skills are scarce.

2.6.3.2 Resistance to change

There is a reluctance to abandon conventional methods until an invention has fully matured, partly because the construction industry tends to be fragmented and conservative. In a similar vein, a variety of research findings indicated that the low adoption rate of smart technologies in the construction industry is primarily attributable to practitioners' resistance to change, particularly among the ageing workforce (Regona, et al., 2022; Ghansah, et al., 2021; Sanka, et al., 2021; Halim, Mohamed and Fathi, 2022). This stems from the fact that they are accustomed to the present working methods, anxiety over anticipated expenses, uncertainty over the benefits of smart technologies and and a lack of concrete evidence on the potential financial returns (Durdyev, et al., 2022).

As most of the boomer generation employees are technophobic, it is fiendishly challenging for them to acquire new technological skills. Consequently, rejective behaviour that stifles the enthusiasm of aspiring personnel will arise among construction practitioners (Nagy, Papp and Szabó, 2021). Eventually, the majority of the construction firms are content adhering to consistent utilisation of conventional work methods rather than embracing smart practices. Incidentally, such a stance has resulted in a lopsided number of construction projects employing smart technologies (Olawumi and Chan, 2020a).

2.6.3.3 Unfamiliarity of smart technology

Since smart technologies have limited applications and are still evolving, most of the construction practitioners are still in the dark about the prospective benefits of this breakthrough. In other words, they are not enlightened about the proper techniques and strategies for operating smart technologies effectively (Ghansah, et al., 2021). In view of this, Newman, et al. (2021) emphasised that lack of knowledge regarding smart technologies has a negative impact on the outcome and performance of the entire project. This is resonated with the findings of Gamil, et al. (2020), who claimed that lack of IoT knowledge and experience is a hurdle of implementing IoT in Malaysian construction projects.

As a result of unfamiliarity, the majority of construction companies have resorted to passive adoption rather than active adoption to minimise potential risks. This is illustrated in the study of Lee and Park (2022), which disclosed that less than one percent of South Korean construction companies adopted unfamiliar smart technologies in their project. Simultaneously, a prevalent misconception exists within the industry that BIM is only ideal for large firms (Hall, et al., 2022). This has reflected the significance of knowledge in preventing the erroneous interpretation of smart technologies adoption. Eventually, conventional approaches are eventually preferred over the adoption of smart technologies.

2.6.3.4 Lack of proper training

Currently, the construction industry is encountering a digital skills gap, leading to a slow uptake of smart technologies. In view of this, insufficient proper staff training has been identified as a critical factor contributing to this issue (Hyarat, Hyarat and Kuisi, 2022; Olanrewaju, et al., 2020). The rationale behind this lies in the perception held by many construction companies that investing in staff training is a time-consuming and costly endeavour, along with no assurance of a significant return on investment (Evans and Farrell, 2021; Hall, et al., 2022; Hasan, et al., 2021; Farouk, et al., 2023). Further, Camngca, Amoah and Ayesu-Koranteng (2022) alleged that several contractors presumed that time devoted to training equated to reduced productivity, thereby aggravating the skills gap.

As a result of the deficiency of supply in the construction industry, Alemayehu, et al. (2021) contended that the cost of BIM training has increased and become prohibitive. This has ultimately imposed a tremendous financial strain and reluctance on the SMEs to skill up their workforce for a seamless digital shift. Additionally, Wong and Ang (2021) attested that smart technologies such as BIM cannot be utilised to its fullest extent without proper training even if a company is equipped with sufficient technological infrastructure. Therefore, the significance of adequate training cannot be overlooked.

2.6.3.5 Lack of organisational support

The process of altering the current environment of the construction sector with smart technologies has experienced difficulties due to a lack of support from the organisation, notably from the top management (Evans and Farrell, 2021). On a similar note, several researchers indicated that low encouragement from top management had hindered the emergence of BIM in a few nations, including Nigeria, Australia, and Jordan (Babatunde, Udeaja and Adekunle, 2021; Hyarat, Hyarat and Kuisi, 2022; Hasan, et al., 2021).

Additionally, Maroufkhani, et al. (2022) intensified that the level of support from top management for smart technologies will decrease in cases where they are incompatible with the current system and culture of the organization due to the substantial learning and alteration involved. In other words, the interest of top management, especially for SMEs will be hindered by the additional costs and efforts required to train employees on smart technologies. On top of that, the statistical test conducted by Demirkesen and Tezel (2022) discovered that younger organisations are more devoted to embrace change despite the inherent risk as compared to older construction firms. Apparently, the success or failure of the adopting smart technologies is contingent upon the level of support provided by organizations.

2.6.4 External Challenges

External constraints are the unfavourable circumstances that are not under the authority of an organisation, such as government, professional bodies and client-related obstacles. Despite this, such limits will have an effect on the organization's general orientation.

2.6.4.1 Lack of standards and guidelines

The goal of the prevalent adoption of smart technologies in the construction industry remains elusive in the absence of necessary implementation protocols and standards. Similarly, several prior studies indicated that the lack of uniform standards and regulations from the government has translated to the low adoption rate of smart technologies such as BIM and blockchain in the construction industry despite the presence of high awareness about these technologies (Akinradewo et al., 2022; Hall, et al., 2022; Ibrahim, et al., 2022; Demirkesen and Tezel, 2022; Babatunde, Udeaja and Adekunle, 2021). In Malaysia, Jamal, et al.(2019) asserted that there is still a lack of standardised BIM operating manuals available despite the existence of BIM for a significant period.

As a consequence, it is common for construction firms to establish their customised standards, including specific data storage formats to effectively manage their workflow and smart technologies adoption (Farouk, et al., 2023). This will inevitably escalate the interoperability issue while simultaneously adding additional complexity to the integration and communication of diverse smart technologies (Hyarat, Hyarat and Kuisi, 2022). Consequently, the construction stakeholders will face a state of perplexity, which in turn increase the likelihood of project delays and related risks. Ultimately, construction practitioners is likely to maintain a wait-and-see approach towards adoption of smart technologies (Xie, et al., 2022).

2.6.4.2 Lack of demand and interest

Generally, the absence of demand will have a detrimental effect on the supply of novel products or services. This is exemplified by the fact that insufficient client interest and demand having exerted a negative spur on the deployment of smart technologies in the construction industry (Hajj, et al., 2021; Georgiadou, 2019; Olawumi and Chan, 2020a; Hall, et al. (2022). The causation of these circumstances can be attributed to the speculative thinking encircling the instant benefits brought about by smart technologies and the elevated costs associated (Munianday, Rahimi and Esa, 2022). Consequently, they often resort to using conventional construction methods that prioritise maintaining the project within a limited budget.

Additionally, Olanrewaju, et al. (2020) claimed that construction firms tend to align with the prevailing industry demand trends to preserve a bidding market advantage. Thus, firms are deterred from investing in smart technologies deficient in client demand and interest as the associated efforts and expenses may not be worthwhile. Saka and Chan (2020) further purported that the client demand possesses excellent driving force and reliance power, which would influence other obstacles. For instance, the lack of demand from clients for BIM adoption in their projects could translate to a decline in support from upper management.

2.6.4.3 Legal and contractual uncertainty

According to Ragab and Marzouk (2021), the rapid growth of smart technologies has outpaced the formation of contractual and legal frameworks, resulting in uncertainty surrounding ownership, data dependency, and risk distribution. In light of this, various studies have propounded that legal and contractual issues serve as a barrier to the widespread adoption of smart technologies and full realisation of their benefits (Almarri, et al., 2019; Demirkesen and Tezel, 2022; Jamal, et al., 2019; Olatunde, et al., 2022; Evans and Farrell, 2021). This will in turn contribute to organisations' disinclination to embrace smart technologies.

Additionally, Zhou, Yang and Yang (2019) alleged that the absence of amendments in the standard form of contract to accommodate smart technologies adoption has led to ambiguity over the legal obligations of the stakeholders. For instance, the PAM Contract 2006, which is a widely utilised standard form of contract in Malaysia’s construction industry lacks a provision specifying the parties responsible for ownership and management of the BIM model (Teoh, et al., 2018). This is in line with the findings of Munianday, Rahimi and Esa (2022), who posited that the present contractual methodology in Malaysia is incapable of accommodating novel technologies. This will in turn elevate the likelihood of misunderstandings and controversies among the stakeholders, thereby lead to project delays. Eventually, legal uncertainties would persist as a potential threat without contractual revisions.

2.7 Summary of findings from literature review

Figure 2.1 provides a summary of the findings gleaned from the literature review. Overall, the summary consists of three major sections, namely the type of smart technologies used in the construction industry, the drivers for adoption of smart technologies, and the concomitant obstacles that impede the adoption of smart technologies in construction industry. In this study, ten prospective smart technologies are discovered, along with twelve drivers and thirteen challenges. BIM, Blockchain, Cloud Computing, 3DCP, IoT, Big Data, AI, Drone, Construction Robotics as well as AR and VR are among the ten types of smart technologies identified. In addition, external drivers, organisational drivers, and technological drivers make up the twelve categories of drivers. Similarly, thirteen challenges are further broken down into four themes, comprising economic, technological, organisational, and external challenges.

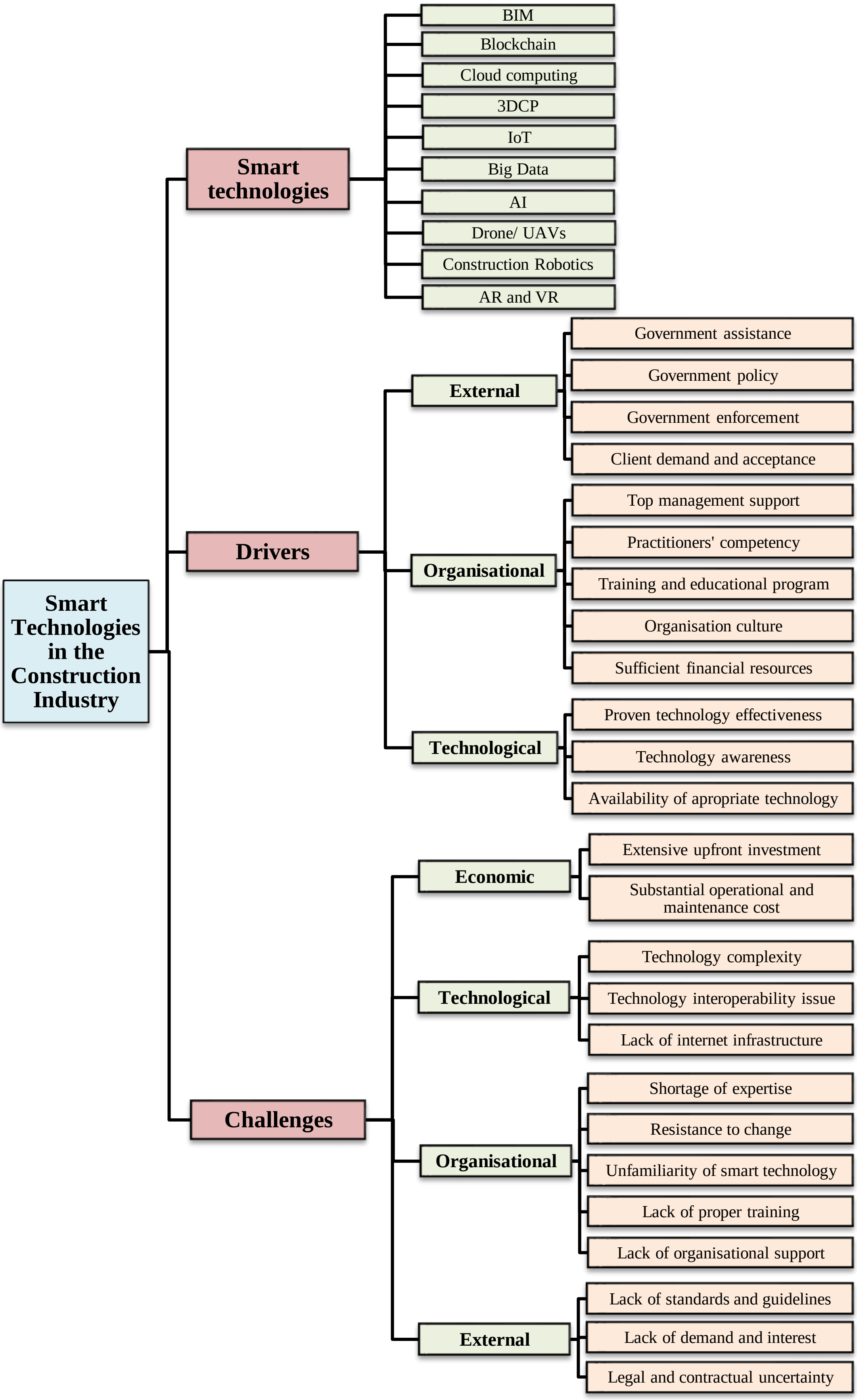

Figure 2.1: Type of smart technologies used, drivers and challenges of adoption of smart technologies in construction industry

2.8 Summary of Chapter

In essence, the definition and concept of smart technologies as well as the benefits of adopting smart technologies were elaborated extensively. Several drivers and impediments for the embracement of smart technologies have subsequently been identified. This chapter is concluded with a summary of the findings from the literature review, including possible technologies, drivers, and challenges.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter primarily detailed the systematic methodologies undertaken to conduct this study. The research method, rationale of selection and steps of executing literature review are outlined. In addition, the instrument for gathering quantitative data, comprising questionnaire formulation, sampling determination, pre-test, and questionnaire distribution are clarified. Furthermore, several statistical tests for data analysis are discussed.

3.2 Research Method

Creswell and Creswell (2018) defined research method as a series of actions that span from formulating overarching hypotheses to identifying specific methods for collecting, analysing, and interpreting data to address the research problems. Primarily, there are three sorts of research methods, which are qualitative, quantitative, and mixed methods. Each of these approaches possesses a distinct set of underpinning philosophy, characteristics, and data collection techniques, as well as strengths and limitations to achieve the research objectives.

3.2.1 Quantitative Method

Quantitative research method is a positivist and deductive approach centred on the measuring numerical data and statistics to derive research outcomes (Saunders, Lewis and Thornhill, 2019). The standard practice in quantitative research is to commence with a theory or hypothesis, followed by the collection of data that either corroborates or contradicts the theory, and thereafter refining and reassessing the theory (Creswell and Creswell, 2018). As a method that adheres to a causal philosophy, the theory is tested by investigating correlations between variables that are computationally measured and analysed using a variety of statistical and graphical approaches.

In the course of the research process, the utilisation of quantitative methods has resulted in a plethora of positive outcomes. Since the quantitative approach involves using numerical data, the result of the research is fact-based and might not be influenced by personal feelings or opinions in considering and representing research and facts (Basias and Pollalis, 2018). As such, the outcomes from quantitative research are robust and consistent. In addition, the quantitative approach develops correlations between variables in a controlled environment to arrive at generalizable hypotheses applicable to the entire population (Farghaly, 2018). In contrast, the shortcoming of the quantitative research method is that it tends to record timestamps of phenomena, where it only analyses variables at a certain instant in time, regardless of whether the instance recorded the subject at their optimum performance or in a highly disordered state (Rahman, 2016). Indeed, the collection of data through this method has posed difficulties in gaining a comprehensive understanding, as the information acquired has predominantly offered a general outlook of the diverse factors involved.

3.2.2 Qualitative Method

Qualitative research is intimately linked with naturalist paradigm and interpretive ideology, which subjectively examine human behaviour and perspectives to develop research outcomes (Saunders, Lewis and Thornhill, 2019). The researchers interpret the connotation of qualitative data collected in the context of the respondent. Typically, the scope of qualitative research is vast, and it can yield copious and detailed data from the sample through a variety of qualitative methodologies, such as interviews and focus groups. For these reasons, qualitative research is ideal for addressing research problems of central phenomenon in which the variables are unknown and the relevant literature lacks information on the subject under investigation (Creswell and Guetterman, 2019).

At times, qualitative technique is favoured by some researchers since it allows for creativity and a greater reliance on paradigms developed by them (Creswell and Creswell, 2018). Moreover, it has a flexible framework due to the absence of specific, standardized and closed questions as in a questionnaire (Basias and Pollalis, 2018). In other words, researchers can express themselves in a more innovative and literary manner without being constrained by preconceived metrics or instruments. Thus, qualitative technique has the ability to facilitate study in novel areas with scant literature (Basias and Pollalis, 2018). Conversely, the possibility of researcher bias constitutes a constraint to qualitative research (Toews, et al., 2017). As such, the reliability of research outcome cannot be guaranteed as qualitative data is inherently subjective. Further, qualitative investigations often need more time than quantitative approaches owing to the time-consuming nature of data collection at study locations and the in-depth nature of evaluating phrases and words, yet cannot produce generalizable results (Farghaly, 2018).

3.3 Justification of Selection

In this research, the quantitative method was adopted to achieve the three research objectives. The primary aim of this research is to explore the potential of incorporating smart technologies in the Malaysian construction industry. In an attempt to deliver the best possible outcome, it is necessary to assemble data from a large sample that accurately represents the entire population.

Pre-eminently, the quantitative method is favoured attributable to the efficiency, timeliness, and cost-effectiveness in gathering data from an immense sample size under time pressure for statistical analysis through questionnaire distribution. This allows for the swift and effective capture of vast quantities of data, while also granting respondents greater confidentiality and anonymity. In this regard, the outputs of a quantitative method may reflect the perspectives of a vast population regarding the significance of adopting smart technologies in the construction industry. Further, owing to the numerical nature of quantitative data, subjectivity concerns can be eradicated, hence minimising bias and ensuring the reliability of the output. Since quantitative methods employ scientific techniques and statistical algorithms to evaluate the acquired data, the consistency and reliability of the research outcome will also be enhanced.

In contrast, the qualitative approach will be less suited for this study. The fundamental reason is that qualitative research prioritises thorough individual viewpoints, perspectives, and experience to grasp the phenomena, whereas this study seeks empirical evidence to address the research problem. As such, it will have a detrimental impact on the reliability and consistency of interpretations as compared to quantitative research approaches that leverage measurable data. Moreover, qualitative research outcomes can only be generalised to the larger population in a restricted manner despite the time-consuming nature of data collection. In other words, the data obtained from a handful of interviews with construction practitioners, such as architects and engineers, cannot comprehensively capture the entire community of construction practitioners in Selangor and Wilayah Persekutuan Kuala Lumpur (WPKL).

3.4 Literature Review

Literature review refers to the process of examining a variety of literature sources, including journal articles, books, conference papers and so forth that summarise the past and current breadth of information pertaining to the research topic and field of study (Creswell and Guetterman, 2019). The relevance of this process stems from the fact that it substantiates the necessity of research and the inadequacy of previous research on a particular issue. In this study, the steps advocated by Creswell and Guetterman (2019) for performing a systematic literature review were undertaken.

Initially, the search term was chosen to include all relevant terms in this study domain, including “construction digitalisation”, “smart technologies” and “potential application of smart technologies in the construction industry”. Subsequently, these key terms were utilised in a variety of resources and databases to locate corresponding kinds of literature from several databases such as ScienceDirect, Emerald, MDPI, and Google Scholar. The third step involves identifying, analysing, and synthesising literature pertinent to the study's scope. Among the accumulated resources, the literatures with substantial contributions to the body of knowledge were selected. Following a comprehensive analysis of the topics addressed by past research, some research gaps were identified. Ultimately, a literature review was composed to highlight the smart technologies that are commonly used in the construction industry as well as the potential drivers and challenges of smart technologies adoption in the construction industry. As depicted in Figure 2.1, a literature map that facilitates the interpretation of the literature's findings was developed.

3.5 Quantitative Data Collection

In this study, quantitative data collection was chosen as it can generate credible results by making use of large samples. The primary data, which is the data that would be analysed to generate findings that correlate with the research objectives was gathered through the administration of questionnaire.

3.5.1 Questionnaire Design

The questionnaire for this research was divided into four sections, with each section striving to gather relevant information pertinent to the research objectives. At the beginning of the questionnaire, a concise summary of the research was presented to ensure that the respondents possessed a fundamental understanding of the research and the three research objectives. Section A was intended to gather demographic details of the respondent, such as company's business activities, profession, position within the organisation, working experience and organisation size.

In the subsequent section, respondents were required to rate 10 types of smart technologies based on the current adoption level in their construction project. While Section C and D evaluating the respondents' viewpoints on 12 listed drivers influencing smart technologies adoption in the construction industry and 13 listed challenges associated with smart technologies adoption in the construction industry depending on their degree of agreement. These sections were developed utilising a five-point Likert scale ranging from 1 to 5, in which 1 corresponds to the lowest importance and 5 to the highest importance to indicate the level of adoption and degree of agreement with the various criteria examined in this research. For the adoption level, the numerical values allotted are 1 = never adopt to 5 = always adopt; whereas, for the degree of agreement, the numerical value allotted are 1 = strongly disagree to 5 = strongly agree. The summary of each questionnaire section is presented in Table 3.1. A copy of the questionnaire is attached in the appendix.

Table 3.1: Summary of sections in the questionnaire

Section	Type of Question Rating	Type of data	Purpose
A	Closed-ended	Nominal (Descriptive)	To retrieve demographic information of the respondents
B	5-points Likert scale	Ordinal (Ranked)	To attain objective 1: Adoption level of smart technologies
C	5-points Likert scale	Ordinal (Ranked)	To achieve objective 2 : Drivers of smart technologies adoption
D	5-points Likert scale	Ordinal (Ranked)	To realise objective 3: Challenges of smart technologies adoption

3.5.2 Pre-Test

Generally, the fundamental purpose of the pre-test is to refine the questionnaire, ensuring that respondents can effortlessly complete it without any difficulties (Saunders, Lewis and Thornhill, 2019). Ahead of the actual data collection, the questionnaire was piloted with seven targeted respondents, which comprised three quantity surveyors, two architects, and two engineers, to identify any potential issues in the questionnaire and appraise its quality in terms of comprehensibility and clarity. Subsequently, the received feedbacks, including complex language and terminology, ambiguous statements, inadequate questions, as well as grammatical errors were rectified accordingly. Ultimately, the explicit and thorough questionnaires were distributed to the targeted respondents.

3.5.3 Sampling Determination

In fact, collecting data from the entire population is infeasible owing to time and resource constraints. In actuality, sampling is a deliberate method for obtaining outcomes that are generalizable to the population. Sampling determination is defined by Sekaran and Bougie (2016) as the process of selecting a subset from a larger population. In other words, it is employed to determine the prevalence of unknown information or outcomes in a larger population and derive inferences about the population as a whole. Besides, studying a sample instead of the entire population eliminates errors in data collection, resulting in more reliable findings (Saunders, Lewis and Thornhill, 2019).

In this study, the sampling was designed to ensure that the target respondents, who are prominent construction practitioners in the Selangor and WPKL, fully represent the study population. The involvement of a vast array of construction practitioners is necessary to improve the quality of inferences reached. However, it would be impractical to examine every individual in the population. Thus, the Cochran's formula is applied to determine the permissible sample size for making inferences about the population.

Across several domains, the vast majority of researchers accept a margin of error typically ranging from 4% to 6% at a confidence level of 95% (Kosar, Bohra and Mernik, 2018). There is a greater degree of confidence that the outcomes will accurately represent the population when the margin of error is smaller. Hence, with a 95% of confidence level, this research will have a z-scores of 1.96. As reported by Department of Statistic Malaysia (2021), the number of individuals employed in the construction industry in Selangor and WPKL is 304,300, while the total employment across various sectors in Selangor and WPKL is 4,374,100. Accordingly, the sample size determined by the Cochran's formula will be composed of 100 individuals. The following equation expresses the formula for determining sample size (Seidu, et al., 2022).

$$n = \frac{z^2 pq}{e^2} \tag{3.1}$$

Where,

n = sample size

z = the z-scores at 95% confidence level, 1.96

p = the proportion of the population with attributes understudy, (304,300/4,374,100)= 0.070

q = 1 – p

e = Margin of error, 5%

$$n = \frac{1.96^2(0.070)(1-0.070)}{0.05^2} = 100$$

In addition, the Central Limit Theorem (CLT) is applied to eliminate sampling error as well as facilitate statistical analysis and inference. The application of CLT necessitates that all samples have a comparable size, regardless of the underlying distribution shape of the population. In general, sample sizes ranging from 30 to 50 are deemed adequate for the CLT to be applicable, implying that the sample means distribution is comparatively normal distributed (Ganti, 2022). Therefore, a sample size of thirty (30) is established for each group of the sample under the investigation of smart technologies implementation in the Malaysian construction industry.

Considering the sampling method, convenience sampling and snowball sampling, both of which are non-probability sampling techniques, were employed to determine the targeted respondents for deriving meaningful insights. As its name suggests, convenience sampling refers to the process of gathering information from easily available individuals in the general population (Sekaran and Bougie, 2016). Whist, snowball sampling is a volunteer sampling in which subsequent respondents are chosen based on the information provided by the initial respondents (Saunders, Lewis and Thornhill, 2019). The respondents to the survey were requested to furnish additional information concerning competent construction professionals in the industry, specifically those with adequate knowledge on smart technologies adoption in the construction industry. The process of snowballing was continued until the requisite sample size was reached.

3.5.4 Questionnaire Distribution

Being the research instruments, the questionnaire was formulated using automated survey software on online platform named Google Form. The targeted respondents are reachable through the distribution of link or uniform resource locator (URL) across multiple mediums, including email, LinkedIn as well as social media sites, such as WhatsApp, Facebook, Twitter, and Instagram. A total of four weeks were allotted for the distribution of questionnaires and subsequent data collecting from the participants.

3.6 Data Analysis

The acquired raw data were analysed using a more advanced data management and statistical analysis software, namely IBM Statistical Practices for the Social Sciences (SPSS). In this study, five statistical tests were adopted to analyse the data collected, which are Cronbach's Alpha Reliability Test, Arithmetic Mean, Friedman Test, Spearman's Correlation Test and Kruskal-Wallis Test.

3.6.1 Cronbach's Alpha Reliability Test

Cronbach's Alpha Reliability test is a statistical instrument employed to evaluate the internal reliability and consistency of data attained from Likert-scaled-based questions, demonstrating its ability to measure the correct hypothesis (Evans, et al., 2021). Besides, this test is a yardstick for evaluating the degree of correlation between the samples (Sekaran and Bougie, 2016). The coefficient of Cronbach's alpha spans between 0 to 1, with a greater value indicating greater reliability and consistency. A high alpha value will ensure the absence of random errors in the data (Saunders, Lewis and Thornhill, 2019). Generally, a coefficient below 0.60 is considered poor, those between 0.70 and 0.80 are deemed fair, and those above 0.90 are regarded as excellent (Sekaran and Bougie, 2016). Before proceeding with a thorough analysis, it is essential to verify the validity of the scaled responses. Therefore, Cronbach's Alpha was employed to evaluate the internal consistency and reliability of the Likert scale- based questions featured in Sections B, C, and D of the questionnaire.

3.6.2 Arithmetic Mean

Arithmetic mean is a widely used measure of central tendency. It is derived by multiplying the frequency of each response option and then dividing that sum by the overall frequency (Lord, Qin and Geedipally, 2021). In this study, arithmetic means were used to determine the central tendency of each smart technology in terms of adoption level. Upon determining the mean value for each variable, the variables were then ranked based on their respective means. By analysing these rankings, the relative adoption levels of each technology as perceived by the respondents can be explored.

Besides, this study adopted interval-level measurement to provide interpretations for the weighted mean which involved dividing each level of the scale into consistent intervals (Pimentel, 2019). Therefore, the adoption level was divided into three categories, which are low level, moderate level, high level as stipulated in Table 3.2. In an attempt to uphold consistency and coherence in the intervals, each interval is computed by dividing the four intervals into three categories (Pimentel, 2019). Thus, the differences across the categories fell within a consistent interval of 1.32 to 1.33.

Table 3.2: Scale to Measure Level of Adoption (Pimentel, 2019)

Level of Adoption	**Interval**
Low	1.00-2.33
Moderate	2.34-3.67
High	3.68-5.00

3.6.3 Friedman Test

Friedman test is a non-parametric test that evaluates three or more correlated groups with ordinal or continuous dependant variables. It identifies the significance of the variance between ranking scores and values anticipated by chance (Pereira, et al., 2015). For this study, the purpose of this test was to evaluate the perceived level of importance that respondents assigned to the drivers and challenges of smart technologies adoption. Thus, it is capable to provide a comparison between the relative importance of various drivers and challenges, thereby providing insight into the importance of various variables in promoting or impeding the adoption of smart technologies in the construction projects.

In an effort to explore the significant difference between the drivers and challenges of smart technologies adoption in construction industry, the null hypothesis (H0) and alternative hypothesis (H1) were developed:

H0 : There is no significant difference between the importance level of drivers and challenges of smart technologies adoption.

H1 : There is significant difference between the the importance level of drivers and challenges of smart technologies adoption.

3.6.4 Spearman's Correlation Test

Spearman's correlation test is a non-parametric test commonly utilised by researchers to establish the course and magnitude of the relationship between variables that are measured at the ordinal scale (Lord, Qin and Geedipally, 2021). In essence, it was executed to evaluate the degree of consensus between the respondents group.

Typically, spearman's correlation test typically results in a correlation coefficient between -1 and 1, wherein the sign of the coefficient denotes whether the variables exhibit a positive or negative linear relationship. A value of -1 shows a perfect negative correlation, whereas 0 indicates no correlation and 1 denotes a perfect positive correlation (Kumar and Abirami, 2018). A pair of variables that exhibit a tendency to move in the same direction are considered to have a positive correlation given that an increase in one variable induces an increase in the other and vice versa. Table 3.3 provides a comprehensive breakdown of degree of correlations and the respective interpretations. For this study, this test was employed to ascertain the extent of correlation between the drivers and challenges of smart technologies adoption in the Malaysian construction industry.

Table 3.3: Grading standards table of Spearman’s Correlation Coefficient (ρ) (Yan, et al., 2019)

Spearman, ρ	Correlation Degree
0	No correlation
0 – 0.19	Very weak correlation
0.20 – 0.39	Weak correlation
0.40 – 0.59	Moderate correlation
0.60 – 0.79	Strong correlation
0.80 – 1.00	Very strong correlation
1.00	Monotonic correlation

3.6.5 Kruskal-Wallis Test

Kruskal-Wallis test, or H-test is a non-parametric substitute to one-way ANOVA used to evaluate the presence of significant difference between more than two independent samples based on their score ranking. The only prerequisite of this test is that the data be ordinal scale, as opposed to analysis of variance, which requires that the data be normally distributed (Ostertagová, Ostertag, Kovac 2014).

This study employed Kruskal-Wallis test to analyse and assess data based on the preferences of respondents across a range of company business activities, profession, organisational position, working experience and company size. The H-value derived from the test is subsequently contrasted to the Chi-square critical value. In the event where the critical Chi-square value is less than the H-value, the null hypothesis is rejected. Conversely, the null hypothesis cannot be rejected if the critical Chi-square value is greater than the H-value. The null hypothesis (H0) and alternative hypothesis (H1) were contrived as below:

H0 : There is no significant difference across the social demographics on the drivers as well as challenges of smart technologies adoption.

H1 : There is a significant difference across the social demographics on drivers as well as challenges of smart technologies adoption.

3.7 Summary of Chapter

Ultimately, this chapter defined the research methodology utilised for this study, namely quantitative method. The questionnaire survey is the primary instrument for quantitative data collection in this study. A pre-study was carried out with seven respondents preceding to questionnaire distribution to verify its effectiveness and suitability in achieving the research objectives. In addition, the Cochran formula and CLT are used to establish the sample size, while convenience sampling and snowball sampling were employed to gather respondents for this study. Following that, the acquired data were analysed by using Cronbach's Alpha Reliability Test, Arithmetic Mean, Friedman Test, Spearman’s Correlation Test, and Kruskal-Wallis Test.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and analyses the findings of a survey, commencing with an overview of respondents' demographic information, followed by an assessment of survey data reliability using Cronbach's Alpha Reliability Test. Next, the adoption levels of smart technologies, as well as the importance of drivers and challenges related to their implementation are determined using Arithmetic Mean and Friedman Test. Additionally, the relationship between drivers and challenges is explored through Spearman's Correlation Test, while Kruskal-Wallis Test is employed to identify significant differences in drivers and challenges among various social demographics.

4.2 Demographic Background of Respondents

In this study, a total of 175 responses were received and analysed. The demographics information of respondents is presented as frequencies and percentages in Table 4.1.

Table 4.1: Summary of Respondents' Demographics

Demographic Information	Categories	Frequency (n)	Percentage (%)
Company Business Activities	Developer	41	23.4
	Consultant	50	28.6
	Contractor	46	26.3
	Subcontractor/ Supplier	38	21.7
Profession	Architect	52	29.7
	Engineer	59	33.7
	Quantity Surveyor	64	36.6
Organisational Position	Junior Executive	55	31.4
	Senior Executive	44	25.1
	Manager/Team Leader/ /Supervisor	42	24.0
	Director / Assistant Director / Technical Director	34	19.4

Table 4.1 (Continued)

Demographic Information	**Categories**	**Frequency (n)**	**Percentage (%)**
Working Experience	Less than 5 years	57	32.6
	5 - 10 years	43	24.6
	11 - 15 years	34	19.4
	More than 16 years	41	23.4
Company Size	Less than 29 employees	58	33.1
	30 - 75 employees	50	28.6
	More than 75 employees	67	38.3

As depicted in Table 4.1, the majority of the respondents of this survey comprised 28.6% of consultant, followed by 26.3% of contractor, 23.4% of developer as well as 21.7% of sub-contractor and supplier. Besides, this survey has captured a balanced view of responses from architects, engineers and quantity surveyors, with 29.7%, 33.7% and 36.6% respectively. This has furnished the survey with a varied mix of industry professionals. In terms of organisational position, 55 respondents hold junior executive roles, preceded by 44 respondents who occupy senior executive positions and 42 respondents in managerial, team leading, and supervisory position. On the other hand, there are only 34 respondents retaining the positions of director, assistant director, and technical director in their company.

With respect to working experience, most of the respondents have less than 5 years of experience, comprising 32.6% of the total respondents. This implies that a significant number of the respondents are new entrants to the construction industry. Meanwhile, 24.6% of the respondents have 5 to 10 years of work experience, 19.4% have 11 to 15 years of work experience, and 23.4% have more than 16 years of work experience in the construction industry. Additionally, the largest proportion of respondents, accounting for 38.3%, are employed in large-scale organisations with over 75 employees. Simultaneously, 33.1 % of the respondents is from the company with less than 29 employees, while the remaining 28.6% of the respondents is from company with 30-75 employees. In other words, most of the respondents are from small and medium sized entreprises (SMEs).

4.3 Cronbach's Alpha Reliability Test

Table 4.2 displays the computed coefficients for three distinct sets of variables. The table shows that all variables possess Cronbach's Alpha values that surpass the minimum acceptable internal consistency threshold of 0.70 (Sekaran and Bougie, 2016). The variables in section B had a coefficient of 0.849, which is regarded as fair, whereas the variables in sections C and D exhibited excellent internal consistency with coefficients of more than 0.90. Consequently, the data gathered for all three sections are reliable and will be exploited for further analysis.

Table 4.2: Reliability Statistics

Section	**Number of Items**	**Cronbach's Alpha Values**
Section B: Adoption level of smart technologies used in the construction industry	10	0.849
Section C: Drivers of adoption of smart technologies in the construction industry	12	0.936
Section D: Challenges of adoption of smart technologies in the construction industry	13	0.915

4.4 Arithmetic Mean

In this section, the mean values of various smart technologies were evaluated and ranked to determine the respective adoption level of smart technologies in the Malaysian construction industry.

4.4.1 Mean Ranking of Adoption Level of Smart Technologies

The mean values of ten distinct types of smart technologies are presented and sorted in descending order in Table 4.3. From Table 4.3, it is notable that the adoption level of the majority of smart technologies in Malaysian construction projects is low, as evidenced by their mean value falling below the interval of 3.68 depicted in Table 3.2. Among the ten smart technologies, only one of them, **ST3** = "Cloud Computing," has a high level of adoption, as its mean value surpasses 3.68.

Table 4.3: Mean Ranking of Adoption Level of Smart Technologies in the Construction Industry

Code	Type of Smart Technologies	Mean	Ranking	Level of Adoption
ST3	Cloud Computing	4.18	1	High
ST1	Building Information Modelling (BIM)	3.45	2	Moderate
ST8	Drones / Unmanned Aerial Vehicles (UAVs)	2.81	3	Moderate
ST5	Internet of Things (IoT)	2.73	4	Moderate
ST6	Big Data	2.37	5	Moderate
ST10	Augmented Reality (AR) and Virtual Reality (VR)	2.02	6	Low
ST2	Blockchain	1.99	7	Low
ST7	Artificial Intelligence (AI)	1.98	8	Low
ST4	Three-Dimensional Concrete Printing (3DCP)	1.87	9	Low
ST9	Construction Robotics	1.69	10	Low

Based on Table 4.3, the smart technologies with the highest mean ranking are **ST3**= "Cloud Computing", with a mean value of 4.18. This indicates that construction practitioners have widely adopted the cloud computing in their projects than other smart technologies, which corresponds to the findings of Demirkesen and Tezel (2022). In view of this, Tan and Abdul-Samad (2022) contended that the construction industry in Malaysia has rapidly adopted cloud computing for virtual collaboration and communication as a strategy to overcome the significant impact of the Covid-19 outbreak on working practices. This is ascribed to the ease of access to cloud-based software, shallower learning curve, abundant storage capabilities, storage, increased flexibility and scalability as well as reduced expenses (Won, et al., 2022). Therefore, it is not astounding that cloud computing has emerged as the most prevalent smart technology in the Malaysian construction sector.

The second highest mean ranking is **ST1=** "Building Information Modelling (BIM)" with a mean value of 3.45, denoting that the construction practitioners are utilising BIM to enhance their project performance. Nevertheless, it is observed that BIM adoption in Malaysia is satisfactory during the design phase but falls short during the construction phase, thereby impeding the industry's pursuit of extensive BIM adoption (Othman, et al., 2021). The broad adoption of BIM is likely driven by its capacity to undertake design optimisation, clash detection, building sustainability evaluation, and effective tracking and monitoring across all project phases (Al-Ashmori, et al., 2020). Apart from that, the establishment of the myBIM Centre by the Malaysian government, which acts as a centralised reference and support centre for BIM-related activities has played a vital role in increasing BIM adoption (Othman, et al., 2021). This initiative aims to alleviate the burden on SMEs by providing free training and trial software.

The smart technology ranked at the third place is **ST8**= “Drones / Unmanned Aerial Vehicles (UAVs)”, with a mean value of 2.81. This conforms to the findings of Balasubramanian, et al. (2021), which divulged that drones appeared as the third most deployed technology in the UAE construction industry. The utilisation of drones is increasingly prevalent in different stages of projects, particularly during the construction phase, due to their established efficacy in other sectors, including agriculture, disaster management, and surveying (Jeelani and Gheisari, 2021). This is further corroborated by the findings of Omar, et al. (2022), who avowed that G7 contractors in Malaysia often use drones for providing progress reports of construction sites to clients as well as conducting site inspections and monitoring works. The underlying rationale for this is that drones possess the capability to offer an in-depth overview of the progress made on the project by capturing high-resolution images and video of the construction site from different angles.

The smart technologies with the lowest mean ranking are **ST9=** “Construction Robotics”, with a mean value of 1.69. Therefore, it is considered the least deployed smart technologies in construction projects. This is bolstered by the findings of Yahya, et al. (2019), who propounded that Malaysian construction practitioners are unaware of the existence of construction robotics. Thus, the respondents still favour conventional and proven solutions in spite of the availability of highly sophisticated and innovative methods. Further, the costs associated with purchasing, operating, and maintaining construction robotics, along with training expenses are relatively high as each construction process may require different robots and software (Bademosi and Issa, 2021). As such, construction robotics is only viable for companies with strong financial standing and market competitiveness. Consequently, this has discouraged construction practitioners from widely adopting this technology.

4.5 Friedman Test

In this study, the Friedman test is employed to evaluate the mean rankings of the relative importance of twelve drivers and thirteen challenges pertaining to the adoption of smart technologies in the construction industry. Subsequently, the test utilised the mean ranking to establish whether a statistically significant difference existed between the variables.

4.5.1 Overall Mean Ranking of Drivers of Adoption of Smart Technologies

The overall mean ranking of the three main aspects of drivers, including external, organisational and technological is tabulated in Table 4.4. The drivers with the highest mean ranking indicate their significance in enhancing the adoption of smart technologies by construction practitioners in their projects.

Table 4.4: Overall Mean Ranking

Code	Aspects of Drivers	Mean	Ranking
DB	Organisational	6.81	1
DA	External	6.42	2
DC	Technological	6.10	3

Referring to Table 4.4, “Organisational Drivers (DB)” has the highest mean ranking, with a mean value of 6.81. This outcome indicated that the participants view organisational drivers as the most impactful aspects in hastening the adoption of smart technologies and positioning firms for success in the digital era. The primary rationale is that the organisation is responsible for providing the necessary direction, knowledge, and resources to implement smart technologies effectively. Despite this, it is notable that differences in organisational structure may occur as a result of varying organisation sizes, including large construction firms and SMEs, which can lead to discrepancies in the level of motivation among decision-makers within the organisation with regards to achieving digital transformation (Makabate, et al., 2022).

On the contrary, the aspect with the lowest mean ranking is "Technological Drivers (DC)", with a mean value of 6.10. This result revealed that construction practitioners consider the impact of technological drivers on the implementation of smart technologies as comparatively modest relative to other drivers. The reason for technological drivers being ranked lowest for enhancing smart technologies adoption is attributed to the fact that digital transformation is not exclusively dependent on technology since it cannot operate in isolation (Ziadlou, 2021). In fact, it necessitates human involvement to reach its full potential. Therefore, a collaborative approach that includes technological implementation, active participation and dedication of individuals within or beyond the organisation is imperative for achieving successful digital transformation.

4.5.2 Mean Ranking of Drivers of Adoption of Smart Technologies

Two hypotheses are generated for this test:

Null hypothesis (H0): There are no significant differences between the twelve drivers of the adoption of smart technologies in the construction industry.

Alternative hypothesis (H1): There are significant differences between the twelve drivers of the adoption of smart technologies in the construction industry.

Table 4.5: Friedman Test on Drivers of the Adoption of Smart Technologies in the Construction Industry

Number of Items	**Chi-Square**	**Degree of Freedom**	**Asymptotic Significance**
12	62.178	11	<0.001

Table 4.5 depicts the results of the Friedman Test, indicating that the null hypothesis (H0) is rejected as the p-value is less than 0.05. This result reveals that significant differences are present among the twelve drivers of smart technologies adoption in the construction industry. Following that, the twelve drivers are ranked based on their mean value and tabulated in Table 4.6.

Table 4.6: Mean Ranking of Drivers of Smart Technologies Adoption in the Construction Industry

Code	Drivers	Mean	Ranking
DB5	Sufficient financial resources	7.22	1
DB1	Top management support	7.15	2
DB3	Training and educational program	6.85	3
DA3	Government enforcement	6.77	4
DA4	Client demand and acceptance	6.63	5
DB4	Organisation culture	6.57	6
DC3	Availability of appropriate technology	6.49	7
DA2	Government policy	6.32	8
DB2	Practitioners' competency	6.25	9
DC1	Proven technology effectiveness	6.23	10
DA1	Government assistance	5.95	11
DC2	Technology awareness	5.57	12

Based on Table 4.6, the driver with the highest mean ranking is **DB5**= "Sufficient Financial Resources" under "Organisational Drivers (DB)", with a mean value of 7.22. Typically, the technological readiness of an organisation is gauged by determining the funding available for adopting and maintaining smart technologies (Chen, et al., 2019). This is owing to the fact that the availability of adequate financial resources empowers organisations to surmount the financial constraints associated with smart technologies, thereby facilitating a smooth adoption (Awwad, et al., 2020). Further, sufficient funding is crucial for organisation to sustain the operation of smart technologies in the long run, as the advantages of smart technologies are not immediately apparent. Therefore, concerned parties should demonstrate relentless dedication toward allocating adequate funding, given that the absence of financial resources may hinder the commencement of the adoption process.

The driver with the second highest mean ranking is **DB1=**"Top Management Support" under "Organisational Drivers (DB)", with a mean value of 7.15. This is consistent with the findings of several past research, which unveiled that commitment and support from top management is the most significant factor shaping adoption decision (Awwad, et al., 2020; Chen et al., 2019). Primarily, the success of technology adoption within the construction firm is inextricably tied to the openness of top management to innovation and their unwavering support of new technologies (Ahmed, et al., 2022; Sinoh, et al., 2020). This is attributable to the fact that executives and top-level management have considerable authority to influence the decision-making process and provide financial backing for adopting smart technologies implementation plans (Liu, et al., 2022). Further, managers who comprehend the significance of smart technologies can usually to convince their employees to adopt it. Thus, the support of top management is critical for establishing a new working culture that revolves around these technologies.

The driver **DB3=**“Training and Educational Program” under “Organisational Drivers (DB)” is ranked third, with a mean value of 6.85. This is echoed by the study of Shojaei, Oti-Sarpong and Burgress (2022), who asserted that firms that have effectively adopted Building Information Modeling (BIM) credit their success to an in-depth training and skills development programme for their staff. The significance of this driver resides in its impact on the capabilities, competencies, and mentality of employees since the implementation of smart technologies entails a transition from conventional work patterns. Therefore, continuous training is vital for ensuring that their staff and members are abreast of the most recent industry trends, due to the constantly evolving nature of new technologies, resulting in new roles and responsibilities (Olawumi and Chan, 2020). As such, organisations must prioritise the development of their workforce’s human capital to surmount the difficulties in adapting innovations and achieve digital transformation objectives.

The driver with the second lowest mean ranking is **DA1**= “Government assistance”, under “External Drivers (DA)” with a mean value of 5.95. The reason behind this ranking is that certain construction practitioners opined that government funding merely serves as an initial impetus for the implementation of smart technologies. This is corroborated by Munianday, Rahimi and Esa (2022), who affirmed that subsidising BIM software costs can encourage the private sector's involvement during the early stages of BIM adoption. Further, the government support and financing for the adoption of smart technologies may be confined to particular technologies, thus failing to fulfil the different needs and preferences of practitioners who may prefer other technologies. For instance, the Malaysian government has dedicated RM1 million to encourage construction companies to adopt BIM through the Transformation Fund programme (Sinoh, et al., 2020). Consequently, respondents perceive that government support does not play a significant role in driving the adoption of smart technology in Malaysia.

While driver with the lowest ranking driver is **DC2**= "Technology awareness" under "Technological Drivers (DC)", with a mean value of 5.57. In Malaysia, 74% of construction firms are aware of the benefits of BIM, but only 49% of firms have implemented it (CIDB Malaysia, 2019). The presence of awareness and action gaps is attributed to a range of obstacles that impede the adoption process. Despite being aware of the benefits of smart technologies, the considerable costs involved in obtaining and maintaining these systems often represent a significant barrier to entry, particularly for small and medium-sized firms (Al-Ashmori, et al., 2022). Therefore, it is notable that merely being aware of smart technologies does not necessarily translate to their effective adoption in the Malaysian construction industry.

4.5.3 Overall Mean Ranking of Challenges of Adoption of Smart Technologies

The overall mean ranking of the four main aspects of challenges, including economic, technological, organisational and external is tabulated in Table 4.7. The categories of challenges that has the highest mean ranking demonstrate their significant role in hindering the interest of construction practitioners in adopting smart technologies for their projects.

Table 4.7: Overall Mean Ranking

Code	Aspects of Challenges	Mean	Ranking
CA	Economic	7.54	1
CC	Organisational	7.22	2
CD	External	6.70	3
CB	Technological	6.56	4

Pursuant to Table 4.7, "Economic Challenges (CA)" has the highest mean ranking, with a mean value of 7.54, which corresponds to the findings of Silverio-Fernández, et al. (2021). This result affirmed that the construction industry persists in acknowledging cost as the most formidable obstacle in its efforts toward achieving digital transformation. The discernible rationale is that smart technologies often require a significant capital investment, encompassing both short-term and long-term financial commitments in acquiring new equipment, software, and training staff (Farouk, et al., 2023). This can present a significant financial burden for construction firms, especially SMEs with limited resources.

Conversely, the less remarkable aspects of challenges are “Technological Challenges (CB)”, with a mean value of 6.56. This implied that technological aspects have received the least attention compared other challenges that impede the adoption of smart technologies in the construction industry. In view of this, Makabate, et al. (2022) accentuated that the most significant obstacle SMEs encounter in adopting BIM is not the technology itself, but rather the insufficiency of properly trained personnel. In other words, construction professionals perceive technological obstacles as surmountable with technical expertise and knowledge.

4.5.4 Mean Ranking of Challenges of Adoption of Smart Technologies in the Construction Industry

Two hypotheses are generated for this test:

Null hypothesis (H0): There are no significant differences between the thirteen challenges of the adoption of smart technologies in the construction industry.

Alternative hypothesis (H1): There are significant differences between the thirteen challenges of the adoption of smart technologies in the construction industry.

Table 4.8: Friedman Test on Challenges of the Adoption of Smart Technologies in the Construction Industry

Number of Items	Chi-Square	Degree of Freedom	Asymptotic Significance
13	59.902	12	<0.001

Table 4.8 presents the results of the Friedman Test, which shows a rejection of the null hypothesis (H0) due to a p-value of less than 0.05. The outcome indicates that there are significant differences among the thirteen challenges of

adopting smart technology in the construction industry. Moreover, Table 4.9 displays a list of the thirteen drivers that are sorted by their mean rank.

Table 4.9: Mean Ranking of Challenges of Smart Technologies Adoption in the Construction Industry

Code	Challenges	Mean	Ranking
CA1	Extensive upfront investment	7.89	1
CC2	Resistance to change	7.68	2
CC4	Lack of proper training	7.32	3
CC3	Unfamiliarity of smart technology	7.26	4
CB1	Technology complexity	7.25	5
CC5	Lack of organisational support	7.20	6
CA2	Substantial operational and maintenance cost	7.18	7
CD3	Legal and contractual uncertainty	6.79	8
CD2	Lack of demand and interest	6.71	9
CC1	Shortage of expertise	6.66	10
CD1	Lack of standards and guidelines	6.61	11
CB2	Technology interoperability issue	6.51	12
CB3	Lack of internet infrastructure	5.94	13

In accordance with Table 4.9, the challenge with the highest mean ranking is **CA1**= “Extensive upfront investment” under “Economic Challenges (CA)”, with a mean value of 7.89. This is consistent with the findings of Regona, et al. (2022), who revealed that the greatest barrier to entry into the realm of smart technologies is the high initial investme cost. In most cases, the presence of uncertainties regarding the prospective return on investment (ROI) and scepticism about the benefits brought by these technologies have significantly impeded the efforts to convince construction practitioners to embrace these innovations (Makabate, et al., 2022). This can lead to a decrease in the confidence of construction practitioners in smart technologies, prompting them to exercise more caution when making investment decisions because of the significant financial burden involved. Consequently, construction practitioners are more likely to favour conventional methods that provide a certain ROI.

The challenge with the second highest mean ranking is **CC2=**“Resistance to change” under “Organisational Challenges (CC)”, with a mean value of 7.68. This is parallel to the findings of Waqar, Qureshi and Alaloul (2023) as well as Demirkesen and Tezel (2022), who identified resistance to change, especially at the management level, as the primary obstacle impeding the adoption of smart technologies. This stems from the fact that the adoption of smart technologies entails radical changes in entrenched practices and ways of thinking, while the construction stakeholders are deeply rooted in a cultural aversion to stepping outside its comfort zone (Sriyolja, Harvin and Yahya, 2021). Typically, construction stakeholders are hesitant to invest in smart technologies unless they can foresee long-term benefits for their organisation and the project client subsidises the considerable costs of investment. Accordingly, construction practitioners may adhere to conventional practices and resist embracing modern technological advancements.

The challenge with the third highest mean ranking is **CC4=**“Lack of proper training” under “Organisational Challenges (CC)”, with a mean value of 7.32. This is coherent with the study of Rajabi, et al. (2022), who discovered that a dearth of training geared to facilitate the transfer of knowledge is a significant impediment to the growth of BIM expertise in Malaysia. This phenomenon arises due to the tendency of employees to depart from the organization upon acquiring the necessary competencies. According to Fateh, et al. (2022), approximately 50% of employees who engage in company-sponsored training programs tend to terminate their employment with their respective employers and seek employment opportunities elsewhere. As such, some firms will perceive staff training as a waste of resources, thereby dampening their desire to invest. Moreover, the absence of assurance regarding the availability of future projects that incorporate smart technologies may exacerbate the employees' inclination towards investing in workforce training (Farouk, et al., 2023).

The challenge with the second lowest mean ranking is **CB2=** “Technology interoperability issue” under “Technological Challenges (CB)”, with a mean value of 6.51. The ranking divulged that interoperability issues do not significantly impede the adoption of smart technologies. In line with this, Munianday, Rahimi and Esa (2022) stipulated that despite there has been a reduction in the occurrence of interoperability issues in the last five years, they continue to pose a potential risk to the effective adoption of smart technologies, which has caused this particular barrier to be ranked lower. This is due to the fact that open standards such as Industry Foundation Classes (IFC) format and Construction Operations Building Information Exchange (COBie) have been developed to facilitate the seamless exchange and integration of smart technologies applications (Matarneh, et al., 2022). Nevertheless, Ahmed et al. (2022) demonstrated that the absence of interoperability is the most crucial factor that affects BIM adoption, which is in contrast to the findings of this study.

The challenge with the lowest mean ranking is **CB3=** “Lack of internet infrastructure” under “Technological Challenges (CB)”, with a mean value of 5.94. This is contrasted with the findings of Kissi, Aigbavboa and Kuoribo (2022), who identified that construction stakeholders encounter significant obstacles in leveraging emerging technologies due to inadequate internet connectivity. According to the Ministry of Communications and Digital (2023), the 5G network coverage has been implemented in almost half of the populated areas in Malaysia, with the Klang Valley region, achieving over 90% coverage by the end of 2022. Consequently, internet connectivity issues are less likely to impede the operation of smart technologies such as the IoT, Cloud Computing, and Big Data in the Malaysian construction industry as compared to developing countries with sluggish internet infrastructure.

4.6 Spearman's Correlation Test

Table 4.10 presents the results of Spearman's correlation test employed to examine the relationship between the drivers and challenges of smart technologies adoption. There is a total of 301 correlations, with each of the 12 drivers having at least nine significantly correlated influential challenges, whereas each of the 13 challenges has at least 10 significantly correlated influential drivers.

As shown in Table 4.10, it is observed that "Organisational drivers (DB)" exhibited more significance in comparison to the other aspects of drivers, which are "External drivers (DA)" and "Technological drivers (DC)", each of which demonstrated between 12 to 13 significant correlations. This implies that the internal forces within an organisation profoundly impact the organisation's capacity to incorporate smart technologies effectively. The rationale behind this is that the successful integration of new technology is contingent on the presence of a supportive framework, rather than simply procuring hardware and software (Sinoh, et al., 2020). Therefore, it is necessary to instigate internal changes within the organisation to address the potential challenges associated with the long-term adoption of smart technologies.

Likewise,"Organisational challenges (CC)" displayed greater significance compared to "Economic challenges (CA)", "Technological challenges (CB)" and "External challenges (CD)", as they have more pairs with 12 total correlations. This is in line with the study of Abbasnejad, et al. (2021), who accentuated that the challenges faced at the organisational level are a primary reason for the unrealised potential of smart technologies. This stems from the fact that smart technologies adoption necessitates a considerable adjustment in the organisation's structure, incurs significant financial investment as well as numerous risks and uncertainties (Kissi, Aigbavboa and Kuoribo, 2022). As the ultimate decision to adopt smart technologies lies with the organisation, it is essential to prioritise efforts towards redefining operational processes in alignment with smart technology principles.

The highest moderate correlation found is between **DC1** = "Proven technology effectiveness" and **CC3** = "Unfamiliarity of smart technology“ with the co-efficient value of 0.493. This indicates that the construction practitioners tend to remain unfamiliar with smart technologies adoption, despite the demonstrated efficacy of smart technologies. The underying reason is that insufficient efforts have been made to raise awareness and understanding on those smart technologies (Ismail, et al., 2022). The inadequate exposure to the features and benefits of smart technologies that are proven effective will escalate the unfamiliarity of construction practitioners. Further, the ageing workforce in the construction industry, who are not digitally literate, may be inclined to conventional working methods, irrespective of the established efficiency of smart technologies (Zulu, Saad, and Gledson, 2023). Such disparities in literacy have the potential to exacerbate the divide between individuals who are able to adopt and reap the benefits of smart technologies and those who lack familiarity with them.

Table 4.10: Correlation between Drivers and Challenges of Adoption of Smart Technologies

Challenges \ Drivers	DA1	DA2	DA3	DA4	DB1	DB2	DB3	DB4	DB5	DC1	DC2	DC3	Total correlations
CA1	.441**	.373**	.338**	.331**	.371**	.354**	.417**	.325**	.414**	.414**	.278**	.390**	12
CA2	.354**	.348**	.282**	.288*	.350**	.402**	.395**	.389**	.432**	.438**	.356**	.484**	12
CB1	.323**	.270**	.257**	.275**	.258**	.227**	.283**	.339**	.437**	.385**	.316**	.384**	12
CB2	.321**	.347**	.258**	.242**	.308**	.366**	.351**	.365**	.429**	.407**	.315**	.440**	12
CB3	-	.190*	-	.155*	-	.221**	.315**	.246**	.173*	.238**	.238**	.251**	9
CC1	.234**	.169*	-	.162*	.208**	.225**	.228**	.264**	.239**	.237**	.174*	-	10
CC2	.318**	.390**	.346**	.397**	.385**	.389**	.384**	.438**	.408**	.369**	.378**	.306**	12
CC3	.408**	.359**	.352**	.370**	.417**	.451**	.417**	.430**	.442**	.493**	.467**	.402**	12
CC4	.323**	.282**	.352**	.272**	.395**	.401**	.421**	.454**	.333**	.421**	.377**	.361**	12
CC5	.403**	.314**	.339**	.260**	.420**	.397**	.313**	.394**	.383**	.384**	.321**	.341**	12
CD1	.350**	.327**	.322**	.238**	.352**	.358**	.341**	.445**	.378**	.432**	.382**	.411**	12

Table 4.10 (Continued)

Challenges \ Drivers	DA1	DA2	DA3	DA4	DB1	DB2	DB3	DB4	DB5	DC1	DC2	DC3	Total correlations
CD2	.359**	.365**	.380**	.427**	.364**	.330**	.330**	.364**	.312**	.406**	.316**	.287**	12
CD3	.271**	.354**	.286**	.233**	.251**	.306**	.322**	.265**	.151**	.263**	.263**	.349**	12
Total correlations	12	13	10	13	12	13	13	13	13	13	13	12	

Note: **. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.7 Kruskal-Wallis Test

Kruskal-Wallis Test is conducted to discover the significant differences in drivers and challenges of smart technologies adoption among various social demographics. The significant differences are determined by evaluating the p-value and computing the chi-square value based on the degree of freedom.

4.7.1 Kruskal-Wallis Test on Company Business Activities

Kruskal-Wallis Test is undertaken to unveil the significant differences in drivers and challenges of smart technologies adoption across different company business activities, including developer, consultant, contractor as well as subcontractor and supplier. Since four groups of respondents were assessed, significant differences exist when the p-value is below 0.05, and the chi-square value exceeds 7.815, which is defined by a degree of freedom of 3.

4.7.1.1 Drivers of Adoption of Smart Technologies in the Construction Industry

Two hypotheses are presented as follows:

Null hypothesis (H0): There is no significant difference across the company business activities on the drivers of smart technologies adoption.

Alternative hypothesis (H1): There is a significant difference across the company business activities on the drivers of smart technologies adoption.

Table 4.11: Kruskal-Wallis Test on Company Business Activities (Drivers)

Code	Drivers	Kruskal-Wallis H	Asymp. Sig.
DA1	Government assistance	8.461	.037

The results of the Kruskal-Wallis test on company business activities is tabulated in Figure 4.11, wherein a driver, **DA1**= "Government Assistance", under "External drivers (DA)" has a p-value less than 0.05 and h-value greater than 7.815. This indicates that there is a noteworthy divergence in viewpoints among developers, consultants, contractors as well as subcontractors and suppliers on the potency of this driver for enhancing smart technologies adoption. Thus, the null hypothesis (H0) for this driver is rejected.

Table 4.12: Mean Rank of Drivers of Smart Technologies Adoption in the Construction Industry across Company Business Activities

Code	Drivers	Company Business Activities	N	Mean Rank
DA1	Government assistance	*Developer*	41	*73.91*
		Consultant	50	95.61
		Contractor	46	**99.38**
		Subcontractor / Supplier	38	79.41

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

According to Table 4.12, it is discovered that the contractor perceived government assistance as a more significant driver for smart technologies adoption than the consultant, subcontractor and supplier as well as developer. This aligns with the findings of Chan, Olawumi and Ho (2019), who indicated that the financial backing provided by the government is perceived as a favorable stimulus by contractors to expedite the implementation of BIM in Hong Kong. The prominence of contractors in the ranking is attributed to their responsibilities in the physical construction activities, which necessitate a greater reliance on smart technologies to optimize their work processes. This is reinforced by the findings of Murguia, Demian and Soetanto (2021) who revealed that the adoption of smart technologies among contractor firms is higher than design or consultant firms. Therefore, the contractors are likely to be more receptive to government assistance as it can help to alleviate their financial burden and improve their competitiveness in the industry.

4.7.1.2 Challenges of Adoption of Smart Technologies in the Construction Industry

Two hypotheses are presented as follows:

Null hypothesis (H0): There is no significant difference across the company business activities on the challenges of smart technologies adoption.

Alternative hypothesis (H1): There is a significant difference across the company business activities on the challenges of smart technologies adoption.

Table 4.13: Kruskal-Wallis Test on Company Business Activities (Challenges)

Code	Challenges	Kruskal-Wallis H	Asymp. Sig.
CD2	Lack of demand and interest	11.108	.011
CD3	Legal and contractual uncertainty	8.216	.042

Table 4.13 presents the results of the Kruskal-Wallis Test on company business activities, indicating that two challenges under "External challenges (CD)" have an h-value greater than 7.815 and a p-value below 0.05. The two challenges are **CD2** = "Lack of demand and interest" and **CD3 =** "Legal and contractual uncertainty". This signifies that there is a considerable difference in perspectives of developer, consultant, contractor as well as subcontractor and supplier with regards to the capacity of these challenges in hindering smart technologies adoption. Thus, the null hypothesis (H0) for these challenges is rejected.

Table 4.14: Mean Rank of Challenges of Smart Technologies Adoption in the Construction Industry across Company Business Activities

Code	Challenges	Company Business Activities	N	Mean Rank
CD2	Lack of demand and interest	Developer	41	83.65
		Consultant	50	**101.52**
		Contractor	46	93.46
		Subcontractor / Supplier	38	*68.30*
CD3	Legal and contractual uncertainty	Developer	41	79.22
		Consultant	50	**100.08**
		Contractor	46	93.74
		Subcontractor / Supplier	38	*74.96*

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

As exemplified in Figure 4.14, consultants ranked lack of demand and interest as well as legal and contractual uncertainty higher than other company business activities, which implies that consultants are more aware of the external challenges that affect the adoption of smart technologies. Despite the fact that consultants are inclined to leverage smart technology, some clients may have differing levels of interest or willingness to incorporate them into their projects (Munianday, Rahimi and Esa, 2022). The client's hesitancy could be due to several factors such as their limited knowledge about the technology, apprehension towards data privacy issues, or a preference for conventional methods. Further, Chan, Olawumi and Ho (2019) alluded that clients who had an adverse experience with technologically driven projects in the past may exacerbate their apprehension. As the client's preference is the main driving force behind the decision to incorporate smart technologies into construction projects, consultants are particularly focused on addressing the challenges that emerge from the client's side.

Furthermore, consultants in the construction industry, such as quantity surveyor, are often involved in preparing construction documentation. Thus, it is understandable that they prioritised concerns about the legal framework and the uncertainty surrounding contracts. The reason behind this is that the integration of smart technologies is only feasible if it is incorporated into the contractual planning from the outset (Olanrewaju, et al., 2020). In light of the fact that the contract delineates the authority and obligations of construction stakeholders, the failure to incorporate adequate provisions pertaining to smart technologies will result in legal and financial peril (Almarri, et al., 2019). As such, it is understandable that the consultant prioritise this challenge over other respondents group to prevent prospective legal disputes that could disrupt the client's business operations and reputation.

4.7.2 Kruskal-Wallis Test on Organisational Position

In order to meet the minimum sample size of 30 as spelled out by the Central Limit Theorem (CLT), the "Assistant Director/Technical Director" position is combined with the "Director" position, which resulted in the creation of a new category of position titled "Director/Assistant Director/Technical Director." Therefore, Kruskal-Wallis Test was conducted on the four categories of organisational position, which are “Junior Executive”, “Senior Executive”, “Manager / Team Leader / Supervisor” and “Director / Assistant Director / Technical Director”. Detecting significant differences between the four respondent categories listed above requires a p-value less than 0.05 and a chi-square value greater than 7.815, with a degree of freedom of 3.

4.7.2.1 Drivers of Adoption of Smart Technologies in the Construction Industry

Two hypotheses are presented as follows:

Null hypothesis (H0): There is no significant difference across the organisational position on the drivers of smart technologies adoption.

Alternative hypothesis (H1): There is a significant difference across the organisational position on the drivers of smart technologies adoption.

Table 4.15: Kruskal-Wallis Test on Organisational Position (Drivers)

Code	Drivers	Kruskal-Wallis H	Asymp. Sig.
DA2	Government policy	16.495	<.001
DA3	Government enforcement	15.958	.001
DA4	Client demand and acceptance	14.860	.002
DB2	Practitioners’ competency	12.477	.006
DB3	Training and educational program	14.332	.002
DB4	Organisation culture	10.242	.017
DB5	Sufficient financial resources	10.000	.019
DC1	Proven technology effectiveness	17.025	<.001
DC2	Technology awareness	12.247	.007
DC3	Availability of appropriate technology	19.229	<.001

Table 4.15 denotes the results obtained from Kruskal-Wallis Test on organisational position. There are ten drivers with an h-value greater than 7.815 and a p-value less than 0.05. The drivers are **DA2** = “Government policy”, **DA3** = “Government enforcement”, **DA4** = “Client demand and acceptance”, **DB2** = “Practitioners’s competency”, **DB3** = “Training and educational program”, **DB4** = “Organisation culture”, **DB5** = “Sufficient financial resources”, **DC1** = “Proven technology effectiveness”, **DC2** = “Technology awareness” and **DC3** = “Availability of appropriate technology”. Thus, the null hypothesis (H0) for the ten drivers is rejected.

Table 4.16: Mean Rank of Drivers of Smart Technologies Adoption in the Construction Industry across Organisational Position

Code	**Drivers**	**Organisational Position**	**N**	**Mean Rank**
DA2	Government policy	Junior Executive	55	89.25
		Senior Executive	44	95.32
		Manager / Team Leader / Supervisor	42	**99.11**
		Director / Assistant Director / Technical Director	34	*59.01*
DA3	Government enforcement	Junior Executive	55	97.26
		Senior Executive	44	88.91
		Manager / Team Leader / Supervisor	42	**98.05**
		Director / Assistant Director / Technical Director	34	*59.43*
DA4	Client demand and acceptance	Junior Executive	55	92.58
		Senior Executive	44	90.70
		Manager / Team Leader / Supervisor	42	**101.19**
		Director / Assistant Director / Technical Director	34	*60.79*
DB2	Practitioners' competency	Junior Executive	55	86.77
		Senior Executive	44	96.07
		Manager / Team Leader / Supervisor	42	**97.45**
		Director / Assistant Director / Technical Director	34	*63.00*
DB3	Training and educational program	Junior Executive	55	86.77
		Senior Executive	44	96.34
		Manager / Team Leader / Supervisor	42	**99.00**
		Director / Assistant Director / Technical Director	34	*61.79*
DB4	Organisational culture	Junior Executive	55	94.58
		Senior Executive	44	87.79
		Manager / Team Leader / Supervisor	42	**97.43**
		Director / Assistant Director / Technical Director	34	*65.41*
DB5	Sufficient financial resources	Junior Executive	55	92.92
		Senior Executive	44	86.70
		Manager / Team Leader / Supervisor	42	**99.93**
		Director / Assistant Director / Technical Director	34	*66.99*

Table 4.16 (Continued)

Code	Drivers	Organisational Position	N	Mean Rank
DC1	Proven technology effectiveness	**Junior Executive**	55	**101.12**
		Senior Executive	44	89.57
		Manager / Team Leader / Supervisor	42	92.43
		Director / Assistant Director / Technical Director	34	*59.10*
DC2	Technology awareness	**Junior Executive**	55	**100.28**
		Senior Executive	44	92.60
		Manager / Team Leader / Supervisor	42	86.38
		Director / Assistant Director / Technical Director	34	*64.18*
DC3	Availability of appropriate technology	**Junior Executive**	55	**102.49**
		Senior Executive	44	92.41
		Manager / Team Leader / Supervisor	42	88.60
		Director / Assistant Director / Technical Director	34	*58.12*

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

As demonstrated in Table 4.16, it is revealed that the respondents from middle managerial positions such as “Manager / Team Leader / Supervisor” have a higher mean rank in comparison to those in junior executive, senior executive, and directorial positions, in terms of the external drivers (DA) and organisational drivers (DB). As influential individuals responsible for designing and implementing smart technologies for project delivery, respondents in middle managerial positions valued government policy that serve as essential references and guidelines for new practices (Shojaei, Oti-Sarpong and Burgress, 2022). In turn, this will confront their short-term mindset, leading to a surge in the company's competitiveness. In addition, respondents in middle managerial positions will have a broader grasp of the advantages of adopting smart technology as a result of the government mandate on BIM implementation in public construction projects exceeding RM100 million (Othman, et al., 2021). This will increase confidence and trust in smart technologies, thereby encouraging their adoption in future projects. In the same vein, the manager is liable for ensuring the client’s requirements are satisfied, given their frequent interactions with clients.

Apart from that, respondents in middle managerial positions stressed the significance of training and educational programmes in promoting the adoption of smart technologies, as this will ramp up the competency of the project team. This is buttressed by Awwad, et al. (2020), who affirmed that the process of adopting smart technologies will be simplified if the project team has extensive knowledge and experience with them. Moreover, respondents in middle managerial positions emphasised organisational culture, as they tend to exert influence on other organisational members to embrace it after realising the merit of smart technologies (Chen, et al., 2019). Concurrently, successful smart technologies adoption requires the managers' willingness of to commit sufficient resources in terms of financial and technological (Ghobakhloo, et al., 2022).

In addition, respondents with "Junior Executive" positions placed a high priority on technological drivers (DC). The reason behind this is that they are more directly engaged in the day-to-day application of various smart technologies, such as drones for data collection, cloud computing for data sharing and so forth. As a result, they are more enlightened about the effectiveness of smart technology in their work. Further, Zulu, et al. (2023) uncovered that individuals with expertise in smart technologies are typically the junior executive, which reside at the bottom of the organisational hierarchy. As such, it is not astonishing that junior executives are more aware of recent developments as well as the availability of new software and hardware.

4.7.2.2 Challenges of Adoption of Smart Technologies in the Construction Industry

Two hypotheses are presented as follows:

Null hypothesis (H0): There is no significant difference across the organisational position on the challenges of smart technologies adoption.

Alternative hypothesis (H1): There is a significant difference across the organisational position on the challenges of smart technologies adoption.

Table 4.17: Kruskal-Wallis Test on Organisational Position (Challenges)

Code	**Challenges**	**Kruskal-Wallis H**	**Asymp. Sig.**
CB1	Technology complexity	15.629	.001
CB2	Technology interoperability issue	9.836	.020
CB3	Lack of internet infrastructure	10.221	.017
CC2	Resistance to change	11.095	.011
CC3	Unfamiliarity of smart technology	9.086	.028
CC4	Lack of proper training	9.101	.028
CC5	Lack of organisational support	12.511	.006
CD2	Lack of demand and interest	8.818	.032
CD3	Legal and contractual uncertainty	9.414	.024

Table 4.17 illustrates the outcomes of the Kruskal-Wallis Test conducted on the organisational position concerning the challenges related to the adoption of smart technologies. There are nine challenges with an h-value more than 7.815 and a p-value less than 0.05. The challenges are **CB1** = "Technology complexity", **CB2** = "Technology interoperability issue", **CB3** = "Lack of internet infrastructure", **CC2** = "Resistance to change", **CC3** = "Unfamiliarity of smart technology", **CC4** = "Lack of proper training", **CC5** = "Lack of organisational support", **CD2** = "Lack of demand and interest" and **CD3** = "Legal and contractual uncertainty". Thus, the null hypothesis (H0) for the nine challenges is rejected.

Table 4.18: Mean Rank of Challenges of Smart Technologies Adoption in the Construction Industry across Organisational Position

Code	**Challenges**	**Organisational Position**	**N**	**Mean Rank**
CB1	Technology complexity	**Junior Executive**	55	**101.13**
		Senior Executive	44	81.61
		Manager / Team Leader / Supervisor	42	97.43
		Director / Assistant Director / Technical Director	34	*63.30*
CB2	Technology interoperability issue	**Junior Executive**	55	**96.64**
		Senior Executive	44	87.27
		Manager / Team Leader / Supervisor	42	95.17
		Director / Assistant Director / Technical Director	34	*65.63*

Table 4.18 (Continued)

Code	**Challenges**	**Organisational Position**	**N**	**Mean Rank**
CB3	Lack of internet infrastructure	**Junior Executive**	55	**94.06**
		Senior Executive	44	87.51
		Manager / Team Leader / Supervisor	42	87.57
		Director / Assistant Director / Technical Director	34	*68.54*
CC2	Resistance to change	Junior Executive	55	87.23
		Senior Executive	44	95.75
		Manager / Team Leader / Supervisor	42	**99.24**
		Director / Assistant Director / Technical Director	34	*65.34*
CC3	Unfamiliarity of smart technology	Junior Executive	55	91.74
		Senior Executive	44	86.44
		Manager / Team Leader / Supervisor	42	**98.71**
		Director / Assistant Director / Technical Director	34	*68.07*
CC4	Lack of proper training	Junior Executive	55	93.71
		Senior Executive	44	89.51
		Manager / Team Leader / Supervisor	42	**96.19**
		Director / Assistant Director / Technical Director	34	*66.69*
CC5	Lack of organisational support	Junior Executive	55	91.87
		Senior Executive	44	94.67
		Manager / Team Leader / Supervisor	42	**96.70**
		Director / Assistant Director / Technical Director	34	*62.24*
CD2	Lack of demand and interest	Junior Executive	55	93.49
		Senior Executive	44	88.35
		Manager / Team Leader / Supervisor	42	**96.64**
		Director / Assistant Director / Technical Director	34	*66.79*
CD3	Legal and contractual uncertainty	Junior Executive	55	92.75
		Senior Executive	44	92.14
		Manager / Team Leader / Supervisor	42	**95.41**
		Director / Assistant Director / Technical Director	34	*65.60*

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

According to Table 4.18, respondents with the "Junior Executive" position have a greater inclination for technological challenges (CB) as an impediment to the adoption of smart technologies, whereas those in the "Director/ Assistant Director/ Technical Director" category ranked this aspect as the least significant. In Malaysia, the incorporation of smart technologies such as BIM into the curriculum of higher learning institutions is limited (Wong and Gray, 2019). Despite having a theoretical understanding of smart technologies, graduates entering the industry lack the hands-on expertise necessary to apply smart technology to practical work on construction projects (Zhao, et al., 2022). Therefore, this assertion is akin to the findings of this study where the junior executives, who are usually fresh graduates in construction field often grappled with technology complexity and interoperability issues. Other than that, junior executives are concerned about issues with internet connectivity since they would affect productivity at work (Farouk, et al., 2023).

On the other hand, respondents from the middle managerial level with “Manager / Team Leader / Supervisor” position express an elevated focus on organisational (CC) and external challenges (CD). Primarily, the responsibilities of manager, team leader, and supervisor could expound their higher ranking on organisational challenges (CC) than the other three positions. This is consistent with the findings of Munianday, Rahimi and Esa (2022), who attested that managers face difficulties in altering the mindset of top-level management, which are acclimatised to conventional ways of working and lack familiarity with the advantages of smart technologies. This will contribute to resistance to change and a lack of support for the implementation of such technologies. Further, Demirkesen and Tezel (2022) claimed that a dearth of labour force due to an absence of appropriate training prompts managers to be sceptical about the competency of the available labour force, thereby reducing their willingness to embrace smart technology-driven change.

In addition, respondents in middle managerial positions prioritise on lack of demand and interest from the client as well as legal and contractual uncertainty. This is justified by the fact that effective adoption of smart technology requires both client and governmental support. According to Olanrewaju, et al. (2020), the adoption of smart technologies will be hindered if clients insist on utilising conventional approaches for their projects. Concurrently, the uncertainties stemming from legal and contractual processes may pose challenges and lead to disputes (Li, et al., 2019). Thus, individuals occupying middle managerial positions express apprehension owing to their accountability for the project's overall achievement.

4.7.3 Kruskal-Wallis Test on Working Experience

In an effort to fulfil the minimum sample size of 30 for each working experience as required by CLT, the categories of "16 – 20 years" was merged with "More than 20 years" to create the new categories of "More than 16 years". Therefore, the respondents were grouped into four categories based on their working experience, which are "Less than 5 years", "5 – 10 years", "11 – 15 years" and "More than 16 years". Since four groups of respondents were assessed, the p-value should be less than 0.05, and the chi-square value should be greater than 7.815, based on a degree of freedom of 3.

4.7.3.1 Drivers of Adoption of Smart Technologies in the Construction Industry

Two hypotheses are presented as follows:

Null hypothesis (H0): There is no significant difference across the working experience on the drivers of smart technologies adoption.

Alternative hypothesis (H1): There is a significant difference across the working experience on the drivers of smart technologies adoption.

Table 4.19: Kruskal-Wallis Test on Working Experience (Drivers)

Code	Drivers	Kruskal-Wallis H	Asymp. Sig.
DA2	Government policy	15.862	.001
DA3	Government enforcement	9.766	.021
DA4	Client demand and acceptance	12.016	.007
DB2	Practitioners' competency	13.640	.003
DB3	Training and educational program	13.714	.003
DB4	Organisational culture	9.423	.024
DC1	Proven technology effectiveness	19.071	<.001
DC2	Technology awareness	13.793	.003
DC3	Availability of appropriate technology	21.631	<.001

Table 4.19 manifests the findings acquired from Kruskal-Wallis Test regarding the drivers of adopting smart technologies in relation to working experience. There are nine drivers with an h-value more than 7.815 and a p-value less than 0.05. The drivers are **DA2** = “Government policy”, **DA3** = “Government enforcement”, **DA4** = “Client demand and acceptance”, **DB2** = “Practitioners’ competency”, **DB3** = “Training and educational program”, **DB4** = “Organisation culture”, **DC1** = “Proven technology effectiveness”, **DC2** = “Technology awareness” and **DC3** = “Availability of appropriate technology”. Thus, the null hypothesis (H0) for the nine drivers is rejected.

Table 4.20: Mean Rank of Drivers of Smart Technologies Adoption in the Construction Industry across Working Experience

Code	**Drivers**	**Working Experience**	**N**	**Mean Rank**
DA2	Government policy	Less than 5 years	57	91.09
		5 - 10 years	43	88.93
		11 – 15 years	34	**102.72**
		More than 16 years	41	*64.00*
DA3	Government enforcement	Less than 5 years	57	92.35
		5 - 10 years	43	83.66
		11 – 15 years	34	**100.82**
		More than 16 years	41	*71.12*
DA4	Client demand and acceptance	Less than 5 years	57	93.95
		5 - 10 years	43	93.42
		11 – 15 years	34	**98.22**
		More than 16 years	41	*65.57*
DB2	Practitioners’ competency	Less than 5 years	57	86.81
		5 - 10 years	43	96.05
		11 – 15 years	34	**99.21**
		More than 16 years	41	*64.96*
DB3	Training and educational program	Less than 5 years	57	95.27
		5 - 10 years	43	88.59
		11 – 15 years	34	**98.88**
		More than 16 years	41	*64.77*
DB4	Organisational culture	Less than 5 years	57	94.86
		5 - 10 years	43	88.94
		11 – 15 years	34	**96.35**
		More than 16 years	41	*68.41*
DC1	Proven technology effectiveness	**Less than 5 years**	57	**102.33**
		5 - 10 years	43	90.53
		11 – 15 years	34	93.62
		More than 16 years	41	*60.76*

Table 4.20 (Continued)

Code	Drivers	Working Experience	N	Mean Rank
DC2	Technology awareness	**Less than 5 years**	57	**103.41**
		5 - 10 years	43	89.49
		11 – 15 years	34	85.87
		More than 16 years	41	*66.78*
DC3	Availability of appropriate technology	**Less than 5 years**	57	**106.28**
		5 - 10 years	43	88.27
		11 – 15 years	34	89.10
		More than 16 years	41	*61.39*

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

Table 4.20 divulges that respondents with "less than 5 years" of work experience demonstrate an elevated propensity towards technological drivers (DC). This is in line with the findings of Zhao, et al. (2022), where there is a significant difference in technical-related factors of smart technologies between construction practitioners with different experience. The underlying reason is that they are more technologically savvy and conversant than individuals with extensive job experience (Zulu, Saad, and Gledson, 2023). In other instances, they have greater technology exposure and practical experience. Thus, this proffers their higher ranking on proven technologies effectiveness, technology awareness, and availability of technology compared to the other three categories of working experience.

Meanwhile, the respondents who have accumulated "11-15 years" of working experience demonstrate a greater inclination towards external (DA) and organisational drivers (DB). This indicates that construction practitioners' perceptions of drivers of smart technologies adoption are significantly shaped by their extensive experience managing diversified projects over the course of their careers. The justification for this lies in the ability of experienced construction professionals to comprehend external factors such as government policies and enforcement, and subsequently implement internal changes within their organisation that foster the deployment of smart technologies (Tavallaei, et al., 2022). Similarly, Zhao, et al. (2022) advocated that practitioners with extensive work experience exhibit a heightened understanding of the advantages presented by smart technologies, which leads to a deeper comprehension of organizational culture and support. Thus, this clarifies the reason respondents with "11 to 15 years" working experience ranked project team competency, training and educational programme, and organisational culture higher than other respondents.

4.7.3.2 Challenges of Adoption of Smart Technologies in the Construction Industry

Two hypotheses are presented as follows:

Null hypothesis (H0): There is no significant difference across the working experience on the challenges of smart technologies adoption.

Alternative hypothesis (H1): There is a significant difference across the working experience on the challenges of smart technologies adoption.

Table 4.21: Kruskal-Wallis Test on Working Experience (Challenges)

Code	Challenges	Kruskal-Wallis H	Asymp. Sig.
CB1	Technology complexity	9.364	.025
CB2	Technology interoperability issue	10.370	.016
CC2	Resistance to change	10.095	.018
CC3	Unfamiliarity of smart technology	10.004	.019
CC5	Lack of organisational support	8.477	.037
CD2	Lack of demand and interest	9.096	.028
CD3	Legal and contractual uncertainty	9.806	.020

Table 4.21 unveils the empirical insights obtained from the Kruskal-Wallis Test on the challenges associated with the adoption of smart technologies concerning the respondents' working experience. There are seven challenges with an h-value larger than 7.815 and a p-value less than 0.05. The challenges are **CB1** = “Technology complexity”, **CB2**= “Technology interoperability issue”, **CC2** = “Resistance to change, **CC3** = “Unfamiliarity of smart technology”, **CC5** = “Lack of organisational support”, **CD2** = “Lack of demand and interest” and **CD3** = “Legal and contractual uncertainty”. Thus, the null hypothesis (H0) for the seven challenges is rejected.

Table 4.22: Mean Rank of Challenges of Smart Technologies Adoption in the Construction Industry across Working Experience

Code	Challenges	Working Experience	N	Mean Rank
CB1	Technology complexity	**Less than 5 years**	57	**97.14**
		5 - 10 years	43	94.14
		11 – 15 years	34	87.94
		More than 16 years	41	*68.90*
CB2	Technology interoperability issue	**Less than 5 years**	57	**95.99**
		5 - 10 years	43	94.51
		11 – 15 years	34	92.19
		More than 16 years	41	*66.59*
CC2	Resistance to change	Less than 5 years	57	90.35
		5 - 10 years	43	**98.50**
		11 – 15 years	34	95.72
		More than 16 years	41	*67.93*
CC3	Unfamiliarity of smart technology	Less than 5 years	57	97.18
		5 - 10 years	43	**98.03**
		11 – 15 years	34	79.79
		More than 16 years	41	*71.51*
CC5	Lack of organisational support	Less than 5 years	57	91.95
		5 - 10 years	43	**98.28**
		11 – 15 years	34	90.46
		More than 16 years	41	*69.70*
CD2	Lack of demand and interest	Less than 5 years	57	95.02
		5 - 10 years	43	**98.91**
		11 – 15 years	34	79.74
		More than 16 years	41	*72.32*
CD3	Legal and contractual uncertainty	Less than 5 years	57	96.78
		5 - 10 years	43	**97.03**
		11 – 15 years	34	83.88
		More than 16 years	41	*69.96*

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

As showcased in Table 4.22, the respondents with "5 - 10 years" of work experience exhibit a higher average ranking in the realms of organisational (CC) and external challenges (CD), while those with "less than 5 years" of work experience demonstrate a greater affinity towards technological challenges (CB). In general, individuals who possess less than 5 years of working experience are commonly novice entrants to the construction industry. According to Omer, et al. (2022), the insufficient inclusion of smart technologies in tertiary education syllabuses impairs fresh graduates from acquiring the necessary skills to comprehend and apply various emerging technologies in the industry. Hence, considerable time is required for fresh graduates to use smart technologies in project delivery proficiently. Consequently, this can expound their higher ranking in terms of technology complexity and interoperability issues as compared to other groups of respondents.

Apart from that, respondents with professional experience spanning from “5 – 10 years” have identified organisational (CC) and external (CD) challenges as significant areas of concern. This stems from the fact that these aspects of challenges are particularly relevant to their responsibilities, which include managing and supervising project as well as liaising with client. In Malaysia, a significant number of design consultants with years of experience have expressed their preference for AutoCAD, considering its ability to produce detailed drawings compared to BIM (Farouk, et al., 2023). This phenomenon is ascribed to unfamiliarity with the potential benefits of smart technologies that will subsequently contribute to an upsurge in resistance to change. Since top management retains the ultimate authority over decision-making, it is unsurprising that individuals with "5-10 years" of experience perceive inadequate organisational support as a hindrance to the adoption of smart technologies.

4.7.4 Kruskal-Wallis Test on Company Size

In an effort to adhere to the requirement of CLT for a minimum sample size of 30 for each company size, the category of “Less than 5 employees” was consolidated with “5-29 employees” to establish the new category of “Less than 29 employees”. Therefore, the respondents were grouped into three categories based on the size of their company, which are “Less than 29 employees” (small firms), “30 - 75 employees” (medium firms) and “More than 75 employees” (large firms). Since three groups of respondents were examined, there are significant differences when the p-value is less than 0.05 and the chi-square value is greater than 5.991, which is determined by a degree of freedom of 2.

4.7.4.1 Drivers of Adoption of Smart Technologies in the Construction Industry

Two hypotheses are presented as follows:

Null hypothesis (H0): There is no significant difference across the company size on the drivers of smart technologies adoption.

Alternative hypothesis (H1): There is a significant difference across the company size on the drivers of smart technologies adoption.

Table 4.23: Kruskal-Wallis Test on Company Size (Drivers)

Code	Drivers	Kruskal-Wallis H	Asymp. Sig.
DA3	Government enforcement	7.030	.030
DB4	Organisational culture	9.631	.008
DC1	Proven technology effectiveness	7.827	.020
DC2	Technology awareness	7.494	.024
DC3	Availability of appropriate technology	7.311	.026

Table 4.23 presents the results of the Kruskal-Wallis Test on the drivers of smart technologies adoption concerning the size of the companies, revealing that five drivers have an h-value greater than 5.991 and a p-value below 0.05. The drivers are **DA3 =** “Government enforcement”, **DB4 =** “Organisational culture”, **DC1 =** “Proven technology effectiveness”, **DC2 =** “Technology awareness” and **DC3 =** “Availability of appropriate technology”. Apparently, there are significant heterogeneity across small firms, medium firms and large firms regarding the drivers of smart technologies adoption. Thus, the null hypothesis (H0) for the five drivers is rejected.

Table 4.24: Mean Rank of Drivers of Smart Technologies Adoption in the Construction Industry across Company Size

Code	Drivers	Company Size	N	Mean Rank
DA3	Government enforcement	**Less than 29 employees**	58	**97.96**
		30-75 employees	50	*73.74*
		More than 75 employees	67	90.01
DB4	Organisational culture	Less than 29 employees	58	89.09
		30-75 employees	50	*71.54*
		More than 75 employees	67	**99.34**

Table 4.24 (Continued)

Code	Drivers	Company Size	N	Mean Rank
DC1	Proven technology effectiveness	Less than 29 employees	58	93.76
		30-75 employees	50	*72.05*
		More than 75 employees	67	**94.92**
DC2	Technology awareness	Less than 29 employees	58	90.36
		30-75 employees	50	*72.86*
		More than 75 employees	67	**97.25**
DC3	Availability of appropriate technology	**Less than 29 employees**	58	**94.36**
		30-75 employees	50	*72.76*
		More than 75 employees	67	93.87

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

Based on Table 4.24, it can be inferred that the most apparent significant difference among respondents from varying company size pertaining to the drivers of smart technologies adoption lies in technological drivers (DC). Large firms with “More than 75 employees” tend to place a greater focus on proven technology effectiveness and technology awareness than small and medium firms. The underlying reason behind this is that large firms have the capacity to devote a significant budget for technology investment (Demirkesen and Tezel, 2022). This affords them the chance to invest in top-notch software and hardware, which are known to positively impact their project (Shojaei, Oti-Sarpong and Burgress, 2022). Simultaneously, large firms can invest in continuous capacity training programs designed to enhance the technological expertise of their employees. This in turn can promote the adoption of smart technologies by raising the technological awareness and skills of their workforce.

Aside from that, the respondents employed in small firms demonstrate a heightened inclination towards government enforcement under external drivers (DA) as catalysts for enhancing smart technologies adoption. This finding coincides with the empirical research conducted by Maroufkhani, et al. (2022), which indicates that external factors significantly influence small construction firms due to their weaker position in the industry. Since small firms have limited resources, the top managers of such firms tend to prioritise compliance with government enforcement to avoid financial losses that may arise from penalties or fines. Nevertheless, Ghobakhloo, et al. (2022) asserted that small firms prioritise external support such as financial assistance, tax exemptions, and client requirements over external pressure in adopting smart technologies, which contradicts the findings of this study.

In terms of organisational drivers (DB), the respondents from large firms placed a greater emphasis on organisation culture than small and medium firms. Despite having greater financial resources, large companies may confront difficulties in implementing smart technologies due to their rigid and hierarchical organisational structure, large workforce, and resistance to change from traditional ways of practice (Saka and Chan, 2020). Therefore, it is essential to focus on fostering a positive organisational culture that promotes innovation, as the success of projects that involve organisational change is greatly influenced by the prevailing culture within the organisation.

4.7.4.2 Challenges of Adoption of Smart Technologies in the Construction Industry

Two hypotheses are presented as follows:

Null hypothesis (H0): There is no significant difference across the company size on the challenges of smart technologies adoption.

Alternative hypothesis (H1): There is a significant difference across the company size on the challenges of smart technologies adoption.

Table 4.25: Kruskal-Wallis Test on Company Size (Challenges)

Code	Challenges	Kruskal-Wallis H	Asymp. Sig.
CA1	Extensive upfront investment	8.345	.015
CB2	Technology interoperability issue	7.241	.027

Table 4.25 depicts the outcomes of the Kruskal-Wallis test conducted on the size of the companies regarding the challenges faced in the adoption of smart technologies. The test demonstrated that two challenges, **CA1**= "Extensive upfront investment," and **CB2**= “Technology interoperability issue” has a p-value less than 0.05 and h-value greater than 5.991, indicating that these challenges were statistically significant and that there were differences in the

perceptions of these challenges across companies of varying sizes. Therefore, the null hypothesis (H0) is rejected for these challenges.

Table 4.26: Mean Rank of Challenges of Smart Technologies Adoption in the Construction Industry across Company Size

Code	Challenges	Company Size	N	Mean Rank
CA1	Extensive upfront investment	**Less than 29 employees**	58	**98.00**
		30-75 employees	50	*72.30*
		More than 75 employees	67	91.06
CB2	Technology interoperability issue	**Less than 29 employees**	58	**95.28**
		30-75 employees	50	*72.30*
		More than 75 employees	67	93.42

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

As illustrated in Figure 4.26, small firms express a stronger proclivity for economic challenges (CA) and technological challenges (CB) compared to medium and large-sized organisations. This corresponds with the study of Makabate, et al. (2022), which observed significant differences in the challenges of BIM adoption across organisations of varying sizes.

Considering the economic challenges (CA), the findings of this study indicated that small firms emphasise the extensive upfront investment associated with smart technologies adoption. This is consistent with the empirical study of Ahmed, et al. (2022), who accentuated that economic challenges exert a more pronounced influence on small firms than larger firms. The reason behind this is that small firms usually have weaker financial standings, which confines their ability to cover the significant initial expenses associated with smart technologies adoption (Hall, et al., 2022). These expenses could include acquiring new software and hardware, altering their operations, and providing the necessary training to their employees. The uncertainty surrounding the return on investment (ROI) and the absence of an assured pipeline for securing future construction projects diminish their confidence in smart technologies investments as they are apprehensive about their survivability in the industry (Farouk, et al., 2023).

Apart from that, small firms perceived technology interoperability issue as a significant impediment to the adoption of smart technologies under technological challenges (CC). This is in line with the findings of Hall, et al. (2022), where small construction firms in United Kingdom were apprehensive about interoperability challenges of current software packages. The establishment of well-developed software interoperability can significantly reduce the total cost of a project and expedite the ROI. However, achieving such interoperability entails a substantial investment in terms of time and financial resources devoted to development (Munianday, Rahimi and Esa, 2022). Consequently, this issue has become a concern for small firms that operate on constrained budgets, thereby exacerbating their reluctance to adopt smart technologies.

4.8 Summary of Chapter

This chapter displays a comprehensive discourse of the adoption level of smart technologies, along with the drivers and challenges that influence its adoption. After receiving a total of 175 surveys, various statistical tests, including Cronbach’s Alpha Reliability Test, Arithmetic Mean, Friedman Test, Spearman’s Correlation Test, and Kruskal-Wallis Test, were employed to analyse the data.

The outcome of arithmetic means demonstrated that Cloud Computing (ST3) had the highest adoption rate among the smart technologies utilised by respondents in their current construction projects. Apart from that, the Friedman test indicated that respondents highly valued organisational drivers (DB) while assigning the least importance to technological drivers (DC). In terms of challenges associated with adopting smart technologies, respondents' primary focus was on economic challenges (CA), while technological challenges (CD) received the least attention. On top of that, the findings of the Spearman's Correlation test demonstrated that the primary drivers and challenges that impact the adoption of smart technologies are related to organisational aspects. Last but not least, the Kruskal-Wallis Test revealed noteworthy distinctions among company business activities, organisational position, work experience, and company size with regards to the drivers and challenges of adopting smart technologies.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter culminates the entire study. It commences with the attainment of the predefined research objectives and proceeds with the contribution of the study, as well as the limitations that were encountered. At the end of the chapter, recommendations for improvements of future studies on relevant topics are proposed.

5.2 Accomplishment of Research Objectives

In the sections that follow, an overview of the accomplishment of the three research objectives is presented.

5.2.1 Objective 1 : To explore the adoption level of smart technologies used in the construction industry

The first objective was accomplished through the synthesis of a literature review and respondents' standpoints on the adoption level of smart technologies in their projects. By reviewing the secondary sources of information, ten types of smart technologies used in the construction industry have been identified, including **ST1**= “Building Information Modelling (BIM)”, **ST2**= “Blockchain”, **ST3**= “Cloud Computing”, **ST4**= “Internet of Things (IoT)”, **ST5**= “Three-Dimensional Concrete Printing (3DCP)”, **ST6**= “Big Data”, **ST7**= “Drones/ Unmanned Aerial Vehicles (UAVs)”, **ST8**= “Construction Robotics”, **ST9**= “Artificial Intelligence (AI)” as well as **ST10**= “Augmented Reality (AR) and Virtual Reality (VR)”. Following that, Arithmetic Mean is performed to rank the adoption levels of smart technologies. A higher mean ranking of smart technologies indicates that they have been adopted to a greater extent. Among the 10 smart technologies, **ST3**= "Cloud Computing" has been embraced the most by construction professionals in their projects, while **ST9**= "Construction Robotics" was adopted the least.

5.2.2 Objective 2 : To ascertain the drivers of adoption of smart technologies in the construction industry

The second research objective was fulfilled by conducting literature review and collecting the perspective of respondents on the drivers of smart technologies adoption. Subsequently, the data gathered was analysed by Friedman test, Spearman's Correlation test and Kruskal-Wallis test.

For the Friedman test, a higher mean ranking of drivers demonstrates that the drivers are prioritised by construction practitioners when comes to enhancing smart technologies adoption. Among the three aspects of drivers, the "Organisational drivers (DB)" is the consider as the most significance drivers for adoption of smart technologies, followed by "External drivers (DA)" and "Technological drivers (DC)". On top of that, Spearman's Correlation test uncovered that "Organisational drivers (DB)" was a noteworthy aspect of drivers. The highest correlation noticed in the relationship between drivers and challenges of smart technologies adoption was **DC1** ="Proven technology effectiveness" and **CC3**="Unfamiliarity of smart technology".

In terms of Kruskal-Wallis Test, the contractors exhibit a higher degree of inclination towards **DA1** = "Government assistance" under external drivers (DA) in comparison to the other three business activities of the company. Considering the organisational position, the respondents who occupied "Manager / Team Leader / Supervisor" position in their organisation mounted a greater emphasis on external (DA) and organisational drivers (DB), while those in "Junior Executive" position displayed a greater focus on technological drivers (DC). Further, respondents with "11-15 years" working experience tend to prioritise external (DA) and organisational drivers (DB), whereas those with "Less than 5 years" of industry experience inclined to concentrate on technological drivers (DC). Last but not least, respondents from small sized firms place a higher priority on external drivers (DA) as compared to medium sized and large sized firms. Meanwhile, large sized firms favour organisational (DB) and technological drivers (DC).

5.2.3 Objective 3 : To discover the challenges of adoption of smart technologies in the construction industry

The third research objective was attained by undergoing the process identical to the process of achieving the second research objective.

For the Friedman test, a higher mean ranking of challenges assigned to challenges implies that construction practitioners have prioritised these challenges as significant hindrances to adoption of smart technologies. Among the four aspects of challenges, the “Economic challenges (CA)” was regarded as the major hurdles to the adoption of smart technologies, followed by “Organisation challenges (CC)”, “External challenges (CD)” and “Technological challenges (CB)”. On top of that, Spearman’s Correlation test divulged that “Organisational challenges (CC)” constituted an important aspect among the challenges.

With regard to the Kruskal-Wallis Test, consultants demonstrate a greater propensity towards external challenges (CD) as contrasted with contractors, developers, subcontractors, and suppliers. In terms of organisational position, it was revealed that respondents who possessed the positions of "Manager/Team Leader/Supervisor" in their companies placed more weight on internal (CC) and external (CD) challenges, while respondents who held the position of "Junior Executive" put a greater emphasis on technological (CB) challenges. Further, respondents with “5-10 years” working experience prioritised organisational (CC) and external challenges (CD), whereas those with “Less than 5 years” of industry experience inclined to focus on technological challenges (CB). Last but not least, respondents from small sized firms exhibit a stronger propensity on economic challenges (CA) and technological challenges (CB) as compared to medium sized and large sized firms.

5.3 Summary of Key Findings of this Research

The advent of Industry 4.0 has provided prospects for the construction industry to transcend its dependence on labour, enhance efficiency and productivity, thereby resulting in greater flexibility to meet future demands. Despite this, the study discovered that the current smart technologies adoption in the Malaysian construction industry is still at low level and has not yet been widely implemented across the entire industry. This is predominantly due to the challenges associated with economic aspects. Meanwhile, the successful implementation of smart technologies is largely contingent upon the organisational related drivers. Thus, it is imperative for the construction industry to overcome these challenges by leveraging the key drivers to fully harness the benefits of smart technologies.

5.4 Research Contributions

This study provided an overview of the implementation of smart technologies in the construction industry by identifying the overall adoption rate of smart technologies, which indicates the degree to which construction practitioners or organisations have integrated these technologies into their current operations, as well as the drivers and barriers impacting their deployment.

Firstly, the findings of this study can serve as the basis for the formulation of digitally driven transformation road map for the Malaysian construction industry. By examining the current adoption rate of smart technologies derived from this study, policymakers, government agencies and professional bodies such as the Ministry of Works as well as Construction Industry Development Board (CIDB) can undertake more proactive action based on the indicated drivers, particularly on smart technologies with low adoption rate. For instance, a variety of effective policies and standard execution framework that coincide with user demands and preferences can be designed to accelerate the digitalisation of the Malaysian construction industry, thereby garnering global competitive advantages.

Besides, the insights gleaned from the research are expected to be of great value to the development of best practices by construction firms for reforming their contemporary operations and pinpointing rooms for improvement. Depending on the nature of their business, construction companies can configure the smart technologies to suit their specific requirements by referencing the rationale behind the adoption of ten distinct types of smart technologies outlined. Simultaneously, the construction firms are able to prioritise challenges in smart technologies adoption, and in turn tailoring strategies to ensure optimum acceptance ahead of committing a substantial amount of money on adoption.

In addition, the list of drivers and challenges presented in this study can be integrated into the existing body of literature on the domain of smart technologies, acting as a reference for researchers undertaking research on this topic in diverse nations or sectors. By taking cognisance of the findings of this study, researchers can also showcase particular areas such as project management and supply chain management that require additional exploration, thereby proposing research questions to address those areas. Further, the findings of this study will equip academics with the necessary theoretical knowledge for developing or refining theories, models, and frameworks in future studies to advance digital transformation in the Malaysian construction industry.

5.5 Research Limitations

Notwithstanding the research contributions, a few limitations are uncovered in this research. In light of the rapid pace rate of technological advancement, it is probable that the findings from this research may be impacted by an array of external factors outside the control of the researcher that may emerge in the future. The uncertainties include alterations in practitioners' behaviours, the emergence of new norms, market dynamics and shifts in the government policies. This may affect the generalisability and reliability of the results over time, as technology may have evolved considerably since the research began.

Besides, the implementation of quantitative research methodology may limit the in-depth exploration of the adoption level of smart technologies notwithstanding its benefits, as it does not allow for a thorough assessment of the respondents' experience and perception. Concurrently, respondents tend to overstate or understate the adoption level of smart technologies with the presence of social desirability biases as opposed to their actual practices. Further, the construction industry involves a variety of distinct stakeholders, and frequently lacks uniformity in respect of construction processes due to the uniqueness of project. As a result, the complexity of synthesising research findings across projects with distinct natures in different regions will increase.

Additionally, it is conceivable that the research findings are not applicable beyond the settings or sample examined since they are mostly based on theoretical concepts. Occasionally, such theories may be founded on assumptions that may not represent the actuality of the matter under scrutiny. This may confine the abilities to arrive at a broader conclusion in the absence of empirical evidence, thereby isolating the research findings from their practical applicability to real-world situations.

5.6 Research Recommendations

Several recommendations are presented for generating future research findings that are more comprehensive. Firstly, future-oriented research methods, including case studies and foresight analysis can be utilised to anticipate future technological breakthroughs and their potential consequences in real-world situations. Besides, longitudinal studies may be conducted due to their capacity to trace the adoption and implications of smart technologies as it evolves. Further, a mixed approach is encouraged for data collection as it capitalises on the strengths of both quantitative and qualitative methods. Investigating from both inductive and deductive viewpoints will certainly result in a deeper comprehension of research problems than just using either approach alone, thereby generating well-grounded outcomes.

Additionally, future research may prioritise comparing the adoption of smart technologies by construction companies with diverse business activities to uncover their practical best practices. This will benchmark their current smart technologies adoption processes to their rivals and industry standards, allowing them to remain abreast of the latest industry trends. Apart from that, a comparative study may be undertaken between construction companies or projects that embraced smart technologies and those that did not in an effort to explore the impact of smart technologies adoption on project performance, including completion time, cost and quality. Moreover, the future study can discover the adoption of smart technologies among professionals working in the office and construction site, as these environments require distinct smart technologies. These studies are necessary to demonstrate empirical evidence smart technologies adoption, thereby bridging the gap between academic research and industry practice.

Apart from that, the distinct characteristics of the construction industry may lead to a different focus on the adoption of smart technologies. This necessitates a thorough study on creating a technology adoption model that can act as a reference for practitioners in the industry. Further, it is recommended that future research concentrate on a specific aspect of drivers and challenges of smart technologies adoption, considering that this study has identified these factors at an aggregate level, encompassing external, organizational, technological, and economic aspects. For instance, the research focusing on the organisational level will result in a more comprehensive review of management viewpoints and actions towards the adoption of smart technologies.

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APPENDICES

Appendix A: Questionnaire

Section A: Demographic Information

1. Which of the following best describes your company's business activities?
   - ☐ Developer
   - ☐ Consultant
   - ☐ Contractor
   - ☐ Sub- Contractor / Supplier
   - ☐ Others (Please specify):___________

2. Which of the following best describes your profession?
   - ☐ Architect
   - ☐ Engineer
   - ☐ Quantity Surveyor
   - ☐ Others (Please specify):___________

3. What is your position in your organisation?
   - ☐ Junior Executive
   - ☐ Senior Executive
   - ☐ Manager/ Team Leader / Supervisor
   - ☐ Assistant Director / Technical Director
   - ☐ Director
   - ☐ Others (Please specify):___________

4. How many years of working experience do you have in the construction industry?
   - ☐ Less than 5 years
   - ☐ 5 – 10 years
   - ☐ 11 – 15 years
   - ☐ 16 – 20 years
   - ☐ More than 20 years

5. How many employees in your organisation?
   - ☐ Less than 5 employees
   - ☐ 5 - 29 employees
   - ☐ 30 - 75 employees
   - ☐ More than 75 employees

Section B: Adoption level of smart technologies used in the construction industry

Industry 4.0 has brought self-monitoring, self-organizing, and self-executing technologies, which is commonly known as smart technologies to revolutionise the construction industry. The adoption of smart technologies is regarded as a major turning point in the industry due to their ability to mitigate a variety of issues plaguing the industry, such as cost overruns, project delays, skills shortages, environmental pollution, stagnant productivity, rising injury rates and so forth. Undoubtedly, smart technologies appear to be a viable solution for streamlining construction operations.

To your fullest extent, please specify the current adoption level of the following smart technologies in your construction project.

Type of smart technologies used in the construction industry	**Never adopt (1)**	**Seldom adopt (2)**	**Sometimes adopt (3)**	**Usually adopt (4)**	**Always adopt (5)**
Building Information Modelling (BIM)					
Blockchain, e.g., Smart Contract					
Cloud Computing, e.g., Google Drive, Microsoft 365, Dropbox					
Three-Dimensional Concrete Printing (3DCP)					
Internet of Things (IoT), e.g., Sensors					
Big Data					
Artificial Intelligence (AI)					
Drones / Unmanned Aerial Vehicles (UAVs)					
Construction Robotics, e.g., Bricklaying robot, concreting robot, Rebar-tying robot, and Welding robot					
Augmented Reality (AR) and Virtual Reality (VR)					

Section C: Drivers of Adoption of Smart Technologies in the Construction Industry

The potential drivers influencing smart technologies adoption in the construction industry are listed below. From your point of view, what is your degree of agreement on the following drivers?

Drivers of Adoption of Smart Technologies in the Construction Industry	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
Government assistance in the form of financing and technological infrastructure					
Government policy including legislation, procedure, and administrative actions, e.g. National Construction Policy (NCP) 2030					
Government enforcement that comprises guidelines and statutes, e.g., mandatory enforcement of BIM					
Client demand and acceptance regarding smart technologies adoption in construction project					
Top management support, dedication, and willingness to adopt new technology					
Project team's competency with respect to smart technologies					
Training and educational program for periodically upskill the employees					
Organizational culture that is supportive, open to change, and human-centered					

Drivers of adoption of smart technologies in the construction industry	**Strongly disagree (1)**	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly agree (5)**
Availability of sufficient financial resources to cover a range of expenses associated with the adoption of smart technologies					
Proven effectiveness of smart technologies, such as the ability of smart technologies to deliver greater benefits than conventional working methods					
Awareness on the current status of smart technologies adoption					
Availability of appropriate software and hardware that led to effective adoption of smart technologies					

Section D: Challenges of Adoption of Smart Technologies in the Construction Industry

The prospective challenges that will impede the smart technologies adoption in the construction industry are presented below. In your opinion, what is your level of agreement on the following challenges?

Challenges of Adoption of Smart Technologies in the Construction Industry	**Strongly disagree (1)**	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly agree (5)**
Extensive upfront investment required for smart technologies adoption					
Substantial operational and maintenance costs to expand smart technologies' capabilities for an extended period of time					
Complexity of adopting smart technologies, particularly at the initial stage					
Incompatibility between smart technologies and other existing software and technologies in the construction industry, which will lead to errors and data loss while transmitting data					
Lack of reliable and stable internet infrastructure to allow smart technologies operate to their full potential					
Shortage of digitally literate employees in the construction industry					

Challenges of Adoption of Smart Technologies in the Construction Industry	**Strongly disagree (1)**	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly agree (5)**
Resistance to change, reluctance to abandon conventional working methods until new innovation has achieved full maturity in the industry					
Unfamiliarity of smart technologies in terms of proper techniques and strategies for operating smart technologies					
Lack of proper staff training due to the significant cost and lengthy duration involved					
Lack of organisational support, particularly from the top management					
Inadequate uniform standards and guidelines for smart technologies adoption					
Lack of demand and interest by client who persistently prefers conventional construction methods for their project					
Lack of legal framework and contractual uncertainty as smart technology-related provisions have yet to be included into the prevalent standard form of contract					

End of Questionnaire Survey

Thank you very much for participating in this survey.