ASSESSING THE READINESS OF MALAYSIAN CONSTRUCTION INDUSTRY TOWARDS CONSTRUCTION 4.0

CHIA CHI WEI

UNIVERSITI TUNKU ABDUL RAHMAN

ASSESSING THE READINESS OF MALAYSIAN CONSTRUCTION INDUSTRY TOWARDS CONSTRUCTION 4.0

CHIA CHI WEI

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

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

May 2024

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.

Signature :

Name : Chia Chi Wei

ID No. : 19UEB03134

Date : 19 May 2024

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"ASSESSING THE READINESS OF MALAYSIAN CONSTRUCTION INDUSTRY TOWARDS CONSTRUCTION 4.0"** was prepared by **CHIA CHI WEI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Science (Honours) Quantity Surveying at Universiti Tunku Abdul Rahman.

Approved by,

Signature :

Supervisor : Sr Li Zi Qian

Date : 19 May 2024

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Sr Li Zi Qian for his invaluable advice, guidance and his enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to my loving parents and friends who had helped and given me encouragement during the preparation of my final year project.

Lastly, I would like to thank all the respondents who took their time to answering my questionnaire survey. Their participation significantly contributes to the comprehensiveness of this study.

ABSTRACT

Industry 4.0 impacts all industries, and the construction industry is no exception. Hence, the emergence of “Construction 4.0” denotes a shift towards digitalisation tailored for the construction industry, triggering various governmental policy initiatives. The previous studies mainly focus on tools in enhancing single project areas. This research aims to investigate the adoption of Construction 4.0 digital tools in the Malaysian construction industry. The objectives are to identify the benefits incurred from adopting Construction 4.0 digital tools, to explore the barriers of implementing Construction 4.0 digital tools and to infer the readiness of Construction 4.0 digital tools by the construction industry players. A questionnaire survey gathered data from 171 respondents in Klang Valley, Malaysia, which underwent reliability analysis and various inferential tests such as Friedman Test, Chi-Square Test, Kruskal-Wallis Test and Spearman’s Correlation Coefficient Test. There are 11 digital tools, 10 benefits, 14 barriers, and 6 strategies identified from the literature review and further analysed in this research. The result of the survey revealed that the top 3 recognised benefits incurred from adopting digital tools are “Precise design, measurement and documentation of my project are facilitated by using digital tools”, “Accident and injuries are minimised by using digital tools in my project” and “My workers feel safer working with digital tools on my project”. However, the findings uncovered a weak correlation between past digital tool adoption and future usage recommendations among respondents. This result can be attributed to three main barriers, high implementation cost, lack of expertise and skilled workers and lack of government support. Considering several factors such as inconsistent implementation of digital tools, varying adoption rates among professionals and companies, selective tool usage and adoption barriers for key players, it can be inferred that Malaysian construction industry players are not ready for Construction 4.0. Following that, there is a moderate to weak correlation between the strategies proposed and the barriers encountered. This conveys an important signal that no one-size-fits-all strategy can fully address a specific barrier. In short, collaboration among stakeholders is vital to overcoming barriers and enhancing the construction industry’s readiness for Construction 4.0.

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
AEC	Architecture, Engineering, and Construction
AI	Artificial Intelligence
AR	Augmented Reality
ANOVA	Analysis of Variance
BIM	Building Information Modelling
CAD	Computer-Aided Design
CEO	Chief Executive Officer
CIDB	Construction Industry Development Board
CLT	Central Limit Theorem
CPS	Cyber-Physical System
GDP	Gross Domestic Product
ICT	Information and Communication Technology
IoT	Internet of Things
IR 4.0/4IR	Fourth Industrial Revolution
NCP 2030	National Construction Policy 2030
PDF	Portable Document Format
PPE	Personal Protective Equipment
PWD	Public Works Department
RFID	Radio Frequency Identification
R&D	Research and Development
SME	Small and Medium-Sized Enterprise
SPSS	Statistical Package for Social Sciences
VR	Virtual Reality

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Up to the first quarter of 2023, the construction industry in Malaysia contributes 3.7% to the gross domestic product (GDP), lagging behind sectors like services (59.1%), manufacturing (23.6%), agriculture (6.0%), and quarrying (6.5%) (Department of Statistics Malaysia, 2023). Despite contributing the least to GDP, the construction sector serves as a national facilitator due to its vital role in infrastructure development, job creation, and fostering economic growth (Chen, et al., 2022; Almatari, et al., 2023). As supported by Osunsanmi, et al. (2020); Rafiq, et al. (2021), the construction industry is critical to promoting sustainable development in developing countries, often serving as a significant sector that provides essential infrastructure for economic prosperity.

However, the construction sector is consistently stigmatised as a ‘3D’ industry, which stands for Difficult, Dirty and Dangerous (Mahmood, et al., 2021). Aureliano, et al. (2019); You and Feng (2020); Ribeiro, et al. (2022) also further revealed that the construction industry tends to use traditional labour-intensive industry processes, resulting in increased energy consumption, environmental pollution, safety dangers, and decreased project completion productivity. According to Craveiro, et al. (2019), the construction sector consumes a considerable percentage of the raw materials produced across the world, accounting for 50% of worldwide steel production, and is responsible for 30% of the global greenhouse gas emissions. In addition, the diversified and fragmented nature of the construction sector has led to increasing inefficiencies in its operations and poses obstacles in sustaining significant advancements (Nagy, et al., 2021; Das, et al., 2022).

Nowadays, industries globally are allocating resources for the adoption of technology to accelerate the digital transformation process (Lau, et al., 2021). Technological developments and improvements have been the catalyst behind the development of Industry 4.0, which represents the fourth industrial revolution (Maskuriy, et al., 2019). In response to Asia’s rapid industrialisation, Germany introduced the concept of Industry 4.0 as an initiative at the beginning of the decade (Klinc and Turk, 2019; Forcael, et al., 2020). Besides, Begić and Galić (2021) and Malik, et al. (2023) have shared the same perspective that, unlike previous technological revolutions, Industry 4.0 has the potential to be the first to operate concurrently across the majority of the globe due to the global trend of industrial digitalisation. The rapid growth of Industry 4.0 in manufacturing is gradually affecting all industries, including construction (Perrier, et al., 2020; You and Feng, 2020). Oesterreich and Teuteberg (2016) further highlighted that by integrating concepts and technologies from Industry 4.0, the construction sector has the potential to grow into a technology-oriented industry. As a result, there is a term called ‘Construction 4.0’ which is particularly suited to the construction sector (Perrier, et al., 2020; Kozlovska, et al., 2021; Siriwardhana and Moehler, 2023).

The construction industry is crucial to the global economy, and it is believed that by using the novel digital tools and techniques of Construction 4.0, the construction will be able to achieve better levels of productivity (Ribeiro, et al., 2022). Hence, various countries are putting effort in launching various national policies. In China, the “Made in China 2025” national policy was launched to boost manufacturing industries, which can have an influence on the construction industry through the use of new technologies such as automation as well as digitalisation (Huimin, et al., 2018). Besides, Jākobsone (2022) stated that the German government was establishing “Digital Strategy 2025” by promoting digital transformation as a means of reducing costly planning mistakes and building delays. In Malaysia, several national policies were launched. For instance, CIDB (2020) introduced the Construction Strategic Plan 4.0 (2021–2025) with the objective of reshaping Malaysia’s construction industry into an environmentally friendly environment that includes sophisticated technology and a well-trained workforce. Besides, National Construction Policy 2030 was released by the Prime Minister with the aim to guide the construction industry through a full transition to the digital age (Ministry of Works, 2021). Not only that, the National Fourth Industrial Revolution (4IR) Policy was also launched to provide guidance in promoting coherence in the progress of the 4IR and leveraging innovative 4IR digital tools (Economic Planning Unit, 2021). This indicates that the Malaysian government has high commitment in transforming the construction industry towards Construction 4.0.

Construction 4.0 appears to be a potential to boost the efficiency of the construction sector and shorten the project duration through more technological advancements and engagement as well as stakeholder collaboration (Lim, et al., 2023). There are several digital tools that have been introduced in accordance with national policies in order to facilitate the transition of the construction industry toward Construction 4.0. Yet, the construction industry has a slow adoption rate for digital tools and holds the lowest level of digital maturity (Li, et al., 2019; Karmakar and Delhi, 2021). Newman, et al. (2021) also found that only a small percentage of construction firms have the capacity of effectively employing digital tools. Likewise, Diana, et al. (2019); Begić and Galić (2021) made the same viewpoint that construction is still very low-tech, relying mainly on craft-based processes, therefore Construction 4.0 adoption is going behind schedule and facing significant obstacles. This phenomenon is also applicable to the Malaysian construction industry (Almatari, et al., 2023).

In addition, COVID-19 triggered significant impacts in the Malaysian construction sector, including project suspensions, increased prices, restricted resources, and a 10% to 30% decrease in project productivity, depending on the project (Esa, et al., 2020). Due to its dependence on traditional practices and brick-and-mortar concepts, the construction sector experienced significant obstacles during lockdown and post-lockdown constraints (Ebekozien and Aigbavboa, 2021; Shafei, et al., 2022). Hence, it is vital to understand the importance of the Construction 4.0, especially in the post-pandemic era. As implied by Kozlovska, et al. (2021); Ribeiro, et al. (2022), the implementation of Construction 4.0 has the potential to yield economic advantages by improving effectiveness, output, quality, and collaboration. It may also help to advance sustainability, safety, and public perception of the construction industry. In short, the earlier the transformation to Construction 4.0 takes place, the more substantial and diversified the advantages that may be realised (Zabidin, et al., 2023).

1.2 Problem Statement

Construction 4.0 is derived from the concept of Industry 4.0. Hence, it is not surprisingly that the majority of studies are still focusing on the implementation of Industry 4.0 principles into the construction sector. A lot of research focused on the issues faced while implementing Industry 4.0 concepts in the construction sector as well as suggesting potential solutions to these challenges (Alaloul, et al., 2020; Bajpai and Misra, 2021; Kuzdikbay and Nadeem, 2022; Chen, et al., 2023). Moshood, et al. (2020); Bhattacharya and Momaya (2021); Aliu and Oke (2023)’s study emphasised on the benefits of implementing Industry 4.0 in the construction sector with the use of various technologies. Some studies also assessed the level of implementation of Industry 4.0 technology in the construction industry (Ibrahim, et al., 2022; Ribeiro, et al., 2022).

Construction 4.0 is still a new relative concept in the construction industry. Only a few studies specifically concentrate on the implementation of Construction 4.0 in various aspects, such as benefits and challenges of its implementation (Sawhney, et al., 2020; Karmakar and Delhi, 2021). However, these studies only reported how the Construction 4.0 digital tools bring benefits to particular aspects of the project. For instance, Fakher and Anandh (2022) studied the adoption of Construction 4.0 digital tools to improve communication; Malomane, et al. (2022) explored their influence on site safety enhancement; and Moon, et al. (2020) assessed their potential to increase productivity as well as efficiency. The other related research concentrated exclusively on the specific Construction 4.0 digital tools such as BIM (Begić and Galić, 2021), IoT (Gamil, et al., 2020; Ibrahim, et al., 2021), AR, and VR (Maqsoom, et al., 2023). Apart from that, Osunsanmi, et al. (2020) and Olatunde, et al. (2022)’s studies are about the implementation of Construction 4.0 with its digital tools in South Africa and Nigeria respectively. There is very limited study pertaining to Construction 4.0 in the Malaysian construction industry. The Malaysian government has introduced various national policies to expedite the transformation within the construction industry, it is essential to examine the response of industry players to this shift toward Construction 4.0. The following questions must be addressed as part of this research: What benefits are associated with deploying Construction 4.0

digital tools? What are the obstacles of adopting Construction 4.0 digital tools in construction projects? Are the construction industry players ready to embrace digital tools for the transition towards Construction 4.0?

1.3 Aim and Objectives

This research aims to investigate the adoption of Construction 4.0 digital tools in the Malaysian construction industry. The aim can be realised through the following objectives:

1. To identify the benefits incurred from adopting Construction 4.0 digital tools.
2. To explore the barriers of implementing Construction 4.0 digital tools.
3. To infer the readiness of Construction 4.0 digital tools by construction industry players.

1.4 Research Methodology

This research embraces pragmatism as its philosophical foundation and utilises a quantitative research approach. In order to collect data from the intended respondents, the questionnaires are prepared in Google Forms and distributed over social media platforms such as Email, WhatsApp and LinkedIn. There are no specific limitations or qualifications for the respondents other than the participants must be part of the construction community. Owing to time restrictions, this research is limited to the Klang Valley area. The data collected from respondents were subjected to Cronbach's Alpha Reliability Test and several inferential tests such as Friedman Test, Pearson's Chi-Square Test, Kruskal-Wallis Test and Spearman's Rank Correlation Coefficient Test. Table 1.1 provides an overview of the methods used to achieve the objectives of this research.

Table 1.1: Summary of Research Approaches

Phase 1 **Literature Review**		*Phase 2* **Questionnaire Survey and Data Analysis**
Objective 1: To identify the types of Construction 4.0 digital tools.	**Objective 2:** To explore the barriers of implementing Construction 4.0 digital tools.	**Objective 3:** To infer the readiness of Construction 4.0 digital tools by construction industry players.

1.5 Chapter Layout

Chapter 1 acts as an introductory section to the entire research. This chapter defines the research background and the matters related to Construction 4.0. Besides that, this chapter discusses the research's aims and objectives, research methods and chapter layout.

In addition, Chapter 2 describes an overview of Construction 4.0, sourced from various publications such as journal papers and websites. This chapter covers the explanation, benefits, digital tools, challenges, and strategies of implementing Construction 4.0. Moreover, in the last section of this chapter, a conceptual framework for the adoption of Construction 4.0 digital tools is developed to illustrate the relationship between the variables.

In Chapter 3, the research definition is established, and the research process is outlined. Moreover, it delineates the research methods and philosophy, followed by a justification for selecting the most suitable approach for this study. The final section of this chapter defines the data analysis methods employed to assess the collected data.

Furthermore, Chapter 4 summaries and tabulates the outcomes obtained from the targeted respondents. The gathered data are analysed through reliability analysis and inferential tests, after which the findings are discussed to fulfil the research aims and objectives.

Lastly, Chapter 5 denotes the final chapter of this research. It concludes the findings and their respective objectives. After that, research implications, limitations and recommendations are provided for future improvements in a related subject topic.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

First and foremost, this chapter describes the concept of Construction 4.0, followed by an exploration of several government policies created by various parties. Apart from that, this chapter also discusses the benefits of Construction 4.0 and its digital tools. Moreover, barriers and strategies of implementing Construction 4.0 are explored. Last but not least, a conceptual framework of the adoption of Construction 4.0 digital tools is proposed.

2.2 Construction 4.0

Industry 4.0 is the term used to denote the fourth industrial revolution, revolutionising decision-making through technological advances and digitalisation (Perrier, et al., 2020; Lim, et al., 2023). This revolution signifies the integration of technologies that enable the emergence of intelligent, self-sufficient, and distributed environments (Santos, et al., 2017; Kozlovska, et al., 2021). Furthermore, Alaloul, et al. (2020) further defined that Industry 4.0 refers to the contemporary trend in the industrial sector towards digitalisation, mechanisation and broad use of ICT. As a result of the great potential of Industry 4.0 technologies to improve the performance of building projects and expedite management procedures, the adoption rate of Industry 4.0 rose, giving rise to the idea of ‘Construction 4.0’ (Forcael, et al., 2020; Perrier, et al., 2020).

Defining Construction 4.0 is a challenge as it is interpreted differently by different individuals. In order to clarify this concept, the following definitions are given in this research. As stated by Chen, et al. (2018), Construction 4.0 refers to the use of technologies that are less than 20 years old in the design and building stages in order to boost efficiency. However, this is argued by Lekan, et al. (2020), Construction 4.0 represents an emerging phase in the construction industry that incorporates digitisation at various phases of the construction process. It will alter the building process and integrate the fragmented construction sector into a united industry by reshaping organisational and project frameworks (Jazzar, et al., 2020). This is supported by Karmakar and Delhi (2021) by explaining that Construction 4.0 relies on data generation, flow, transformation, and storage to enable cooperation among stakeholders across its levels.

Apart from that, Craveiro, et al. (2019) proposed a possible classification that might help in defining Construction 4.0, which is based on the industrialization of construction techniques and the digitization of the construction industry. Similarly, Osunsanmi, et al. (2020) also defined that Construction 4.0 symbolises digitalisation, in which a variety of digital tools collaborate to improve project performance and customer satisfaction. As perceived by Forcael, et al. (2020), Construction 4.0 is more than just the leveraging of advanced technologies to enhance traditional buildings; it represents a new perspective of viewing and interpreting construction in light of increasing productivity and innovation.

In conclusion, although there are different points of view among researchers when defining the term ‘Construction 4.0’, they share key similarities, including the use of digital tools and increased productivity. It cannot be denied that Construction 4.0 has a substantially favourable influence on the construction industry’s culture, economy, and government (Lau, et al., 2021). Therefore, understanding the core concept of Construction 4.0 is essential for transitioning the current construction industry towards digitalisation.

2.3 Government Policies Toward Construction 4.0

A digital revolution propelled by IR 4.0 has taken place in the industrial sector. Therefore, different parties have initiated several national policies to respond to this paradigm shift in order to transform the Malaysian construction industry towards Construction 4.0.

Firstly, the National 4IR Policy outlines 10 key sectors, including manufacturing, tourism, and healthcare, that will leverage 4IR technologies to enhance productivity, along with six supporting sectors like construction and entertainment (Economic Planning Unit, 2021). It comprises 16 strategies targeting societal, industrial, and public sector improvements, with completion dates set through 2030, aiming to align with Malaysia’s 4IR agenda, mitigate risks, and optimise resource allocation to achieve maximum benefits. Besides, National Construction Policy (NCP) 2030 guides the public and private construction sectors towards achieving inclusive and sustainable national development by 2030, while also stimulating infrastructure development to restructure the economy. With six outlined thrusts and corresponding strategies, NCP 2030 emphasises long-term sustainability, quality, safety, professionalism, and the integration of technology, particularly aligned with the principles of IR 4.0, to promote holistic and proactive business practices within the industry (Ministry of Works, 2021).

The Construction 4.0 Strategic Plan highlights four key thrusts and recommendations to initiate Construction 4.0 from 2021 to 2025, aligning local needs with global demands and addressing challenges in people, governance, economy, and integrated technologies. Over the next five years, this plan will cover 12 developing technologies, emphasising a practical approach that promotes leveraging current technology for ongoing improvement rather than pursuing digitalisation for its own sake (CIDB, 2020). Last but not least, Pelan Strategik Jabatan Kerja Raya (JKR) Malaysia 2021-2025 seeks to improve project execution and asset management through themes like internationalisation, professionalism, quality, productivity, and sustainability. One crucial milestone of this policy is to increase the implementation of BIM, with 50% of projects valued at RM10 million and above using BIM by 2025, ultimately aiming to elevate the country’s infrastructure development to international standards (PWD, 2020).

2.4 Types of Construction 4.0 Digital Tools

The Malaysian government, in collaboration with various parties, has actively promoted Construction 4.0 in the construction sector by launching several national policies. These initiatives include specific digital tools to speed up the digitalisation process, with the main tools discussed below. As outlined in Table 2.1, previous studies have recognised different types of Construction 4.0 digital tools.

Table 2.1: Summary of Types of Construction 4.0 Digital Tools.

No.	Digital Tools	Aliu and Oke (2023)	Almatari, et al. (2023)	Okpo, et al. (2023)	Wayne, et al. (2023)	Hwang, et al. (2022)	Kissi, et al. (2022)	Malomane, et al. (2022)	Statsenko, et al. (2023)	Talla and Mcllwaine (2022)	Yousif, et al. (2022)	Bhattacharya and Momaya (2021)	Adekunle, et al. (2021)	Begić and Galić (2021)	El Jazzar, et al. (2021)	Kasim, et al. (2021)	Kozlovska, et al. (2021)	Newman, et al. (2021)	Forcael, et al. (2020)	Perrier, et al. (2020)	Hossain and Nadeem (2019)	Klinc and Turk (2019)
1	BIM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Cloud Computing	✓	✓	✓			✓				✓	✓		✓		✓	✓	✓		✓		
3	IoT	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
4	Big Data	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
5	CPS	✓				✓			✓		✓		✓	✓			✓					✓
6	AI	✓	✓		✓		✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	
7	Robotics and Automation Systems	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	
8	RFID			✓	✓	✓		✓	✓		✓	✓	✓				✓			✓		
9	AR / VR	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓		✓	✓	✓	
10	3D Printing	✓	✓	✓			✓	✓			✓	✓		✓	✓	✓	✓	✓	✓		✓	
11	Blockchain		✓	✓			✓			✓						✓	✓			✓		

2.4.1 Building Information Modelling (BIM)

BIM is a process that uses 3D models to generate and regulate building information (Zaher, et al., 2018; Andersson and Eidenskog, 2023). Every component of a building is essential. BIM integrates all the technical details unique to a structure and facilitates the exchange of this information (Saka and Chan, 2020). It allows for the consolidation of all building data into a digital, singular, and measurable model, assuring consistency and synchronisation over the structure's entire lifecycle, from initial concept to demolition (Toyin and Mewomo, 2022). Hence, BIM extends beyond the building's exterior and encompasses details integrated into each of the project's constituent elements.

Besides that, Ibrahim, et al. (2021) elaborated that the process begins with producing, using, and sharing project data through a digitalisation system, specifically a 3D model that integrates comprehensive project details from various perspectives to portray an accurate project image. In this collaborative environment, each expert is able to incorporate his or her area of expertise into a shared model, including architectural, electromechanical, civil, equipment, construction and structural (Forcael, et al., 2020; Hall, et al., 2022). This allows for a comprehensive review of the project's evolution and work product. Moreover, Zaia, et al. (2023) also highlighted that in contrast to 2D drawings, BIM provides excellent support for clash detection and issue resolution during the design phase. Therefore, BIM is a real accelerator for the construction industry.

2.4.2 Cloud Computing

The term 'cloud computing' was introduced based on the common use of a cloud symbol to represent the Internet in diagrams (Kumar and Cheng, 2010). Zhang and Min (2020) defined that it is a collaborative supercomputing construction that uses the Internet to centralise huge amounts of information and processing power from desktops, smartphones, and other devices. Cloud computing in construction involves utilising virtual servers to access project-related documents, drawings and data via an internet connection (Branco, et al., 2017). The technology will prove to be very beneficial to the construction industry as it requires mobility of consultants and employees and frequent setup of new sites.

Cloud computing technologies have enabled construction firms, especially SMEs, to attain access to sophisticated computer infrastructure and applications that would otherwise be financially prohibitive to acquire (Oke, et al., 2021b). Besides, cloud security has grown and now includes commonly used methods like encryption, the use of current security software, cyber insurance coverage, security audits, and others (Chen and Yang, 2022). The integration of emerging digital tools like IoT and AR results in significant data generation. As illustrated by Bello, et al. (2021), an aerial photograph of a location will consume cloud storage points equivalent to hundreds of gigabytes on a standard computer. Not only that, Li, et al. (2023) also highlighted that on-site data storage relies on physical access, while cloud storage enables remote storage and retrieval without any restrictions on space and time. Thus, this brings cloud storage a favourable prospect for the construction industry.

2.4.3 Internet of Things (IoT)

IoT has been rapidly embraced by the construction industry, where different stakeholders use it as a common trend (Arowoiya, et al., 2020). According to Tanko, et al. (2023), IoT creates a network of physical objects and sensors to enable communication and data sharing. Likewise, IoT is defined as a network where intelligent devices, or “Things”, connect and interact over the Internet with minimal human intervention (Dilakshan, et al., 2021; Dosumu and Uwayo, 2023). Hence, in order to guarantee the connectivity and performance of IoT devices on construction sites, contractors should ensure that the network infrastructure is sufficient (Halim, et al., 2021).

The IoT has become a fundamental part of building technology, and it is dramatically changing the way the construction industry works. Several IoT applications in the construction sector had been identified by Oke and Arowoiya (2021b), including remote usage monitoring, machinery servicing and maintenance, construction tool and equipment tracking, and so on. In general, IoT operates by connecting items to the Internet and leveraging the connection to remotely supervise or take control of the items. For example, wearable devices such as fitness trackers and smartwatches are useful for tracking employees’ on-site presence and reporting current involvement (Kariuki, et al., 2021). Besides, IoT is also useful in home automation as well as building automation systems. IoT possesses the capability of supervising and managing mechanical, electrical, and electronic systems present in a variety of buildings, ranging from public and private areas to industrial, institutional, and residential structures (Lawal and Rafsanjani, 2022).

2.4.4 Big Data

Big data refers to large datasets that are used to identify hidden trends, behavioural patterns, and unknown connections, enabling improved business decision-making and acting as the basis for artificial intelligence and automation systems (Oyedele, et al., 2020). Big data is typically classified using the 3Vs, which stand for Volume pertains to the quantity of data generated; Velocity relates to the speed at which data is produced; Variety refers to the type of data sources, including structured and unstructured data (Ismail, et al., 2018). This data is acquired via online searches and services, mobile devices, digital images, social platforms, as well as a variety of other digital communication technologies (Talla and McIlwaine, 2022).

A project's construction activity is dynamic, requiring a large amount of data interchange from multiple stakeholders to be acquired and analysed. The enormous number of people participating, as well as the vast amount of equipment and jobs being performed at the same time, construction sites have begun to generate large amounts of data (Madanayake and Egbu, 2019). This is further supported by Ismail, et al. (2018), data is created and collected during the different stages of construction projects, from planning until the completion of the project. Hence, big data may be used in conjunction with BIM as well as social networks to identify sustainable energy options that optimise project performance during the design stage (Hatoum, et al., 2020).

2.4.5 Cyber-Physical System (CPS)

Bagheri, et al. (2015) described that CPS is a system that combines both man-made and natural systems (physical space) with computing, communication, and control systems (cyber space). Similarly, Klinc and Turk (2019); Banerjee and Nayaka (2022) also defined that CPS is a dynamic system wherein virtual and physical operations establish connections through embedded computers. To achieve decentralised activities, physical and digital instruments should be combined and connected with other devices. Thus, CPS in construction incorporates the use of sensors, actuators, robotics, AI, and other technologies to improve numerous aspects of the building process (Salkin, et al., 2018).

Correa (2018) found out that using CPS systems that include BIM and sensors throughout the construction process enables for the quick identification of prefabricated construction progress. On the other hand, CPS employs intelligent machines with enhanced intelligence as well as communication capabilities, allowing them to participate in the planning and execute specialised or non-repetitive activities (Alcácer and Cruz-Machado, 2019). Furthermore, Jiang, et al. (2020) claimed that the system creates a synchronised mapping of risk data between virtual buildings and physical construction sites via scenario reconstruction design, data sensing, data communication and data processing modules. As a result, an on-site safety management system can be developed through CPS.

2.4.6 Artificial Intelligence (AI)

AI is the result of an ongoing effort to create machines that exhibit human-like intelligence (Talla and McIlwaine, 2022). Cui, et al. (2020); Kor, et al. (2021) described that AI is used to define machines is capable of mimicking functions of the human brain such as spotting patterns, learning from experiences and problem-solving. Besides, Boute, et al. (2022) further explained that automation and smartness are the two capabilities that are possessed by AI, both of which are connected to physical devices or software that either replace manual labour through automated processes or complement human labour via smart judgements.

As a technology, AI has already created an impact on the world. AI technology can enhance the entire lifespan of a building, from planning and design to construction, maintenance, operation and eventual decommissioning (Prabhakar, et al., 2023). Apart from that, it cannot be denied that humans and traditional computer systems are incapable of analysing massive amounts of data and identifying patterns using rule-based procedures. Thus, AI’s ability to manage massive amounts of data, spot trends, and form large statistical models to analyse its digital data is one of the key drivers sustaining the building and construction business (Eber, 2020). Not only that, in the scope of Construction

4.0, AI may be used in artificial vision systems to identify particular objects within a construction area, as well as voice and pattern recognition to assess construction workers' real-time effectiveness (Forcael, et al., 2020).

2.4.7 Robotics and Automation Systems

Automation can be characterised as a self-regulating process that employs programmable machines for specific tasks (Kamaruddin, et al., 2016; Alcácer and Cruz-Machado, 2019), while robotics is defined as the capability of a single, multi-axis adaptable machine to independently perform various jobs (Kamaruddin, et al., 2016; Devadass, et al., 2019). Construction robots need to navigate large construction sites, handle vast and diverse components, operate during inclement weather, and endure constant exposure to dust and debris (Yahya, et al., 2019). Thus, the produced robots must have higher durability and functionality to perform tedious, dangerous and repetitive jobs.

Drones and self-driving cars, exoskeletons, off-site prefabrication setups, and on-site automated and robotic systems are some of the basic categories of robotic and automation systems (Bock, 2015). Digital tools involving on-site automated and robotic systems are capable of being physically applied at construction sites to fabricate buildings and structures (Oke, et al., 2023). Apart from that, Vanderhorst, et al. (2022) stated that unmanned aerial vehicles (UAVs) are a commonly used term for drone technology, and its present application is to gather real-time photos from the field. Not only that, Tehrani, et al. (2022); Oke, et al. (2023b) also found out that robotic arms are commonly employed in jobs such as drilling, painting, welding, laying brick and so on. Thus, Forceal, et al. (2020) concluded that the current main functions performed by robotics include assessing civil constructions, assembling elements in the building of timber structures, and undertaking additional activities like steel setup and brick or concrete block assembly.

2.4.8 Radio Frequency Identification (RFID)

RFID system is made up of three parts which are a tag, a reader, and a backend system (Osunsanmi, et al., 2020; Proctor-Parker and Stopforth, 2021). The tag is normally affixed to the targeted item, and it transmits information about the item to the reader, which in turn transmits it to a back-end system (Wang, et al., 2020). Besides, Oke, et al. (2023c) mentioned that unlike older barcode technology, RFID systems do not require line-of-sight for long-range identification. In addition to using computers for data monitoring via RFID, mobile phones can also be used for this same purpose (Yap, et al., 2021). RFID has found widespread application in many construction projects due to its ability to precisely locate one or more objectives in both fixed and dynamic operational circumstances.

Firstly, Dobrucali, et al. (2022) revealed that RFID uses radio waves to provide contactless recognition of things, including the reading of digital data, improving the monitoring and control of the use and appropriateness of personal protective equipment (PPE). It works by placing tags to construction workers' PPE and enables equipment and machinery to automatically transmit performance data to relevant parties (Yap, et al., 2021). Furthermore, RFID is used to produce material delivery data, which is then stored in RFID tags for automated retrieval by RFID readers (Kasim, et al., 2019). For instance, RFID tag is applied directly to the material surfaces for a single prefabricated component (Chen, et al., 2020). This is further explained by Ibrahem, et al. (2020), RFID readers are used by site specialists to scan these tags, collecting data that is then saved in a database for analysis. Moreover, Su, et al. (2019) also discovered that throughout the process of assembling a prefabricated structure on a construction site, RFID may capture up-to-date information by tracking embedded tags within the components.

2.4.9 Augmented Reality (AR) / Virtual Reality (VR)

VR and AR are seen as revolutionary aspects for the construction domain. AR is distinguished by two distinct features, namely the combination and alignment of actual and virtual objects in 3D space, as well as real-time interactivity (Hajirasouli, et al., 2022). Besides, Chen and Xue (2020) claimed that AR permits simultaneous interpretation of virtual and real-world aspects by matching digital representations with people's perceptions of reality, leading to enhanced information perception and considerably easing decision-making processes. AR facilitates a paradigm change from a traditional desktop interface to a real world-centred interface, thereby transforming the surroundings and actual world into the reality interface (Elghaish, et al., 2021)

VR systems employ a computer-generated setting to simulate real-time interactions between the user and a virtual world (Forcael, et al., 2020). Furthermore, Uhomoibhi, et al. (2019) also further described that VR is built on the construction of an artificial environment, which provides the human sensation of immersion and engagement through the collaboration of software, hardware, and human senses. On the technical side, VR technologies can have a variety of approaches and instruments with varying degrees of sophistication. The most basic installations consist of a 3D animation that allows an individual to interact via a desktop or laptop using a keyboard and mouse (Guray and Kismet, 2022). In short, VR permits users to engage fully within simulated environments, whereas AR overlays digital information onto the actual world. With the integration of digital tools such as AR and VR, construction firms and clients may now examine elements of their projects' designs, construction, and post-construction stages in real-time (Balali, et al., 2018). They offer immersive experience and simulations that enable stakeholders to visualise designs, conduct virtual walkthroughs and identify design problems (Alizadehsalehi, et al., 2019). Thus, VR-AR implementations are successful in gathering user feedback, which enhances customer satisfaction and design performance (Ahmed, 2019).

2.4.10 3D Printing

3D printing, also called additive manufacturing, is an automated technique that constructs complicated 3D shapes by building up successive cross-sectional layers, following a 3D model (Olsson, et al., 2019). Ali, et al. (2022) described that CAD is the primary tool for creating digital prototypes that will be printed layer by layer with a very thin cross-sectional area. The widespread use of this automated manufacturing technique is attributed to its significant benefits in generating functional prototypes within a reasonable timeframe while reducing human participation and material waste (Tay, et al., 2017)

Concrete, polymers as well as metallic materials are the most common materials that can be utilised in 3D printers. As explored by El-Sayegh, et al. (2020), polymer materials are often employed for aesthetic reasons due to their lack of structural characteristics and it will give a low-risk choice for using additive manufacturing technologies. Apart from that, printing concrete for houses and villas using additive technology seems to be more promising than constructing large buildings (Hossain, et al., 2020). 3D printed buildings can easily lay out structures using curved forms rather than the typical straight forms, which makes them more durable. While metallic characteristics are highly favoured as a building material, 3D-printed construction exclusively using metallic materials tend to be quite hefty. Additionally, metals have limitations in terms of both time and cost when used in 3D printing (Ali, et al., 2022).

2.4.11 Blockchain

Blockchain validates transactions using a decentralised peer-to-peer (P2P) network (Safa, et al., 2019). A P2P network exists in which every server on the network is equal and each workstation gets permission to access data (Weerapperuma, et al., 2023). Hence, it eliminates the need for a reliable third party to supervise or verify transactions as all the information exchange takes place between end users (Kang, et al., 2022). Once a transaction is begun, it is transmitted to network nodes for validation and verification. Each node in the chain holds different kinds of information, comprising financial transaction data, contracts, ownership documents, and statements of legitimacy (Akinradewo, et al., 2022). The information stored in such a chain cannot be altered or deleted due to the characteristic of the P2P network.

Every node in the chain is responsible for data security, preserving its own information using digital authentication (Weerapperuma, et al., 2023). This enables fast and secure data transfer while eliminating the need for any external intermediaries. Blockchain networks may withstand attacks even if hackers control many nodes because the P2P network creates a dispersed topography without a centralised authority (Wahab, et al., 2022). Any tampering or alteration of the project data would result in the disqualification of that information block, which can be completely tracked back to the responsible party. In other words, the data registered within the blockchain network is safe and immune to alteration. Therefore, Ebekozien, et al. (2023); Xu, et al. (2023) expressed that the technology is commonly employed in project cost, contract tendering, as well as construction procurement assessment in the construction project operations.

2.5 Benefits of Construction 4.0 Digital Tools

The implementation of Construction 4.0 is a notable obstacle in this traditionally sluggish sector. As such, it is imperative to fully utilise the potential of Construction 4.0 digital tools in construction projects; their significance should not be underestimated. Numerous benefits are gained from the implementation of Construction 4.0, but the main benefits will be discussed below. As indicated in Table 2.2, previous studies have identified several benefits associated with the implementation of Construction 4.0 digital tools.

Table 2.2: Summary of Benefits Incurred from Adopting Construction 4.0 Digital Tools

No.	Benefits	Aliu and Oke (2023)	Arowoiya, et al. (2023)	Maqsoom, et al. (2023)	Okpo, et al. (2023)	Prabhakar, et al. (2023)	Sajjad, et al. (2023)	Malomane, et al. (2022)	Ngo and Hwang (2022)	Rachmawati and Kim (2022)	Adekunle, et al. (2021)	Begić and Galić (2021)	Bhattacharya and Momaya (2021)	El Jazzar, et al. (2021)	Nagy, et al. (2021)	Elghaish, et al. (2021)	Moon, et al. (2020)	Moshood, et al. (2020)	Sawhney, et al. (2020)	Maskuriy, et al. (2019)	Tang, et al. (2019)
1	Time Savings		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓		✓	✓	✓	
2	Cost Savings		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	
3	Quality Improvement	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
4	Safety Enhancement	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓
5	Boosting Sustainability				✓		✓	✓	✓			✓		✓				✓	✓	✓	
6	Collaboration and Communication Improvement	✓		✓	✓			✓	✓				✓		✓	✓	✓	✓	✓		✓
7	Increase Time and Cost Predictability	✓			✓							✓	✓	✓					✓	✓	
8	Promote Innovation			✓							✓				✓			✓	✓	✓	
9	Enhance project management		✓				✓	✓	✓	✓	✓		✓	✓						✓	
10	Enhance site design and logistical planning						✓			✓											

2.5.1 Time Savings

Delaying is a common issue faced by the construction industry and it is not a phenomenon welcomed by construction participants as it will have a negative influence on the overall project performance (Tariq and Gardezi, 2023). Thus, Oke and Arowoiya (2021a) stressed that the construction sector will gain significantly from the complete use of Construction 4.0 with its digital tools in building projects, particularly in terms of addressing the delays.

Moon, et al. (2020) discovered that offsite techniques such as 3D printing and additive manufacturing can help in reducing the project time over traditional brick and mortar construction. Furthermore, Sawhney, et al. (2020) also revealed that any potential time lags can be mitigated through immediate access to on-site data, leading to efficiency gains in terms of time. IoT devices and sensors can capture job site data in a more economical, efficient, and effective manner than ever before (Rane and Narvel, 2019). Besides that, drones may also be employed to collect aerial information that can be used to perform 3D mapping, surveying as well as monitoring (Fadamiro and Oke, 2019). However, people and traditional computer systems are incapable of analysing massive amounts of data. Hence, Prabhakar, et al. (2023) declared that the capacity of AI to manage massive amounts of data, spot trends, and form large statistical models to analyse its digital data is one of the major reasons sustaining the building and construction companies. In short, all Construction 4.0 digital tools must work hand-in-hand in order to maximise their effectiveness.

2.5.2 Cost Savings

Cost overrun was, has been and still is a woe in the construction industry. Most construction projects in Malaysia have encountered cost escalations, falling within the range of 5% to 10% of the overall contract value (Kamaruddeen, et al., 2020). Undeniably, the adoption of Construction 4.0 with its digital tools will involve significant initial costs, yet it promises substantial long-term savings (Yahya, et al., 2019). This is further emphasised by Okpo, et al. (2023), increased the use of Construction 4.0 digital tools would result in building projects being completed under budget, as well as avoiding cost overruns.

Construction 4.0 digital tools can yield cost savings in different aspects. Bhattacharya and Momaya (2021) investigated that the use of robots and automated processes, whether in jobs such as bricklaying or plastering, not only increases production but also contributes to lower labour costs. The construction labour sector is therefore a strong candidate for automation as robots can work over lengthier periods of time, at higher speeds, and with more efficiency (Ebekozien and Aigbavboa, 2021). On the other hand, through the use of fixed sensors such as RFID for supply monitoring, additive manufacturing and prefabrication processes may reduce logistics expenses and material wastage (Moshood, et al., 2020). Besides, Maqsoom, et al. (2023) also mentioned that with the use of AR and VR, project designs may be optimised to save money and minimise the likelihood of human mistake by discovering and correcting faults in the virtual world. Integrating the physical and digital environments simplifies project management by allowing improvements to be made virtually and observed in real time (Oke and Arowoiya, 2021a). Thus, the project may be done as efficiently as feasible, resulting in better outcomes at a cheaper cost.

2.5.3 Quality Improvement

Implementing the Construction 4.0 with its digital tools streamlines the monitoring and management of design as well as manufacturing activities, ultimately elevating the quality of construction (Sawhney, et al., 2020). Construction 4.0 digital tools in construction activities and procedures can result in a better operational framework, enhanced accuracy, fewer construction mistakes, and greater efficiency (Aliu and Oke, 2023).

As mentioned by Moshood, et al. (2020); Bhattacharya and Momaya (2021), BIM may improve construction quality by making it easier to identify potential problems during the design phase with extraordinary detail and information. Not only that, Ikuable, et al. (2020) further provided that IoTs, 3D printing, cloud computing and so on are transforming the construction industry, enabling higher precision and cohesive information. This data can provide construction stakeholders with an indicator of potential mistakes, project progress performance, and project productivity duration in digital form (Tang, et al., 2019). On the other hand, AR and VR play an important role in transforming the construction industry towards Construction 4.0. This is due to the construction industry being inextricably linked to 3D space, and experts in this area rely largely on visual images to communicate (Maqsoom, et al., 2023). Hence, Oke and Arowoiya (2021a) stated that AR and VR may bring virtual components and computer-generated items into a physical or real world. The outcome of a design may be evaluated to minimise the errors and changes that occur during the construction stage, which can jeopardise the project's value (Aliu and Oke, 2023).

2.5.4 Safety Enhancement

Fatality rate of the Malaysian construction sector is increasing at an alarming rate. Based on National Occupational Accident and Disease Statistics 2021, the Malaysian construction industry had a fatality rate of 6.30 per 100,000 employees, which was the second highest compared to other sectors (Department of Statistics Malaysia, 2021). Therefore, Aliu and Oke (2023) stressed that poor construction site health and safety culture is to blame for the consistently high incidence of accidents and fatalities during the development of construction projects.

Hence, it is crucial to stress the importance of Construction 4.0 as it has the ability to minimise the workforce and results in a safer and less labour-intensive workplace for workers (Demirkesen and Tezel, 2021). Likewise, Sawhney, et al. (2020); Malomane, et al. (2022) accentuated that applying Construction 4.0 digital tools has the potential to offer safer alternatives to employees while also enhancing safety inspections as well as supervision. For instance, by leveraging IoT devices, the enhanced safety of on-site work becomes attainable due to the industry's elevated vulnerability to workplace injuries and accidents; this has been aided by the implementation of RFID and wireless wearable sensors, which have effectively lowered the occurrence of accidents and casualties within construction sites (Bhattacharya and Momaya, 2021). Besides, site accidents and human mistakes can be significantly decreased with the introduction of automation technologies such as robots (Aghimien, et al., 2022a). Moreover, Aliu and Oke (2023) also supported that robotics is the programming of robots to interact independently with things in order to execute activities in a safer and more efficient manner. Not only that, BIM, as one of the safety facilitators might, promote a safe environment and improve danger detection by enhancing safety planning and decision-making on the suitable safety practices (Oesterreich and Teuteberg, 2016; Fargnoli and Lombardi, 2020).

2.5.5 Boosting Sustainability

It is a well-known fact that the construction sector contributes to a variety of pollution, such as air and water contamination, creates noise pollution and destroys natural ecosystems. According to the NCP 2030, the construction industry is also responsible for up to 50% of climate change impacts, 40% of worldwide energy consumption, and 50% of trash dumped in landfills (Ministry of Works, 2021). Apart from that, the building industry produces around half of all carbon emissions and energy consumption (Sepasgozar, 2021). Therefore, Sajjad, et al. (2023) believed that there is the potential to boost construction industry sustainability by embracing Construction 4.0 with its digital tools.

Construction 4.0 digital tools improve the integration of construction waste into the design phase and optimise design, manufacturing, and consumption for improved reuse, repair, remanufacture, and recycling processes (Talla and McIlwaine, 2022). 3D printing, as a pivotal digital tool within Construction 4.0, contributes significantly to enhancing sustainability. As mentioned by El-Sayegh, et al. (2020), 3D printing is environmentally friendlier than conventional techniques due to its reduced waste generation, achieved by customising materials to match the output. Besides, Wilts, et al. (2021) also applied AI in conjunction with a robotic sorting system to separate bulky municipal material trash. Furthermore, several of Construction 4.0 digital tools, including BIM, sensors, and the IoT, have shown to be beneficial for fulfilling the aims of a sustainable building environment (Fokaides, et al., 2020). Thus, the adoption of Construction 4.0 digital tools in construction can increase the number of employment hours and fully utilised materials with minimal wastage (Moshood, et al., 2020). This would therefore contribute significantly to environmental and economic sustainability.

2.5.6 Collaboration and Communication Improvement

Effective collaboration among varied stakeholders is critical for project success. Construction 4.0 with its digital tools guarantees that correct information is available to the right person at the right time (Bajpai and Misra, 2021). A study conducted by Tanga, et al. (2021), Construction 4.0 will boost communication success through its digital tools by allowing faster access to essential information, better data storage, and improved client engagements through improved customer feedback and communication systems.

Aliu and Oke (2023) ascertained that cloud computing has been used to give continuous monitoring capabilities, which may provide rapid data on material purchases and consumption, as well as real-time reports and dashboards to deliver changes. Thus, cloud computing allows construction workers to share and access files and data from anywhere and at any time, increasing flexibility and communication among professional groups (Okedara, et al., 2020; Bajpai and Misra, 2021). Besides that, cloud computing, in conjunction with BIM-based technologies or social media tools, may effectively boost company cooperation and assist in supply chain management (Bhattacharya and Momaya, 2021). Okpo, et al. (2023); Hossain and Nadeem (2019) pointed out that BIM is a standard enabling project stakeholders and participants to share information and communicate. Moreover, Maskuriy, et al. (2019) also agreed by explaining that BIM as a necessary tool for engagement and cooperation throughout the project life cycle, as well as an examination of the current trends that BIM provides to building projects in the context of Construction 4.0. Moreover, blockchain also facilitates trust between stakeholders by enhancing the transparency of transactions and the security of data transfers, as well as the efficiency and quality of communications (Kowalski, et al., 2021).

2.5.7 Increase Time and Cost Predictability

Successful construction projects are achieved in terms of timeliness, expense, customer satisfaction, cost-effectiveness, and efficiency (Okpo, et al., 2023). Construction 4.0 digital tools have the potential to revolutionise the way construction projects are designed, managed, operated and decisions are made (Shafei, et al., 2022). Effective decision-making improves project management by providing opportunities to improve approaches for addressing costs, various demands, and time management in building projects (Szafranko, 2017). For example, drones deliver high-quality pictures for tracking job progress, allowing for informed decision-making via real-time and latest information availability (Aliu and Oke, 2023). Besides that, the IoT is a network of Internet-connected things that can gather and share data in real time. It includes cyber-physical technologies that allow humans to observe operations in real time without physically being present (Bhattacharya and Momaya, 2021).

A building cost estimating method based on VR has been developed. Du, et al. (2018a) explained that VR utilises a dynamic virtual reality model that allows customers and users to change materials for various areas of the construction while witnessing real-time pricing implications. Furthermore, AI assists in ensuring that the project keeps within its budget and timeline and detects concerns that require prompt attention (Shang, et al., 2023). Thus, Sawhney, et al. (2020) concluded that the accuracy of time and cost estimates for ongoing projects can be improved through consistent tracking, automated field data collection, image analysis, AI and digital analytical tools. In addition, the presence of extensive historical data and information can aid in setting benchmarks for preliminary estimation of time and cost for upcoming projects (Adekunle, et al., 2021). Hence, implementing Construction 4.0 digital tools generates meaningful data and important information, which helps in facilitating better time and cost predictability. As a result, this leads to efficient decision-making that offers the potential for cost savings, enhanced quality, and increased project output (Wang, et al., 2022).

2.5.8 Promote Innovation

Apart from the benefits listed above, Construction 4.0 also helps in promoting innovation in the construction industry. Gong and Wang (2021) stated that when compared to other industries, the construction sector receives criticism for its relatively low level of innovative performance. By merging the physical and digital areas, innovation can produce integrated solutions that address the current fragmentation of the industry in terms of horizontal, vertical, and longitudinal aspects (Sawhney, et al., 2020).

As part of the society's innovation practice and ongoing progress, Construction 4.0 may aid the Malaysian construction sector in cutting costs, saving time, and reacting more effectively to client demands (Moshood, et al., 2020). Even with complicated buildings, Construction 4.0 technologies can assist users in developing a feel of the project and identifying an appropriate design area (Du, et al., 2018b). For instance, the concept of merging AR and VR with construction management is increasing in popularity through introducing innovative ways to construction process management (Guray and Kismet, 2022). Moreover, Bhattacharya and Momaya (2021) introduced a construction cost estimation framework employing VR technology. It utilises a real-time virtual reality model, enabling clients to modify materials for floors, walls, and other components, observing the immediate impact on the project cost and promoting innovation spontaneously (Arowoiya, et al., 2023). Monitoring of all phases of a project will result in a greater understanding about the design and the reduction of risks associated with the project. Therefore, Demirkesen and Tezel (2021) supported the idea that adopting Construction 4.0 digital tools may stimulate innovation by increasing efficiency in building projects and reducing unpredictability.

2.5.9 Enhance Project Management

The utilisation of Construction 4.0 digital tools has the potential to optimise managerial processes (Maskuriy, et al., 2019; Sajjad, et al., 2023). The amount of data will increase correspondingly with the commencement of the building process. According to Newman, et al. (2021), big data may be analysed and its full worth can be recognised by organisations, and cloud computing provides flexible and affordable solutions to support a range of organisational activities, such as data backup, remote work, and large-scale data storage. Proper data gathering and processing can support better contracts. All parties will be able to access various data and information more clearly and transparently, which will strengthen coordination and allow for the intelligent management of construction activities (Fakher and Anandh, 2022).

Project risk management is a component of project management that emphasises identifying and managing any hazards as they arise. While health, safety, and environmental risks are significant concerns in a project, other project risks include contractual, financial, procurement, design, and security risks (Ngo and Hwang, 2022). A small project with limited funding and resources that seeks to prevent mistakes can successfully adopt digital innovations by striking a balance between cost, time, safety, and quality (Nagy, et al., 2021). Hossain and Nadeem (2019) recommended that the organisation should have a well-established BIM-based project management system as BIM is a digital planning technique widely adopted by the construction industry. The integration of cloud computing with BIM improves organisational communication and streamlines supply chain management (Bhattacharya and Momaya, 2021); while IoT tackles waste reduction and resource as well as budget management in construction (Oke and Arowoiya, 2021a). Conforming to Adekunle, et al. (2021), while Construction 4.0 may be disruptive to current systems and workflows, it prompts companies to formulate survival strategies. As a result, it impacts all stakeholders in the construction industry, influences the supply chain, and enhances the project management.

2.5.10 Enhance Site Design and Logistical Planning

Construction 4.0 with its digital tools play a significant role in enhancing site design and logistical planning in construction due to their ability for promoting efficiency, precision, and collaboration. According to Yousif, et al. (2022), “project information” on any construction project refers to all of the data, regardless of format, that is used to coordinate, plan, and carry out the project from its inception to its completion. The precise data helps identify the potential dangers involved in every process, from commencement to completion. As claimed by Rachmawati and Kim (2022); Elghaish, et al. (2021), unmanned aerial vehicles (UAVs) use imagery and data collection to generate a 3D model of the building site. Then, this model is contrasted with a planned model developed through BIM. Real-time AR/VR visualisation of as-built and as-planned on multiple devices dramatically improves site design and logistics planning by increasing visual clarity, accelerating decision-making, and enabling remote collaboration (Nagy, et al., 2021).

Besides, mass customisation of house construction was made possible by design automation, which combines genetic algorithms and sophisticated simulation tools with the BIM model (Maskuriy, et al., 2019). This is due to BIM can assist planners and architects in optimising spatial layouts for sites, assuring resource efficiency and lessening logistical difficulties. Besides, El Jazzar, et al. (2021); Wayne, et al. (2023) disclosed that AI may use previous data to forecast possible bottlenecks in logistics by continually evaluating a wide range of plan alternatives. It is quite vital for underground construction sites, which are high-risk settings with possible dangers. A CPS is used to simulate and monitor the hoisting process in order to prevent dangerous situations in cranes and the hoisted cutter wheel while blind hoisting (Statsenko, et al., 2023). In conclusion, the construction sector may optimise site design and streamline logistical planning by implementing Construction 4.0 digital tools.

2.6 Barriers of Implementing Construction 4.0 Digital Tools

Construction sector is a labour-intensive industry where the implementation of Construction 4.0 is important to elevate the industry’s reputation. However, it is not essayed to be done without any expertise and procedures as Construction 4.0 requires special planning and collaboration from various parties. Therefore, this often results in a number of barriers that hinder the stakeholders in the implementation towards Construction 4.0.

There are many barriers that may impede the implementation of Construction 4.0. However, several main barriers are explored. Previous studies have revealed a variety of barriers to implementing Construction 4.0 digital tools, as illustrated in Table 2.3.

Table 2.3: Summary of Barriers of Implementing Construction 4.0 Digital Tools

No.	Barriers	Chen, et al. (2023)	Ebekozien, et al. (2023)	Oke, et al. (2023c)	Shang, et al. (2023)	Xu, et al. (2023)	Hall, et al. (2022)	Hwang, et al. (2022)	Kuzdikbay and Nadeem (2022)	Olatunde, et al. (2022)	Shafei, et al. (2022)	Wang, et al. (2022)	Nicole, et al. (2022)	Aghimien, et al. (2021)	Bajpai and Misra (2021)	Demirkesen and Tezel (2021)	Ibrahim, et al. (2021)	Jelodar and Shu (2021)	Karmakar and Delhi (2021)	Alaloul, et al. (2020)	Osunsanmi, et al. (2020)	Sawhney, et al. (2020)	Diana, et al. (2019)
1	High Implementation Cost	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Lack of Expertise and Skilled Workers			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
3	Resistance to Change	✓	✓			✓		✓	✓		✓		✓	✓	✓	✓	✓			✓		✓	✓
4	Concerning on Data Security and Protection Issues	✓	✓	✓		✓		✓	✓			✓	✓		✓	✓			✓	✓		✓	
5	Lack of Regulations and Standardisation	✓	✓			✓		✓	✓	✓		✓			✓	✓	✓		✓			✓	
6	Lack of Awareness of the Benefits of Construction 4.0 Digital Tools	✓	✓						✓		✓		✓			✓	✓	✓			✓	✓	✓
7	Lack of Research on Construction 4.0 Digital Tools		✓	✓						✓		✓				✓					✓	✓	
8	Pertaining to Legal and Contractual Matters		✓		✓	✓		✓								✓				✓		✓	
9	Lack of Government Support	✓	✓		✓		✓		✓									✓		✓			
10	Fragmentated Nature of Construction Industry					✓										✓			✓		✓	✓	
11	Poor Connectivity Network					✓		✓							✓		✓						
12	Low Interest and Market Demand	✓		✓			✓																
13	Higher Requirements for Computing Devices						✓	✓	✓														✓
14	Lack of Knowledge Management	✓						✓				✓		✓									

2.6.1 High Implementation Cost

The implementation of Construction 4.0 digital tools in the construction industry is hampered by high implementation cost (Kozlovska, et al., 2021). According to Jazzar, et al. (2020), the significant financial constraints include the high costs involved with adopting new technology, the requirement for more skilled workers, and investments in R&D. This indicated that additional training is required to provide to existing employees when novel technologies are deployed. Not only that, Balasubramanian, et al. (2021) mentioned that the annual subscription fees, cyber-security fees, staff training expenses and ICT update expenses are the hidden and recurring costs of Construction 4.0 technologies. Also, maintenance fees for new robotics equipment are often greater due to the requirement for a specialised professional to do the maintenance (Yahya, et al., 2019). Besides, Newman, et al. (2021) also commented that Construction 4.0 adoption may result in high expenses for possessing and employing technology as some technologies may require continuous improvement and development.

Apart from that, Sawhney, et al. (2020) declared that the investment in Construction 4.0 technologies could demand significant upfront costs with high risk as the lack of clarity of the benefits and the forecasting of cost savings. This statement was further supported by Karmakar and Delhi (2021), the payback period for the technology in question is longer compared to the duration of the project. Construction 4.0 technologies' return on investment will be lower for smaller businesses than for larger ones because of insufficient scale economies (Balasubramanian, et al., 2021; Maqsoom, et al., 2023). Therefore, purchasing pricy technologies, recruiting professionals, and providing training are the main factors contributing to the high implementation cost. Smaller companies might encounter huge challenges in adopting Construction 4.0 technology due to financial and human resource constraints.

2.6.2 Lack of Expertise and Skilled Workers

Lack of expertise and skilled workers is normally a steppingstone in implementing Construction 4.0. Wang, et al. (2022) made the point that the construction industry would not immediately move towards digitalisation without the necessary skills. Successful digitalisation in the construction sector requires a solid foundation in ICT skills, as professionals trained as analysts, software developers, maintenance specialists and technical consultants are scarce in the industry (Aghimien, et al., 2021). Therefore, it becomes challenging for construction firms to begin a transition process towards Construction 4.0 when the availability of skilled labour is unpredictable and insufficient (Demirkesen and Tezel, 2021).

Since some of the Construction 4.0 digital tools have only recently been introduced to the construction industry, there are few professionals that are competent in using these tools effectively (Ghosh, et al., 2020). A study conducted by Shang, et al. (2023) showed that the critical shortage of workers with the training or skills required to run AI systems has become one of the key barriers to AI adoption in the construction industry. In order to become a professional or skilled worker to operate the Construction 4.0 digital tools, skills must be acquired through participation in all relevant training (Kissi, et al., 2022; Nicole, et al., 2022). Hence, Diana, et al. (2019) claimed that for the formal acquisition of fresh knowledge and the updating of on-site abilities to operate the digital tools of Construction 4.0, extra training is necessary. This will hinder the adoption of Construction 4.0 as it takes time for a person to have an in-depth understanding of the tools and training on how to use them before they can become experts (Delgado, et al., 2019).

2.6.3 Resistance to Change

Resistance to change among the construction players might block the digitalisation process in construction. According to Ghosh, et al. (2020); Shafei, et al. (2022), construction industry professionals are reluctant to change as change often demands changes in routines, processes, and systems which lead to disturb the current construction practices. Since most of the professionals already established a comfortable environment with their own familiar processes and traditional methods, they want to maintain the status-quo with the familiarity and predictability (Lau, et al., 2019). For instance, instead of embracing new methods that involve training, contractors are typically eager to employ those that they are already familiar with (Chen, et al., 2023). This is due to the familiar routines giving professionals a sense of control over their work environment.

Apart from that, Ibrahim, et al. (2021); Kissi, et al. (2022) explained that construction workers are hesitant to change since emerging technology keeps developing, requiring upgrades and adjustments that would spend their time and result in more expenses each time when the digital devices have any evolvement. New technology puts a lot of pressure on employees who have become accustomed to the status quo to learn new procedures quickly (Nicole, et al., 2022). Moreover, Prabhakar, et al. (2023) also discovered that fear of losing their jobs caused employees to be hesitant to implement Construction 4.0. Aghimien, et al. (2021) further elaborated that digital tools may readily take over boring and repetitive activities as digitalisation becomes popular in the construction industry. The reason behind this is that digital tools are progressively gaining the ability to replicate human behaviour, thereby posing a potential threat to jobs (Delgado, et al., 2019). As a result, employees may adopt the mindset that they will be replaced by machines in the future, which could discourage them from embracing new technologies.

2.6.4 Concerning on Data Security and Protection Issues

Data security and data protection have become one of the main concerns for construction companies when implementing Construction 4.0 (Nicole, et al., 2022). As explored by Wang, et al. (2022), by 2029, there will be more than 15 billion IoT devices connected to company infrastructure, which creates critical situations for data transforming for construction activities. As more digital platforms are adopted in the construction industry, the risk of cyberattacks is increasing. According to Mantha and de Soto (2019), the AEC sector has encountered multiple cases of cyberattacks with the purpose to steal confidential information, access unauthorised files, and alter current data. Besides, Bajpai, et al. (2023) also claimed that project-related data may become accessible to several clients due to unauthorised access, poor user verification, and other authentication confirmations. Therefore, the device may be exposed to a cyberattack if security is inadequate.

Furthermore, security and privacy are crucial when the building is being occupied by users. Digitalisation in the industry enables the integration of a wide range of sensors that keep items fully linked to each other without any outside interference (Bajpai and Misra, 2021). The potential threat of using this confidential information exists because of the increasing availability of data provided from several sources. An example was provided by Forcael, et al. (2020), smart homes with IoT integration have the difficulty of managing massive amounts of data provided over the Internet to prevent device communication issues. Since all data is transmitted through computer networks and the Internet, the possibility of data leakage is present (Alaloul, et al., 2020; Kuzdikbay and Nadeem, 2022). This may lead to the sensitive user data being abused, and confidentiality can be violated.

2.6.5 Lack of Regulations and Standardisation

According to Chen, et al. (2023), lack of adequate rules and standards for the application of digital tools may deter professionals from implementing the developing digital tools in working places. Many professionals are quick to point their fingers at the government which plays a part in the rules and regulations. Olatunde, et al. (2022) mentioned that the government organisation charged with creating and enforcing regulations for the use of digital innovations has not been aggressive enough to set standards for the implementation of Construction 4.0 technology. Besides, this was also further explained by Wang, et al. (2022), digital transformation has the potential to upset an existing organisational structure or business process in the absence of government regulations. Therefore, regulations from the government are necessary for construction firms to use as a guide when deciding how to strategically address internal operations.

Every digital tool adopted in Construction 4.0 has unique requirements and limitations. There are different requirements in terms of energy, bandwidth, security and computational limitations (Bajpai and Misra, 2021). An example was provided by Xu, et al. (2023), it is difficult to incorporate blockchain with other construction technologies since various blockchains are unable to interact with one another due to the absence of universal standards. Also, in Sweden, the lack of regulations for BIM models encourages companies to utilise 2D drawings in legal contracts (Andersson and Eidenskog, 2023). In addition, contracting procedures are seldom standardised in practice because of the dynamic nature of the interactions between Construction 4.0 technologies (Karmakar and Delhi, 2021).

Stakeholders may be discouraged from embracing developing digital technologies due to a lack of technical standards and trustworthy information. Without any standardisation is facilitated through government initiatives as well as policy agendas, Construction 4.0 is unattainable.

2.6.6 Lack of Awareness of the Benefits of Construction 4.0 Digital Tools

Zabidin, et al. (2021) discovered that a significant number of stakeholders reported only low to moderate familiarity with the idea of Construction 4.0. This implies that a lack of awareness of the potential advantages of Construction 4.0 remains a major obstacle in the construction sector. SMEs face difficulties embracing digital tools due to limited exposure to the global construction industry and technology, leading to a lack of understanding among construction participants (Ibrahim, et al., 2021). The construction stakeholders are not updating themselves on the latest applications of digital tools; hence, the awareness level about the application of these tools is getting lower (Nicole, et al., 2022).

Moreover, Ebekozien, et al. (2023) underlined the uncertainty of the adoption of Construction 4.0 concept in the construction industry, with low priority given by stakeholders to technologies such as blockchain. Construction 4.0 technology such as drones currently used in the construction industry are highly prioritised, this is associated with a lack of awareness of construction-related technologies (Osunsanmi, et al., 2020). Not only that, the unpredictability of the advantages of Construction 4.0 digital tools may lead workers to resist technological advancements and face challenges in adaptation (Sawhney, et al., 2020; Demirkesen and Tezel, 2021; Kuzdikbay and Nadeem, 2022). Hence, construction participants lack awareness of the benefits of Construction 4.0 technologies, which hinders their adoption in construction workplaces.

2.6.7 Lack of Research on Construction 4.0 Digital Tools

A lack of research on Construction 4.0 technologies has been noted as a roadblock to Construction 4.0. Spending on R&D is frequently neglected by the construction industry, which eventually results in a low level of R&D

investment (Sawhney, et al., 2020). In the UK, Atkinson, et al. (2022) uncovered that construction firms spend less than 1% of their revenue on R&D and technological advancements. Oke, et al. (2023c) further revealed that professionals prefer to use the manual and conventional methods of tracking and monitoring site operations instead of relying heavily on technology, which results in a relatively small investment in technology. Nevertheless, Wang, et al. (2022) argued that the investments in digital tools are riskier as they have a high degree of uncertainty and the return on investment is uncertain.

According to Shang, et al. (2023), cost as well as profit are typically the main determinants of decision-making in the majority of firms. Since Construction 4.0 requires construction companies to take strong measures and investment to ensure the availability of advanced technology and skilled workers, the construction firms especially SME firms might not have additional funds to invest in R&D (Yahya et al., 2019). This is due to the fact that R&D investments raise costs in the short run and do not provide returns immediately, AEC businesses that make these investments are more likely to encounter budget overruns (Demirkesen and Tezel, 2021).

2.6.8 Pertaining to Legal and Contractual Matters

Legal and contractual problems are anticipated if the digital tools included in the contract for that specific job are not clearly stated (Ebekozien and Samsurijan, 2022). Moreover, Vanderhorst, et al. (2022) also expressed that when new technologies, strategies, or processes emerge in the industry, it demands clear and unambiguous terms that do not allow for any misunderstandings, with initial contracts needed to protect the interests of all project stakeholders. However, several construction projects may encounter legal and contractual issues because the contracts either fail to clearly explain the terms and conditions of the project or include confusing legal terms (Almatari, et al., 2023).

As mentioned by Demirkesen and Tezel (2021), regarding the usage of BIM, there are a few legal and contractual problems that remain unresolved, such as who is legally responsible for inaccuracies in the model and who owns the BIM model. Besides, Xu, et al. (2023) revealed that a lot of nations are not yet prepared to implement blockchain technology due to legal and regulatory constraints. Not only that, Shang, et al. (2023) also implied that one of the main obstacles to the application of AI in the Singapore construction sector is legal and contractual concerns. They worry that employing the latest digital tools without any support or legal protection might have unexpected legal consequences. Therefore, the implementation of cutting-edge devices may expose organisations to risk.

2.6.9 Lack of Government Support

The significance of the government’s contribution in realising Construction 4.0 should not be overlooked. As described by Chen, et al. (2023), the government might significantly assist in offering construction firms access to financing and boosting market demand for digital tools. However, Kuzdikbay and Nadeem (2022) emphasised that lack of government support is the main barrier to the adoption of Construction 4.0 in Kazakhstan. This is because the implementation of Construction 4.0 will incur a lot of money. In addition to investing a lot of money on costly digital tools purchases and personnel training, stakeholders must also cover costs like yearly licensing fees and maintenance costs (Onososen, et al., 2023).

Since SMEs contribute to the majority of the businesses in construction, they rely heavily on the government to help them via financing initiatives and cooperative partnerships (Alaloul, et al., 2020). This will only increase the financial burden of construction firms especially for SMEs. Moreover, Ibrahim, et al, (2021) also further added that the failure of the government to promote the adoption of cutting-edge digital tools in the construction industry is another obstacle. Without any support given from the government, they tend to maintain their current construction practices.

2.6.10 Fragmented Nature of Construction Industry

A lot of construction firms find it difficult to invest in digitization and implement innovations because of the construction industry’s fragmentation and project-based structure (Osunsanmi, et al., 2020). Besides, Karmakar and Delhi (2021) also emphasised that Construction 4.0 requires a more organised and collaborative approach, which can be difficult in a sector that has as high levels of fragmentation as the construction industry. This is because the construction process involves various parties including client, consultant team, contractor, and supplier at different phases, which are starting from the initial stages to the end of the project. As defined by Mohd Nawi, et al. (2014), traditional project delivery methods led to several fragmentation-related issues, including individualism among professionals, a lack of cooperation between design and construction, and the sequential nature of the process. In addition, the industry’s fragmented structure generates knowledge barriers that make it difficult to communicate and work effectively (Demirkesen and Tezel, 2021). The digital tools cannot be used effectively without collaboration between the construction players. Thus, project fragmentation contributes to low project quality, poor productivity, and resistance to adopting new ideas (Yahya, et al., 2019).

2.6.11 Poor Connectivity Network

Construction 4.0 is also hindered by issues with the current network connectivity. With the purpose of moving towards the future Construction 4.0 technologies, consistent and quick Internet access is required to guarantee excellent service delivery and management of digital as well as network assets (Bajpai and Misra, 2021). Nevertheless, it is still difficult to obtain adequate network coverage in construction sites, particularly in undeveloped areas (Gamil, et al., 2020; Kissi, et al., 2022).

Internet connection is a prerequisite for Construction 4.0 technologies to be used in construction sites. As mentioned by Ibrahim, et al. (2021), Internet connectivity will be the primary method used to link the IoT device with the system and transmit data into the information while the device remains in functioning. Poor network connectivity at the construction site will prevent the equipment from operating effectively (Bello, et al., 2021). As a result, the operator is unable to obtain the data and the information accuracy as well as interoperability may be seriously impacted by this. Besides, Xu, et al. (2023) also identified that insufficient storage, limited processing power and poor monitoring capabilities are the problems that may arise due to the lack of high-speed Internet connection.

2.6.12 Low Interest and Market Demand

Low interest and market demand may slow down the adoption of Construction 4.0. Hall, et al. (2022) presented that the primary obstacles to the wide-scale use of the digital tools are a lack of interest from different parties such as customers and subcontractors. As identified by Nagy, et al. (2021), the government being one of the major customers in the construction industry, engages in all phases of the building lifecycle. The customer has the right to make the decision whether they want to construct the project with the use of digital tools. There is no rationale for consultants to offer customers digital services if they are not digitally prepared (Chen, et al., 2023). As a result, customers may not be interested in developing digital technologies since they are unaware of the technologies and their advantages (Nagy, et al., 2021).

On the other hand, a technology that is unfamiliar to a wide range of experts will not be effective in its field of application (Oke, et al., 2023b). Likewise, Ebekozien and Samsurijan (2022) also agreed that the demand will only increase when many professionals are familiar with the technology and are able to perform it at an optimum level. Moreover, each of the construction projects has different characteristics and nature, and the customer’s requirements are different as well. Hence, it is difficult to guarantee that the spending committed to integrate robotic systems may be utilised in subsequent projects (Davila Delgado, et al., 2019). This is further explored by Yahya, et al. (2019) who noted the construction industry’s lack of enthusiasm for robotic technology may be linked to the uniqueness of each project, dynamic production relocation, fragmented power over the procedure, challenging environment, and an uncertain market environment.

2.6.13 Higher Requirements for Computing Devices

Higher requirement for computing devices has also been identified as a barrier to Construction 4.0. As underlined by Kuzdikbay and Nadeem (2022), weather, traffic and the surrounding environment are external circumstances influencing the dynamic nature of the construction industry. The temperature and humidity vary greatly between day and night, requiring the digital tools or materials used in the construction or printing process to be resistant to both heat and cold (Hossain, et al., 2020).

Dust and humidity levels place higher demands on computing devices used in construction site environments, mainly outdoor environments (Klinc and Turk, 2019). For instance, robotic automation is one of the technologies that has been adopted in Construction 4.0. The complexity of tasks that robots have to perform in construction is obviously greater when compared to other industrial sectors (Turner, et al., 2021). Conforming to Yahya, et al. (2019); Oke, et al. (2021a), robots used in construction should be able to perform difficult tasks, work effectively in adverse conditions, and withstand a lot of dust and grime on the job site. Moreover, Diana, et al. (2019) claimed that it would be difficult to handle and develop digital tools if the devices were utilised in an open area without an appropriate setting for quality and safety monitoring. As a result, it is also necessary to continuously modify the standards, maintenance practises, as well as conditions.

2.6.14 Lack of Knowledge Management

A lack of knowledge management will worsen the process of Construction 4.0 as top management has less involvement in the implementation of the digital tools. Therefore, the approach is never completely understood at management level, managers would be less able to appreciate its importance and discover its advantages (Zulu, et al., 2023). When the relevant knowledge is insufficient, it can be incredibly costly to a business due to the top management may not be able to evaluate their current digital abilities and competencies (Wang, et al., 2022). Besides that, Bajpai and Misra (2022) also expressed that top management’s decision to accept digitalisation is being influenced by this lack of information; in terms of cost, the managers’ struggles to decide how much to spend and where to allocate their money might postpone the application of Construction 4.0 technologies.

Due to a lack of familiarity with the implementation of Construction 4.0, top management did not aggressively identify skill shortages or pay greater attention to the project strategy or the organisational structure of the project team (Toyin and Mewomo, 2022). As a result, this may lead to less support from top management. According to Aghimien, et al. (2022b), the commitment of the company’s upper management is crucial since their understanding of technological issues will affect whether they approve of or disagree with digital transformation in their company. Likewise, Wang, et al. (2022) also stated that digitalisation may not be achieved without any ongoing support and motivation provided by top management to employees. Therefore, a lack of comprehensive understanding and knowledge management of Construction 4.0 among senior management will lead to reduced support for these digital tools and further strengthen worker resistance to this innovative transformation.

2.7 Strategies to Improve the Implementation of Construction 4.0 Digital Tools

Moving towards Construction 4.0 is complex, uncertain and expensive; however, the return brought from the Construction 4.0 with its digital tools is worth it. There are several strategies to be taken to improve the implementation.

2.7.1 Financial Support

Government incentives will help to lighten the burden on construction firms, especially SMEs, in moving toward Construction 4.0. The implementation of Construction 4.0 digital tools required high costs for acquiring and installing the technologies, as well as for obtaining the software licence (Perera, et al., 2023). To enhance accessibility to digital tools and technology for construction companies, the government should actively offer subsidies for purchasing these resources. According to Kissi, et al. (2022), governments should proactively establish comprehensive policies and initiatives, which include offering technical and financial assistance to incentivize construction companies in adopting new technologies. Those working in the construction industry that are unable to purchase the technology needed for their project will be drawn to this effort (Xu, et al., 2023).

On the other hand, offering incentives to SMEs is essential, and it is crucial to ensure they are not left behind in the existing fragmented construction sector (Georgiadou, 2019; Saka and Chan, 2020). Besides, Ibrahim, et al. (2021) also proposed an alternative measure by mentioning that the government may implement a rental programme with acceptable costs and lease terms. Hence, the contractors may have the opportunities to adopt various digital tools in their projects and determine which technology is most suitable for their use. As a result, this could lead to further cost savings for contractors, as they have the ability to choose the technology and invest accordingly (Aliu and Oke, 2023). Other than that, the government may provide financial assistance for research related to digital tools to enhance knowledge and develop a localised framework for the implementation of Construction 4.0 (Olanrewaju, et al., 2021).

2.7.2 Training and Education

Poor skills and knowledge are another reason for the failure to implement Construction 4.0. Thus, adequate understanding and application of construction digital tools in educating and training professional stakeholders are vital to achieving a comprehensive and effective adoption of digital technologies (Fakher and Anandh, 2022; Toyin and Mewomo, 2022). Similarly, Chen, et al. (2023) also stated that enhancement of staff knowledge and capacity in digital tools through the provision of professional training and upgrading of skills. Therefore, Oke, et al. (2022) recommended that management stakeholders should explore ways to enhance the abilities of workers already employed in the construction industry. This can be achieved by implementing programs or intensive training sessions that enable upskilling, multi-skilling, and reskilling, thereby ensuring that workers become technologically savvy (Hwang, et al., 2022). It is possible to lower the threat of technology rejection brought on by concern over loss of employment. In addition, in industries where specific jobs are at risk of becoming obsolete, retraining will help to mitigate the effects of unemployment (Aghimien, et al., 2021).

On the other hand, to realise the huge potential of Construction 4.0 technologies to increase productivity, both construction organisations as well as governments should invest significantly, which may include the offering of software training (Olanrewaju, et al., 2021). However, Lew, et al. (2019) argued that software company’s efforts were effective and successful in achieving the goals in a shorter period than those of the government, whose implementation programmes required resources and an extended period. In order to enable users to completely understand and take advantage of the potential benefits of the software, the software producers should take steps to set up various types of training. Thus, training might help workers acquire the necessary abilities to use digital tools and software and overcome the expertise issues that many developing nations encounter (Senanayake et al., 2023).

2.7.3 Increase Awareness of Construction 4.0

It is essential to increase stakeholders’ awareness regarding the importance of achieving digital progress, specifically within the construction industry. A recommendation was given by Maqsoom, et al. (2023), stating that publishing advertisements is useful in spreading awareness about the benefits of digital tools in the construction sector. The Internet has become an immediate and affordable platform for creative advertising and reaching out to the global users. Hence, this implementation necessitated top management to keep up to date on developing technologies and the advantages their organisations can obtain by adopting these technologies (Aghimien, et al., 2022). For example, well-publicised through social media, industry publications, and other channels to highlight the advantages and potential uses of developing technology (Chen, et al., 2023). The media, through its visual and printed abilities, can effectively convey the message about the importance of implementing digital tools to achieve the objectives of Construction 4.0.

Besides that, Osunsanmi, et al. (2020); Akinradewo, et al. (2022); Toyin and Mewomo (2022) also suggested that raising awareness of the concept of Construction 4.0 among construction experts through workshops, conferences and meetings is crucial to effectively enhance the construction professionals’ familiarity with digital technologies and their uses. Olatunde, et al. (2022) proposed that the professional organisations should regularly and consistently hold seminars for their members and make it compulsory for professionals to attend at least a few times. This will open the construction participants’ mind to the needs and availability in the market and allow them to improve their skills to suit what is needed. Not only that, but professionals in the construction industry will also have the chance to learn about the numerous methods that digital technologies may be introduced into the industry firsthand by attending these events (Aliu and Oke, 2023).

2.7.4 Early Technology Involvement

Graduates produced today by the local universities are examination focused and therefore lack the skills a hands-on industry may require. Thus, Georgiadou (2019); Lim, et al. (2023) suggested that the government and professional organisations examine the integration of digital tools into the collaborative-built environment programs in higher education in order to address the existing skills as well as knowledge gap. Likewise, some advanced digital tools or online platforms can be provided in the teaching and learning process for students to do practical work. This will give them early exposure to the application of technologies in an actual construction environment (Zabidin, et al., 2023). For example, higher education institutions, like universities, polytechnics, and vocational colleges, have incorporated IoT devices to educate and familiarise construction and engineering students with BIM and IoT technologies, preparing them to become future industry leaders (Ibrahim, et al., 2021; Lim, et al., 2023).

Apart from that, university institutions must review and restructure their current curricula to reflect the underlying technologies in Construction 4.0, in order to develop proficient graduates in technology who can integrate quickly into the disruptive workplace (Zabidin, et al., 2021; Oke, et al., 2022). Universities must always be aware of the latest development in the construction industry and providing early exposure to these concepts helps improve student comprehension and gives graduates a competitive edge (Onososen, et al., 2023). Moreover, Aghimien, et al. (2022b) mentioned that facilitating industry-academia engagement through industrial training for undergraduate students helps construction organisations to discover digital talent early in the careers of these individuals. Hence, this will improve the employability of students and the practical application in the construction industry.

2.7.5 Regulations and Policies by Government

It is the onus of the government to provide suitable regulations and policies in realising Construction 4.0. In order to facilitate the advancement of the construction sector’s digital evolution, it is necessary for the government to express its greatest concern for the adoption of cutting-edge tools by establishing an enabling environment through the implementation of regulations and policies (Aliu and Oke, 2023). Thus, Davila Delgado, et al. (2019); Ebekozien and Samsurijan (2022) pointed out that mandatory programmes are highly disruptive but can accelerate the rate of adoption.

According to the Malaysia BIM Report 2021 (CIDB, 2022), it stated that the mandatory use of BIM for public projects of RM100 million or above from 2019 onwards has contributed to the adoption of BIM in Malaysia. Furthermore, the National Construction Policy 2023 expects that at least 50% of the industry’s operations, including the phases of procurement and monitoring, will be digitalized by 2030, with full automation planned through the use of BIM (Ministry of Works, 2021). Since there is currently no mandatory requirement to implement BIM for private projects, the Malaysian government may face huge challenges in accomplishing this target. Thus, Saka and Chan (2020) stated that it is crucial to consider the involvement of SMEs while developing BIM policy to avoid the further widening of the existing digital divide with the industry.

2.7.6 Guidelines by Professional Bodies

Professional bodies have a great responsibility in helping the construction industry in transforming to Construction 4.0. According to CIDB (2020), Construction 4.0 Strategic Plan (2021-2025) with the goal to reshape the construction sector into a smart, sustainable and productive industry by adopting IR 4.0 technologies. The effective incorporation of digitalisation in the construction sector significantly depends on the involvement of professional organisations. One of the key aspects of their contribution is outlining and providing clear guidelines to the construction participants (Onososen, et al., 2023). For instance, organisations such as the CIDB, whose mission is to promote the development of the construction industry and to contribute to social and economic progress, also have the potential to mitigate legal risks by easing the strict enforcement of regulations that inhibit the adoption of digital technologies in the implementation of public projects (Aghimien, et al., 2021). Moreover, Ebekozien, et al. (2023) also further supported that Construction 4.0 digital tools should be examined by professional bodies for the construction sector and incorporated into ongoing professional development.

2.8 Conceptual Framework for the Adoption of Construction 4.0 Digital Tools

The theoretical framework shown in Figure 2.1 provides an overview of the literature review. It helps to explore the readiness of the Malaysian construction industry for Construction 4.0 digital tools. This research is supported by analysing the benefits, types, barriers and strategies of digital tools in the industry.

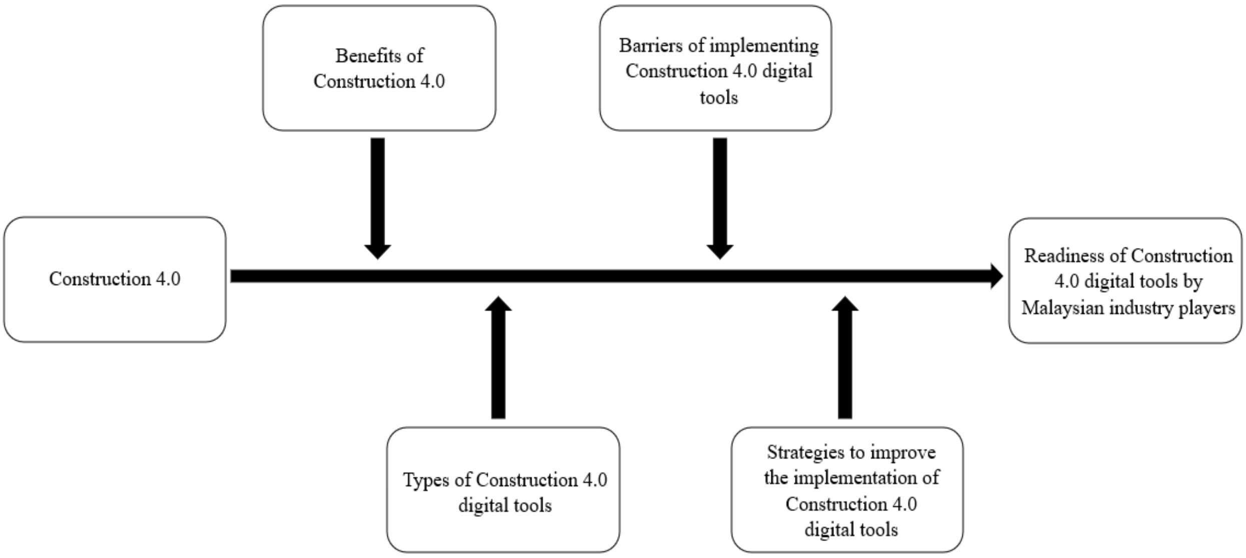

Figure 2.1: Conceptual Framework for the Adoption of Construction 4.0 Digital Tools.

2.9 Summary

The concept of Construction 4.0 is initially explained in this chapter through the perspectives of different researchers. The chapter also explores the benefits of Construction 4.0 and its digital tools. Furthermore, this chapter discusses several barriers faced during the implementation of Construction 4.0 and suggests various strategies for overcoming them.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter begins by defining the definition of research. Besides, this chapter also describes different types of research philosophy and methods, the rationale for the chosen research philosophy and approach, research design, research instrument, sampling process and data analysis.

3.2 Definition of Research

Research is described as a process of discovering new knowledge and as a non-political endeavour to contribute to society (Salkind, 2006). As defined by Kabir (2016), research means conducting repeated searches, implying that the previous search was insufficient and that there are possibilities for improvement. Research involves systematically gathering, organising, and analysing information to support effective decision-making. Likewise, Sekaran and Bougie (2016) also highlighted that research helps organisations to make informed choices, as effective decisions lead to problem solving.

3.3 Research Philosophy

Research philosophy consists of beliefs about the nature of the reality under study and guides how to collect, analyse, and utilise data about the phenomenon (Saunders, et al., 2016). As claimed by Creswell and Creswell (2018), a researcher’s philosophical beliefs about the world and the nature of their study are influenced by their worldview, which is affected by disciplines, mentors, and prior experiences. According to Saunders, et al. (2016), positivism, critical realism, interpretivism, post modernism, and pragmatism are the main philosophies to be discussed as below.

3.3.1 Positivism

The basic principle of positivism is the idea that knowledge may be acquired by impartial observations and measurements (Saunders, et al., 2016). In other words, positivist philosophy holds that solutions may be discovered by rigorous measurement and analysis, especially of numerical data. As elaborated by Creswell and Creswell (2018), research often explores causal relationships between variables, while a positivist philosophy aims for objectivity, generalisability and reproducibility of findings (Sekaran and Bougie, 2016).

3.3.2 Critical Realism

According to Saunder, et al. (2016), critical realism recognises the existence of external reality or objective truth but rejects the idea that such reality can be accurately measured. As further explained by Sekaran and Bougie (2016), it emphasises that observations, especially of unmeasurable phenomena such as satisfaction, motivation and culture, are fundamentally open to interpretation. In order to achieve objectivity, researchers can adopt a variety of methods that both encourage methodological diversity and provide interpretive insights into causes and antecedents (Ghauri and Gronhaugh, 2010).

3.3.3 Interpretivism

Interpretivism holds that reality is subjective and determined by the experience of the observer. It is used in research aimed at understanding the meanings and interpretations that individuals attribute to their experiences, commonly employing qualitative methods such as interviews, observation and textual analysis (Sekaran and Bougie, 2016). Conforming to Creswell and Creswell (2018), such research usually explores complex societal issues and personal viewpoints, which are naturally more subjective as well as nuanced.

3.3.4 Post Modernism

According to Saunders, et al. (2016), with the goal of challenging traditional thinking and amplifying neglected alternative viewpoints, post modernism emphasises the significance of language and power relations. The presentation of research results in an objective and unbiased manner is objected to by postmodernists. As explained by Neuman (2014), post modernism opposes the use of science for prediction and policy making while stresses the importance of explicitly and openly uncovering concealed meanings.

3.3.5 Pragmatism

Pragmatism emphasises practical and applied research, where different perspectives on the research process and the object of study contribute to problem solving (Sekaran and Bougie, 2016). As mentioned by Creswell and Creswell (2018), there is no single philosophy or reality system that pragmatism adheres to. Thus, pragmatism aims to achieve diverse research goals by reconciling objectivity and subjectivity, facts and values and accurate knowledge with varied contextual experiences (Saunders, et al., 2016).

3.4 Research Methodology

Research methodology entails a structured approach to solving a research problem, considered as scientific research conducted out systematically (Kothari, 2004). As explained by Sekaran and Gougie (2016), scientific research is committed to problem-solving, employing a rigorous, logical, and comprehensive approach to recognise challenges, collect data, analyse it, and draw appropriate conclusions. Qualitative, quantitative, and mixed methods are the research methodologies provided by Creswell and Creswell (2018).

3.4.1 Quantitative Method

Quantitative research is a method to gather numerical data and analyse it in the form of statistics through the use of mathematically based procedures (Apuke, 2017). Patel and Patel (2019) also defined that quantitative method relies heavily on primary data sources such as surveys and questionnaires. The data can be quantified numerically, analysed statistically, or represented visually in tables, charts, histograms, and graphs (Rugg, 2010). A large number of respondents are necessary to demonstrate that the results are attainable and capable of representing the interests of the population (Queirós, et al., 2017).

3.4.2 Qualitative Method

Qualitative research aims to gain a better understanding of a topic rather than to express it numerically, focusing on the quality and nature of phenomena through in-depth interviews to uncover root causes and desires (Queirós, et al., 2017). Similarly, rather than providing a surface perspective of a large population sample, qualitative research attempts to acquire insights inside a particular organisation or event (Bhawna and Gobind, 2015). Thus, qualitative researchers focus on understanding how individuals perceive and experience reality, using methods like interviews and observation to gather data in the forms of words, images, or objects (Wilson and Sharples, 2015).

3.4.3 Mixed Method

Mixed methods research seeks to solve complex research topics that cannot be addressed only by “qualitative” or “quantitative” methodologies (Sekaran and Bougie, 2016). In order to ensure the final database consists of both research data, the data collection adopted in a mixed method requires collecting both statistical data and textual data (Bhawna and Gobind, 2015). Thus, Sekaran and Gougie (2016); Lamprecht and Guetterman (2019) highlighted that the popularity of this strategy stems from its ability to combine inductive and deductive thinking, employ numerous research methodologies, and leverage diverse data forms to address issues effectively.

3.5 Justification of Selected Philosophy and Research Method

The pragmatism philosophy is appropriate for this research because it prioritises the research that begins with identifying problems and aims to develop practical solutions that inform future practices. Applying pragmatism to solve the objectives of identifying the benefits and barriers of adopting Construction digital tools involves considering theories, concepts, and study outcomes in terms of their practical results in specific situations. Besides, it can help to assess the practical implications of adopting Construction 4.0 digital tools in the context of the construction industry in Malaysia. This involves examining how these tools are realistically implemented, identifying the barriers faced, and understanding how they impact the readiness of construction industry players for Construction 4.0.

The quantitative research method is chosen because this research focuses on gathering numerical data to examine the readiness of Construction 4.0 digital tools by Malaysian construction industry players. A survey research approach will be used, in which questionnaires will be distributed to a large population of selected respondents. By adopting this method, it tends to be more objective as a larger number of the sample of a population. Furthermore, this method also enables researchers to collect large amounts of data efficiently in a time constrained period. Apart from that, quantitative research used to identify the relationship between independent and dependent variables in a population. In this regard, the data collected may be evaluated to determine the challenges impeding the implementation of Construction 4.0 digital tools in construction projects as well as the strategies for improvement. As a quantitative research method gives quantifiable data that cannot be readily misinterpreted, the results or generalisations are more reliable as well as valid. In addition, with the use of statistical techniques in this method, it enables for more complex data analysis and allows researchers to understand a huge amount of crucial data characteristics. Therefore, a quantitative research method is selected.

3.6 Research Design

The research design is meant to present a suitable structure for research (Jilcha Sileyew, 2020). It is used to guide the process to obtain results in order to answer the research problem; hence, selecting a suitable research design is crucial since it can impact the overall relevance of the research outcomes (Moffatt, 2015).

Before selecting a study topic, the research scope of “digitalised construction” is defined. As the area of digitalised construction is too broad to study extensively in a single report, a preliminary search for background information on the scope is carried out from various sources. After performing a preliminary search, a more specific and clearer direction is obtained. With the increasing popularity of IR 4.0 in the construction sector as well as the associated national policies established by the government, “Assessing the Readiness of Malaysian Construction Industry towards Construction 4.0" was chosen as the topic of this research.

After that, the review of literature begins with a vast variety of secondary data sources such as journal articles, conference papers and e-books. For example, “Construction 4.0” and “IR 4.0 in the construction industry” are some of the main keywords used for searching. Meanwhile, the problem of research topics is recognised. At this reviewing step, document management is used to tidy up all of the sources. For instance, all journal articles are kept in a specific file and named with the year and title. Moreover, in order to avoid plagiarism, Harvard citation and reference are applied when writing the literature review. During the literature review, research topics covered by previous researchers were investigated to identify research gaps. The identified research gap pertains to the readiness of Malaysian construction players in adopting Construction 4.0 digital tools. Hence, the aim and objectives of this research were established to address this gap.

Afterwards, the pragmatism philosophy and the quantitative method is selected for this research. This is due to the large population required to examine the readiness of construction industry players towards Construction 4.0 as well as to gain information about Construction 4.0 in the aspects of types of digital tools, barriers and strategies. Therefore, questionnaires are developed and distributed through social media and email in order to collect the data from targeted respondents. After receiving data from respondents, reliability analysis and various inferential tests will be conducted to analyse the data. As a result, in order to achieve the research objectives and aim, the data analysis results are examined and conclusions are formed.

Lastly, the final part of this study offers a conclusion. It also highlights the limitations encountered while performing this research, as well as the research topic recommendation which assists future researchers interested in carrying out similar research. Figure 3.1 shows the research design which is used to present the whole processes involved in this research.

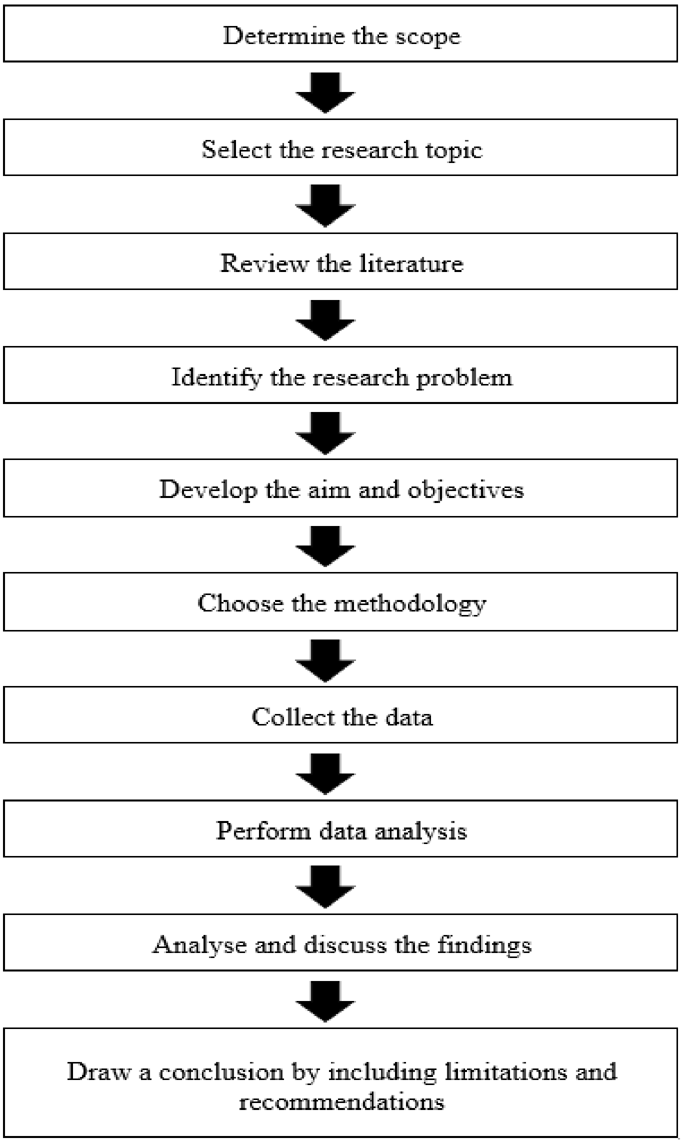

Figure 3.1: Research Design Workflow.

3.7 Research Instrument

A research instrument is any procedure, tool, or method for collecting, evaluating, and analysing data relevant to the research topic. The subsequent sections elucidate on the data collection procedures for this research.

3.7.1 Questionnaire Design

For this research, a questionnaire survey was used to obtain input from the specified respondents. The survey is segmented into five separate sections, as outlined in Table 3.1. Section A of the questionnaire investigated the demographic information of the respondents, including details such as the type of business the company is engaged in, the professional role played, their working experience in the construction industry, the respondent’s current organisational position, and the size of the company.

Following that, Section B featured three questions concerning Construction 4.0 digital tools. The first question assessed the implementation of Construction 4.0 digital tools for their current or past projects, while the second question gauged the respondents’ likelihood of implementing Construction 4.0 digital tools for their future projects. Both of these questions adopted a five-point Likert scale for the respondents to assess their opinion regarding 11 distinct Construction 4.0 digital tools. The final question in Section B aimed to determine whether respondents preferred using traditional or Construction 4.0 digital tools for various construction tasks.

Furthermore, Section C discussed the benefits of using digital tools for Construction 4.0, Section D addressed the barriers to their implementation, and Section E focused on strategies to enhance implementation. A five-point Likert scale was utilised in each section to gather the respondents’ perceptions on various aspects.

Table 3.1: Summary Sections in Questionnaire Survey

Section	Description
A	Respondent’s Background
B	Types of Construction 4.0 Digital Tools
C	Benefits of Implementing Construction 4.0 Digital Tools
D	Barriers of Implementing Construction 4.0 Digital Tools
E	Strategies to Improve the Implementation of Construction 4.0 Digital Tools

3.8 Sampling Process

Sampling is the process of choosing an adequate number of appropriate components from a larger group with the goal of examining the sample and understanding its characteristics (Sekaran and Bougie, 2016). This allows making inferences about those characteristics and applying them to the entire population. Sampling facilitates the fast collection of information and shortens the time between the realisation that information is required and its actual availability. Hence, it is important to understand the major steps in sampling to obtain information from the right representative sample.

3.8.1 Defining the Population

The population is a collection of people, events, or objects under research from which the researcher gathers data to make inferences using sample statistics (Sekaran and Bougie, 2016). It is essential to meticulously determine the target population in order to ensure that it is in line with the goals and practicality of the research. As one of the research objectives is to infer the readiness of construction industry players regarding Construction 4.0 digital tools, the population is restricted to current construction practitioners, who possess the most suitable expertise to provide valuable insights on the research topics.

3.8.2 Determining the Sampling Frame

The sampling frame is like a population map that lists all the elements from which a sample is drawn (Cooper and Schindler, 2014). It should ideally include every member of the population. The proper techniques must be used by researchers to guarantee that they only use the chosen elements from this list. In this research, the sampling frame consists of five groups which include architect, engineer, quantity surveyor, builder and supplier or subcontractors or specialist. Various official websites, such as CIDB, the Board of Architects Malaysia (BAM), the Board of Engineers Malaysia (BEM), the Board of Quantity Surveyors Malaysia (BQSM), and Pusat Khidmat Kontraktor (PKK), provide access to these professional groups registered under the government. By using official government websites to define the sampling frame, it facilitates regulatory compliance, accuracy, legitimacy, and inclusion in the research process.

3.8.3 Determining the Sampling Design

Two major types of sampling design, including probability and non-probability sampling, have been identified. In probability sampling, each case in the target population has an equal and known probability of being chosen; in non-probability sampling, the likelihood of selecting each case from the target population is unpredictable (Sekaran and Bougie, 2016). In other words, in non-probability sampling, individuals are chosen based on specific criteria rather than randomly, meaning not everyone has an equal chance of being included in the study. Non-probability sampling is generally used when time restrictions or other considerations take precedence over generalisability. Due to the time restrictions for data collection in this research, which is approximately 2 months, a non-probability sampling design has been selected.

There are few types of nonprobability sampling which include convenience, snowball, quota and purposive sampling. However, only convenience sampling and snowball sampling had been used in this research. According to Saunders, et al. (2016), convenience sampling is the process of selecting a sample of people who are readily accessible. On the other hand, snowball sampling, also known as network sampling, involves researchers being directed by respondents to other individuals who share similar or different characteristics, experiences, or perspectives (Cooper and Schindler, 2014). This method allows researchers to reach different respondents who possess specific expertise in answering the questionnaire by initially selecting a few respondents. Both sampling designs possess the similarity of being a convenient and cost-effective method for collecting data, especially considering the time constraints in this research.

3.8.4 Determining the Sampling Size

Selecting the right sample size may be quite difficult. Hence, as suggested by Saunders, et al. (2016) and Islam (2018), central limit theorem (CLT) suggests that sample means will approximately follow a normal distribution when sufficiently large samples are collected, with each sample size being at least 30, from a population, regardless of its distribution. CLT allows researchers to use the normal distribution to estimate the population mean using summary statistics from just one large enough sample, without having to gather many samples of the same size (Ali, et al., 2018). In this research, five questions have been designed to gather demographic information, with up to five groups available for selection. According to CLT, it is estimated that a minimum of 150 samples is required with consideration of five categories of respondents’ attributes.

3.8.5 Executing the Sampling Process

It is necessary to make decisions on the target population, sampling frame, sampling method, and sample size. Subsequently, questionnaires were distributed to five professional background groups identified in the sampling frame section. Various platforms, including LinkedIn, WhatsApp, and email, were employed to improve response rates. In cases where the sample size for a specific group did not meet the minimum requirement for CLT, follow-up procedures were implemented to maximise responses. After data collection, it would be evaluated using the inferential tests outlined in the following section.

3.9 Data Analysis

Data analysis must be conducted after collecting data from respondents as it enhances data interpretation via the use of statistical analysis to uncover patterns, trends, and relationships among variables. Hence, Statistical Package for Social Sciences (SPSS) is used for data analysis. The following sections will discuss the several inferential statistical tests performed in this research.

3.9.1 Cronbach's Alpha Reliability Test

Cronbach's alpha is a statistical tool for ensuring that tests and scales are suitable for their intended purpose (Taber, 2018). To put it simply, it assesses the reliability of Likert scale questions in a questionnaire, with values closer to 1 indicating higher consistency. As mentioned by Glen (2024), the data demonstrates internal consistency when α exceeds 0.7. Table 3.2 provides the interpretation criteria for evaluating the outcome of this test. In this research, the questions in Section B, C, D and E are subjected to this reliability test.

Table 3.2: Interpretation of Cronbach's Alpha Reliability Index (Glen, 2024)

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

3.9.2 Friedman Test

Friedman Test is a useful analytical tool for nonparametric data. The aim of this test is to assess whether there is a significant statistical difference between the means of three or more groups that consist of the same individuals (Bobbitt, 2020). Regardless of group size and even in situations with a small number of respondents, this method allows test results to be generated for groups that may be compared with each other (Jussila, et al., 2008). This test will be deployed to determine the means of the dependent variables in questionnaire Sections B, C, D, and E.

3.9.3 Pearson's Chi-Square Test

Pearson's Chi-Square test, also known as the Chi-Square test of association or independence, is a non-parametric statistical hypothesis test. It compares observed outcomes with expected ones to assess if differences are due to chance or indicate a relationship between variables (Biswal, 2023). As such, it is a useful instrument for improving the comprehension and interpretation of the relationship between two category variables. In this research, this test will focus on Question 8, which asks about preferences between traditional methods and Construction 4.0 tools for various activities outlined in Section B. The objective is to ascertain if there is any correlation between different groups' preferences in Section A regarding the two methods.

3.9.4 Kruskal-Wallis Test

Kruskal-Wallis test, a non-parametric alternative to one-way analysis of variance (ANOVA), is capable of recognising significant differences in medians between three or more independent groups, if that the data is non-normally distributed. When applied to ordinal or dependent continuous level variables, it compares group medians using ranks as opposed to means or variances (Niedoba, et al., 2023; Ahmed, 2024). The null hypothesis states no significant differences between groups on dependent variables and is rejected if $p < 0.05$. This test will be applied to Section C and D to assess whether significant differences exist among the demographic profiles of respondents regarding the benefits incurred from adoption and barriers that impede the implementation of Construction 4.0 digital tools.

3.9.5 Spearman’s Rank-Order Correlation Coefficient Test

The strength and direction of the relationship between two ranked variables is evaluated using Spearman’s rank-order correlation coefficient (Gupta, 2023). The coefficient spans from -1 (strongest negative correlation) to 1 (strongest positive correlation) (Schober and Schwarte, 2018). A negative correlation shows that when one variable increases, another variable tends to decrease, whereas a positive correlation demonstrates that variables increase simultaneously. Table 3.3 shows the interpretation of Spearman’s Rank Correlation Coefficient. This test will be adopted in Section B for Questions 6 and 7 to determine whether the adoption of digital tools in past or previous projects will affect the recommendation for their future usage. Meanwhile, this test will also be applied to gauge the strength of the relationship between the six strategies outlined in Section E and their effectiveness in addressing the 14 barriers detailed in Section D.

Table 3.3: Interpretation of Spearman’s Rank Correlation Coefficient (Yan, et al., 2019)

Grading Standards	**Correlation Degree**
$\rho = 0$	No Correlation
$0 < \lvert\rho\rvert \leq 0.19$	Very Weak
$0.20 \leq \lvert\rho\rvert \leq 0.19$	Weak
$0.40 \leq \lvert\rho\rvert \leq 0.59$	Moderate
$0.60 \leq \lvert\rho\rvert \leq 0.79$	Strong
$0.80 \leq \lvert\rho\rvert < 1.00$	Very Strong
$\rho = 1$	Monotonic Correlation

3.10 Summary

In summary, this chapter outlines the research definition and methodology, including a discussion of the quantitative research approach employed in the research and the overall research procedure. Subsequently, it introduces the proposed data analysis methods, including Cronbach’s Alpha Reliability Test, Friedman Test, Pearson’s Chi-Square Test, Kruskal-Wallis Test and Spearman’s Rank-Order Correlation Coefficient Test, along with their respective purposes and applications to specific sections of the questionnaire.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will analyse the collected data with the use of SPSS. Various tests will be conducted to identify the current trend in digital tools adoption among the construction participants, facilitating the transition of Construction 4.0 and contributing to the achievement of the research's aim and objectives.

4.2 Demographic Information of Respondents

Table 4.1 below demonstrated an overview of the demographic information of 171 respondents. Data were collected over a span of approximately two months, commencing from 16 February 2024 to 5 April 2024. During this period, around 320 questionnaires were distributed through various platforms such as LinkedIn, WhatsApp, and Email. The distribution included 55 to architects, 55 to engineers, 65 to quantity surveyors, 65 to builders, 45 to subcontractors, and 35 to suppliers. By 5 April 2024, a total of 171 responses were received, resulting in a response rate of 53%. As depicted in Table 4.1, it reveals that the largest proportion of responses came from the property development category, constituting 28.10% of the total respondents. In terms of professional background, 37 respondents identified themselves as builders, making up 21.60% of the overall sample.

There are 54 individuals in total who reported having 6 to 10 years of work experience, comprising the largest segment of the overall sample at 31.60%. Besides, among the respondents, 49 respondents held senior executive positions within their respective organisations, indicating the highest representation among all job roles. Lastly, the most substantial number of responses came from medium-sized companies with 31 to 75 people, amounting to 64 and representing 37.40% of the entire sample.

Table 4.1: Demographic Information of Respondents

Demographic Information	Categories	Frequency (n)	Percentage (%)
Company Business Activities	Property Development	48	28.10
	Consultancy	41	24.00
	Contracting Business	35	20.50
	Building Material Merchant	23	13.40
	Equipment Supply/ Hiring/ Renting Business	24	14.00
Professional	Architect	33	19.30
	Engineer	32	18.70
	Quantity Surveyor	35	20.50
	Builder	37	21.60
	Supplier/ Subcontractor/ Specialist	34	19.90
Working Experience	0-2 years	25	14.60
	3-5 years	35	20.50
	6-10 years	54	31.60
	11-20 years	33	19.30
	21 years and above	24	14.00
Position	Junior Executive	46	26.90
	Senior Executive	49	28.60
	Assistant Manager/ Manager/ Team Leader	42	24.60
	Director/ Managing Directors/ CEO	34	19.90
Company Size	Micro (Less than 5 people) & Small (5-30 people)	53	31.00
	Medium (31-75 people)	64	37.40
	Large (More than 75 people)	54	31.60

4.3 Cronbach's Alpha Reliability Test

The Cronbach's Alpha Reliability Test results for Sections B, C, D. and E were summarised in Table 4.1. If α is greater than 0.7, the data shows internal consistency. Each section fulfils the 0.7 criteria, indicating that the questions within each section are designed with internal consistency.

Table 4.2: Cronbach's Alpha Reliability Test

Section	Cronbach's Alpha	Number of Items
B	0.812	33
C	0.826	16
D	0.858	14
E	0.811	6

4.4 Implementation of Construction 4.0 Digital Tools in Past or Current Projects

Table 4.3 shows the mean ranking of the implementation levels for Construction 4.0 digital tools in past or current projects. Cloud computing emerges as the most commonly adopted tool, followed by BIM and RFID, while 3D printing appears to be the least used among respondents in their past or current projects.

Table 4.3: Mean Ranking of Implementation Levels for Digital Tools

Code	Statements	Mean Rank	Chi-square	Asymp. Sig.
BA2	Cloud Computing	10.27	948.556	<.001
BA1	Building Information Modelling (BIM)	9.13		
BA8	Radio Frequency Identification (RFID)	6.68		
BA4	Big Data	6.44		
BA3	Internet of Things (IoT)	6.35		
BA11	Blockchain	6.16		
BA6	Artificial Intelligence (AI)	5.36		
BA5	Cyber-Physical System (CPS)	4.91		
BA9	Augmented Reality (AR) / Virtual Reality (VR)	4.52		
BA7	Robotics and Automation Systems	3.81		
BA10	3D Printing	2.38		

4.5 Recommendation for Adopting Construction 4.0 Digital Tools in Future Projects

The mean ranking for recommending the adoption of Construction 4.0 digital tools in future projects was outlined in Table 4.4. Cloud computing, BIM and blockchain stand out as the top three most welcomed digital tools to be adopted in future projects. However, 3D printing is the least popular tool to be considered for future implementation.

Table 4.4: Mean Ranking of Recommendation Levels for Digital Tools

Code	**Statements**	**Mean Rank**	**Chi-square**	**Asymp. Sig.**
BS2	Cloud Computing	7.89	382.113	<.001
BS1	Building Information Modelling (BIM)	7.46		
BS11	Blockchain	6.87		
BS8	Radio Frequency Identification (RFID)	6.68		
BS6	Artificial Intelligence (AI)	6.22		
BS4	Big Data	6.13		
BS9	Augmented Reality (AR) / Virtual Reality (VR)	5.84		
BS3	Internet of Things (IoT)	5.54		
BS5	Cyber-Physical System (CPS)	5.01		
BS7	Robotics and Automation Systems	4.75		
BS10	3D Printing	3.60		

To appraise the relationship between the implementation of Construction 4.0 digital tools in previous and ongoing projects and the recommended use of these tools in future projects, Spearman’s Rank-Order Correlation Coefficient test was applied. Since digital tools possess unique characteristics and functions for specific uses, comparing them with other digital tools is irrelevant. Hence, each tool was only matched to its past or current use and future recommendations. The findings of this test are shown in Table 4.5.

Table 4.5: Correlation Coefficient between the Implementation and Recommendation Levels for Digital Tools

Code	Statements	Correlation	Asymp. Sig.
BA9	Augmented Reality (AR) / Virtual Reality (VR)	0.398	0.000
BA1	Building Information Modelling (BIM)	0.310	0.000
BA8	Radio Frequency Identification (RFID)	0.291	0.000
BA11	Blockchain	0.198	0.009
BA2	Cloud Computing	0.184	0.016
BA10	3D Printing	0.163	0.034
BA3	Internet of Things (IoT)	0.124	0.107
BA7	Robotics and Automation Systems	0.071	0.356
BA4	Big Data	0.062	0.421
BA5	Cyber-Physical System (CPS)	-0.049	0.525
BA6	Artificial Intelligence (AI)	-0.053	0.495

4.6 Preferences for Various Construction Activities: Traditional Methods versus Construction 4.0 Digital Tools

Table 4.6 illustrates respondents' preferences for traditional methods versus Construction 4.0 digital tools across different construction activities by presenting the frequency and percentage of each preference. Pearson Chi-Square test was performed to analyse the relationship between respondents' demographic profiles and their preferences for these methods across various activities. Table 4.7 outlines the null hypotheses that were rejected based on statistical significance ($p < 0.05$).

Table 4.6: Preference of Traditional Methods and Construction 4.0 Digital Tools among the Respondents

Code	Statements	Traditional Methods		Construction 4.0	
		Frequency (N)	Percentage (%)	Frequency (N)	Percentage (%)
BTC1	Design or Modelling/ Measurement (Printed or CAD drawings / Microsoft Excel vs BIM)	7	4.10	164	95.90
BTC2	Data Storage (Pendrive/ Email/ Hard disk vs Cloud Computing)	5	2.90	166	97.10
BTC3	Data Generation (Analog sensors and gauges / Field notes / Camera vs IoT)	70	40.90	101	59.10
BTC4	Data Collection (Microsoft Excel / Field Notes / Camera/ Voice Recorder vs Big Data)	44	25.70	127	74.30
BTC5	Monitoring construction activities (Microsoft Excel / Mobile devices / Manual Labour vs CPS)	72	42.10	99	57.90
BTC6	Data Analysis (Microsoft Excel / SPSS vs AI)	37	21.60	134	78.40
BTC7	Performing Construction Activities / Building, Demolition, Excavation, Material Handling (Heavy machine / hand tools vs Robotics and Automation)	62	36.30	109	63.70
BTC8	Resources Management / Managing Materials, Equipment and Inventory (Barcode scanner / mobile devices vs RFID)	19	11.10	152	88.90
BTC9	Simulation and Visualisation (Printed or CAD drawings vs AR & VR)	16	9.40	155	90.60
BTC10	Prefabrication (Heavy machine/ Manual labour vs 3D printing)	83	48.50	88	51.50
BTC11	Transaction and Contract Management (Paper-based documents vs Blockchain)	36	21.10	135	78.90

Table 4.7: Pearson's Chi-Square Test for the Preference of Traditional Methods and Construction 4.0 Digital Tools among the Respondents

Code	**Statements**	**Categories**	**Traditional Method**		**Construction 4.0**		**Asymp. Sig.**
			Frequency (N)	**Percentage (%)**	**Frequency (N)**	**Percentage (%)**	
	Business Activities						
BTC3	Data Generation (Analog sensors and gauges / Field notes / Camera vs IoT)	Property Development	9	18.80	39	81.30	0.004
		Consultancy	23	56.10	18	43.90	
		Contracting Business	18	51.40	17	48.60	
		Building Material Merchant	10	43.50	13	56.50	
		Equipment Supply/ Hiring/ Renting Business	10	41.70	14	58.30	
BTC7	Performing Construction Activities / Building, Demolition, Excavation, Material Handling (Heavy machine / hand tools vs Robotics and Automation)	Property Development	15	31.30	33	68.80	<.001
		Consultancy	8	19.50	33	80.50	
		Contracting Business	12	34.30	23	65.70	
		Building Material Merchant	9	39.10	14	60.90	
		Equipment Supply/ Hiring/ Renting Business	18	75.00	6	25.00	
BTC9	Simulation and Visualisation (Printed or CAD drawings vs AR & VR)	Property Development	1	2.10	47	97.90	0.013
		Consultancy	2	4.90	39	95.10	
		Contracting Business	3	8.60	32	91.40	
		Building Material Merchant	4	17.40	19	82.60	
		Equipment Supply/ Hiring/ Renting Business	6	25.00	18	75.00	

Table 4.7 (Continued)

Code	**Statements**	**Categories**	**Traditional Method**		**Construction 4.0**		**Asymp. Sig.**
			Frequency (N)	**Percentage (%)**	**Frequency (N)**	**Percentage (%)**	
	Professional						
BTC7	Performing Construction Activities / Building, Demolition, Excavation, Material Handling (Heavy machine / hand tools vs Robotics and Automation)	Architect	6	18.20	27	81.80	0.001
		Engineer	15	46.90	17	53.10	
		Quantity Surveyor	6	17.10	29	82.90	
		Builder	16	43.20	21	56.80	
		Supplier/ Subcontractor/ Specialist	19	55.90	15	44.10	
BTC9	Simulation and Visualisation (Printed or CAD drawings vs AR & VR)	Architect	0	0.00	33	100.00	0.006
		Engineer	2	6.30	30	93.80	
		Quantity Surveyor	1	2.90	34	97.10	
		Builder	5	13.50	32	86.50	
		Supplier/ Subcontractor/ Specialist	8	23.50	26	76.50	
BTC10	Prefabrication (Heavy machine/ Manual labour vs 3D printing)	Architect	14	42.40	19	57.60	0.012
		Engineer	20	62.50	12	37.50	
		Quantity Surveyor	9	25.70	26	74.30	
		Builder	19	51.40	18	48.60	
		Supplier/ Subcontractor/ Specialist	21	61.80	13	38.20	

Table 4.7 (Continued)

Code	**Statements**	**Categories**	**Traditional Method**		**Construction 4.0**		**Asymp. Sig.**
			Frequency (N)	**Percentage (%)**	**Frequency (N)**	**Percentage (%)**	
	Working Experience						
BTC3	Data Generation (Analog sensors and gauges / Field notes / Camera vs IoT)	0-2 years	5	20.00	20	80.00	0.022
		3-5 years	21	60.00	14	40.00	
		6-10 years	24	44.40	30	55.60	
		11-20 years	13	39.40	20	60.60	
		21 years and above	7	29.20	17	70.80	
BTC4	Data Collection (Microsoft Excel/ Field Notes/ Camera/ Voice Recorder vs Big Data)	0-2 years	5	20.00	20	80.00	0.008
		3-5 years	9	25.70	26	74.30	
		6-10 years	23	42.60	31	57.40	
		11-20 years	4	12.10	29	87.90	
		21 years and above	3	12.50	21	87.50	
	Company Size						
BTC9	Simulation and Visualisation (Printed or CAD drawings vs AR & VR)	Micro (< 5 people) & Small (5-30 people)	8	15.10	45	84.90	0.024
		Medium (31-75 people)	1	1.60	63	98.40	
		Large (> 75 people)	7	13.00	47	87.00	

4.7 Agreement on the Benefits Incurred from Adopting Construction 4.0 Digital Tools in Construction Project

Table 4.8 presents the mean ranking on the benefits incurred to the respondents' project through the adoption of Construction 4.0 digital tools. The top three ranked benefits are CF6 – *"Precise design, measurement and documentation of my project are facilitated by using digital tools"*, followed by CF7 – *"Accident and injuries are minimised by using digital tools in my project"* and CF8 – *"My workers feel safer working with digital tools on my project"*. Apart from that, the last two rankings are CF4 – *"My project becomes more cost-effective by using digital tools"* and CF3 – *"My project is executed within budget by using digital tools"*.

Table 4.8: Mean Ranking of the Benefits Incurred from Adopting Construction 4.0 Digital Tools

Code	**Statements**	**Mean Rank**	**Chi-square**	**Asymp. Sig.**
CF6	Precise design, measurement and documentation of my project are facilitated by using digital tools.	9.99	324.114	<.001
CF7	Accident and injuries are minimised by using digital tools in my project.	9.92		
CF8	My workers feel safer working with digital tools on my project.	9.80		
CF5	Quality standards of my project are maintained by using digital tools.	9.74		
CF1	Time is saved by using the digital tools in my project.	9.69		
CF9	Lesser resource waste is generated by using digital tools in my project.	9.58		
CF12	Time and cost predictability of my project are increased by using digital tools.	8.88		
CF11	Communication and collaboration within my project are enhanced by using digital tools.	8.71		
CF10	Conflict among stakeholders is reduced by using digital tools in my project.	8.48		
CF13	More innovative solutions are promoted by using digital tools in my project.	8.18		
CF14	The exploration of new aesthetic possibilities is enabled by using digital tools in my project.	7.68		
CF16	The layout and logistical planning of the site in my project are improved by using digital tools.	7.29		
CF15	My project is properly managed by using digital tools.	7.21		
CF2	My project is completed earlier than the completion date by using digital tools.	7.20		
CF4	My project becomes more cost-effective by using digital tools.	7.07		
CF3	My project is executed within budget by using digital tools.	6.58		

This research investigates the relationship between respondents' demographics and their agreement with the benefits of deploying Construction 4.0 digital tools using the Kruskal-Wallis test. The results in Table 4.9 reveal rejected null hypotheses, indicating a significant difference ($p < 0.05$) between respondents' demographic variables and the benefits derived from employing Construction 4.0 digital tools in their projects.

Table 4.9: Rejected Null Hypothesis for the Respondents' Agreement on the Benefits Incurred from Adopting Construction 4.0 Digital Tools

Code	**Null Hypothesis**	**Asymp. Sig.**
	Professional	
CF8	My workers feel safer working with digital tools on my project is same among respondents with the group of Architect, Engineer, Quantity Surveyor, Builder and Supplier/ Subcontractor/ Specialist.	0.021
CF13	More innovative solutions are promoted by using digital tools in my project is same among respondents with the group of Architect, Engineer, Quantity Surveyor, Builder and Supplier/ Subcontractor/ Specialist.	0.014
CF14	The exploration of new aesthetic possibilities is enabled by using digital tools in my project is same among respondents with the group of Architect, Engineer, Quantity Surveyor, Builder and Supplier/ Subcontractor/ Specialist.	0.035
	Working Experience	
CF4	My project becomes more cost-effective by using digital tools is same among respondents with the working experience of 0-2 years, 3-5 years, 6-10 years, 11-20 years and 21 years and above.	0.007
CF6	Precise design, measurement and documentation of my project are facilitated by using digital tools is same among respondents with the working experience of 0-2 years, 3-5 years, 6-10 years, 11-20 years and 21 years and above.	0.045
CF7	Accident and injuries are minimised by using digital tools in my project is same among respondents with the working experience of 0-2 years, 3-5 years, 6-10 years, 11-20 years and 21 years and above.	0.040

Table 4.9 (Continued)

Code	**Null Hypothesis**	**Asymp. Sig.**
	Position	
CF7	Accident and injuries are minimised by using digital tools in my project is same among respondents with the position of Junior Executive, Senior Executive, Assistant Manager/ Manager/ Team Leader and Director/ Managing Directors/ CEO.	0.016
CF8	My workers feel safer working with digital tools on my project is same among respondents with the position of Junior Executive, Senior Executive, Assistant Manager/ Manager/ Team Leader and Director/ Managing Directors/ CEO.	0.032
	Company Size	
CF15	My project is properly managed by using digital tools is same among respondents with company size of Micro (<5 people) & Small (5-30 people), Medium (31-75 people) and Large (>75 people).	0.008
CF16	The layout and logistical planning of the site in my project are improved by using digital tools is same among respondents with company size of Micro (<5 people) & Small (5-30 people), Medium (31-75 people) and Large (>75 people).	0.005

(A) The group of 21 years and above working experience agreed

- (i) more towards CF4 – *"My project becomes more cost-effective by using digital tools"* (mean rank = 101.21) than group of 3-5 years (mean rank = 97.74), 0-2 years (mean rank = 97.08), 6-10 years (mean rank = 74.44) and 11-20 years (mean rank = 73.00).

(B) The group of Micro-sized (<5 people) & Small-sized (5-30 people) company agreed

- (i) more towards CF15 – *"My project is properly managed by using digital tools"* (mean rank = 100.42) than group of Medium-sized (31-75 people) (mean rank =83.36) and Large-sized (>75 people) (mean rank = 74.98).
- (ii) more towards CF16 – *"The layout and logistical planning of the site in my project are improved by using digital tools"* (mean rank = 100.98) than group of Medium-sized (31-75 people) (mean rank = 82.84) and Large-sized (>75 people) (mean rank = 75.04).

4.8 Perception on Barriers that Undermine the Implementation of Construction 4.0 Digital Tools

The mean ranking on barriers that undermine the implementation of Construction 4.0 digital tools is displayed in Table 4.10. DB1 – *"High Implementation Cost"*, DB2 – *"Lack of Expertise and Skilled Workers"* and DB9 – *"Lack of Government Support"* are the top three barriers that hinder the utilisation of Construction 4.0 digital tools in the respondents' project. On the other hand, DB12 – *"Low Interest and Market Demand"* and DB7 – "*Lack of Research on Construction 4.0 Digital Tools"* ranked as the last two among the 14 barriers.

Table 4.10: Mean Ranking of the Barriers that Undermine the Implementation of Construction 4.0 Digital Tools

Code	**Statements**	**Mean Rank**	**Chi-square**	**Asymp. Sig.**
DB1	High Implementation Cost	9.41	268.446	<.001
DB2	Lack of Expertise and Skilled Workers	8.87		
DB9	Lack of Government Support	8.75		
DB3	Resistance to Change	8.10		
DB8	Pertaining to Legal and Contractual Matters	8.03		
DB13	Higher Requirements for Computing Devices	7.55		
DB4	Concerning on Data Security and Protection Issue	7.41		
DB5	Lack of Regulations and Standardisation	7.34		
DB14	Lack of Knowledge Management	7.20		
DB11	Poor Connectivity Network	6.93		
DB6	Lack of Awareness of the Benefits of Construction 4.0 Digital Tools	6.85		
DB10	Fragmentated Nature of Construction Industry	6.74		
DB12	Low Interest and Market Demand	6.61		
DB7	Lack of Research on Construction 4.0 Digital Tools	5.19		

The Kruskal-Wallis test was adopted to look into the relationship between the demographic profile and the implementation barriers. The findings in Table 4.11 show that the null hypotheses were rejected and that there is a significant difference ($p < 0.05$) between the demographic characteristics of the respondents and the barriers deterring them from deploying Construction 4.0 digital tools in their projects.

Table 4.11: Rejected Null Hypothesis for the Respondents' Perception on the Barriers that Undermine the Implementation of Construction 4.0 Digital Tools

Code	**Null Hypothesis**	**Asymp. Sig.**
	Business Activities	
DB7	Lack of Research is same among respondents with the group of Property Development, Consultancy, Contracting Business, Building Material Merchant and Equipment Supply/ Hiring/ Renting Business.	0.026
DB11	Poor Connectivity Network is same among respondents with the group of Property Development, Consultancy, Contracting Business, Building Material Merchant and Equipment Supply/ Hiring/ Renting Business.	0.011
	Professional	
DB12	Low Interest and Market Demand is same among respondents with the group of Architect, Engineer, Quantity Surveyor, Builder and Supplier/ Subcontractor/ Specialist.	0.016
DB13	Higher Requirements for Computing Devices is same among respondents with the group of Architect, Engineer, Quantity Surveyor, Builder and Supplier/ Subcontractor/ Specialist.	0.004
	Working Experience	
DB1	High Implementation Cost is same among respondents with the working experience of 0-2 years, 3-5 years, 6-10 years, 11-20 years and 21 years and above.	0.024
	Position	
DB2	Lack of Expertise and Skilled Workers is same among respondents with the position of Junior Executive, Senior Executive, Assistant Manager/ Manager/ Team Leader and Director/ Managing Directors/ CEO.	0.036
DB5	Lack of Regulations and Standardisation is same among respondents with the position of Junior Executive, Senior Executive, Assistant Manager/ Manager/ Team Leader and Director/ Managing Directors/ CEO.	0.020
	Company Size	
DB7	Lack of Research on Construction 4.0 Digital Tools is same among respondents with company size of Micro (<5 people) & Small (5-30 people), Medium (31-75 people) and Large (>75 people).	<.001

(A) The group of Building Material Merchant perceived

- (i) more towards DB11 – *“Poor Connectivity Network”* (mean rank = 108.91) as the barrier to the implementation of Construction 4.0 digital tools than group of Equipment Supply/ Hiring/ Renting Business (mean rank = 99.50), Consultancy (mean rank = 81.73), Contracting Business (mean rank = 80.49) and Property Development (mean rank = 75.94).

(B) The group of Builder perceived

- (i) more towards DB13 – *“Higher Requirements for Computing Devices”* (mean rank = 96.66) as the barrier to the implementation of Construction 4.0 digital tools than group of Supplier/ Subcontractor/ Specialist (mean rank = 91.16), Architect (mean rank = 90.50), Engineer (mean rank = 88.95) and Quantity Surveyor (mean rank = 62.77).

(C) The group of Micro-sized (<5 people) & Small-sized (5-30 people) company perceived

- (i) more towards DB7 – *“Lack of Research on Construction 4.0 Digital Tools”* (mean rank = 107.23) as the barrier to the implementation of Construction 4.0 digital tools than group of Large-sized (>75 people) (mean rank = 77.14) and Medium-sized (31-75 people) (mean rank = 75.90).

4.9 Perception towards Strategies for Fostering the Utilisation of Construction 4.0 Digital Tools

The respondents’ perceptions on the mean ranking of six strategies to promote the utilisation of Construction 4.0 digital tools are shown in Table 4.12 below. The findings indicate that financial support from government ranks highest among the strategies, while early technology involvement holds the lowest ranking.

Table 4.12: Mean Ranking of the Strategies for Fostering the Utilisation of Construction 4.0 Digital Tools

Code	**Statements**	**Mean Rank**	**Chi-square**	**Asymp. Sig.**
ES1	Financial Support from Government	4.15	121.750	<.001
ES2	Training and Education	3.92		
ES5	Regulations and Policies by Government	3.45		
ES3	Increase Awareness of Construction 4.0	3.32		
ES6	Guidelines by Professional Bodies	3.29		
ES4	Early Technology Involvement	2.88		

In order to assess the effectiveness of strategies on the various barriers listed in Section 4.8, Spearman's Rank-Order Correlation Coefficient test was conducted. The result of this test is presented in Table 4.13. Additionally, the total number of significant correlations is determined by $P < 0.05$, which means that there is a statistically significant relationship between the strategies and barriers.

Table 4.13: Correlation Coefficient of the Strategies in Combating Barriers Encountered

		ES1 Financial Support from Government	ES2 Training and Education	ES3 Regulations and Policies by Government	ES4 Increase Awareness of Construction 4.0	ES5 Guidelines by Professional Bodies	ES6 Early Technology Involvement
DB1	High Implementation Cost	.327**	.160*	0.140	0.113	.242**	0.075
DB2	Lack of Expertise and Skilled Workers	.311**	.472**	.327**	.245**	.429**	.253**
DB3	Resistance to Change	.221**	.368**	.352**	.306**	.439**	.239**
DB4	Concerning on Data Security and Protection Issue	.200**	.283**	.281**	.249**	.277**	.212**
DB5	Lack of Regulations and Standardisation	.178*	.318**	.218**	.229**	.206**	.260**
DB6	Lack of Awareness of the Benefits of Construction 4.0 Digital Tools	0.101	.169*	.224**	.198**	.253**	0.148
DB7	Lack of Research on Construction 4.0 Digital Tools	-0.023	.156*	.193*	.224**	.232**	.180*
DB8	Pertaining to Legal and Contractual Matters	0.096	.181*	0.104	0.116	.233**	.226**
DB9	Lack of Government Support	.277**	.307**	.322**	.172*	.306**	.281**
DB10	Fragmentated Nature of Construction Industry	.161*	.248**	.307**	.204**	.246**	.169*
DB11	Poor Connectivity Network	0.119	.217**	.185*	.267**	.261**	0.119
DB12	Low Interest and Market Demand	.176*	0.133	.219**	0.114	.270**	0.029
DB13	Higher Requirements for Computing Devices	.208**	.291**	0.141	.172*	.290**	.226**
DB14	Lack of Knowledge Management	.153*	.242**	.184*	.205**	.250**	.178*
	Total number of significant correlations	10	13	11	11	14	10

4.10 Discussion

This section elaborates on the previously mentioned results in a thorough manner. It is divided into several sections, discussing the benefits incurred with its relevant digital tools, and the barriers encountered from adopting digital tools in construction projects and the readiness of Malaysian construction industry players towards Construction 4.0.

4.10.1 Builders, Micro & Small Sized Companies and 6-10 Years Work Experience Groups Perceive Differently in Benefits Incurred

Table 4.9 illustrates significant differences in 10 benefits across respondents' demographic profiles. However, these benefits are universally applicable and beneficial across different specialties within the construction industry, rather than being limited to particular professions. In view of this condition, three category groups, including builders, micro and small-sized companies and those with 6-10 years of work experience, which perceive slight differences compared to others, are addressed as follows.

Firstly, builders ranked CF8 – *"My workers feel safer working with digital tools on my project"* and CF14 – *"The exploration of new aesthetic possibilities is enabled by using digital tools in my project"* as the most significant variables. It is unsurprising that the results show builders are more inclined to place workers safety as one of the main benefits of adopting digital tools compared to consultants. This inclination can be attributed to their direct involvement with site workers, risk management considerations and operational impact (Iyer, et al., 2020). Builders often have direct supervision and responsibility for workers' safety on construction sites, facing higher levels of risk and liability related to workplace accidents and injuries (Osei-Asibey, et al., 2021). Safety incidents interrupt project timelines, leading to costly delays and financial losses for builders, who may incur liquidated damages for failing to meet deadlines. By adopting digital tools, it offers a safer working environment for workers, assists in reducing the chance of accidents and protects the organisation from any legal and financial consequences. However, in many countries where construction project bidding depends on the "lowest bid" approach, builders that choose to use digital tools to improve health and safety procedures may lose bids to competitors who are less likely to prioritise such measures (Khudzari, et al., 2021; Oke, et al., 2023a). Therefore, builders in a competitive construction industry may look for strategies to differentiate themselves and win project bids. Adopting digital tools that allow for the exploration of new and visually attractive design possibilities can provide builders with a competitive advantage by allowing them to deliver different solutions that stand out to clients and project stakeholders. Digital technologies may help them efficiently translate design concepts into real building and accurately integrate aesthetic features.

Meanwhile, the majority of the respondents who work in micro (< 5people) and small (5-30 people) sized construction companies are more in agreement with the benefits of digital tools in managing projects compared to medium and large-sized companies. This includes CF15 – *"My project is properly managed by using digital tools"* and CF16 – *"The layout and logistical planning of the site in my project are improved by using digital tools."* This could be rooted in the fact that micro and small sized companies possess limited resources and tend to adopt low-cost digital tools such as cloud computing and CAD software. Due to cloud computing being less expensive than traditional technology, these applications have the potential to significantly increase adoption of information management technology among small and medium-sized construction businesses (Ashraf, et al., 2016; Chowdhury, et al., 2019; Aghimien et al., 2022a). These programs provide fundamental services to the public, such as free cloud storage and file sharing. As highlighted by Yan and Kah (2018), the majority of small-sized construction companies in Malaysia still use traditional paper-based and 2D digital formats such as PDFs and CAD files. Many low-cost or free CAD tools in the current market offer powerful functionality for developing and visualising layouts. As a result, micro and small-sized businesses frequently use CAD software to generate precise drawings and schematics of their sites.

On the other hand, it was noted that respondents with 6 to 10 years of work experience exhibited a greater inclination towards CF6 – *"Precise design, measurement and documentation of my project are facilitated by using digital tools"* and CF7 – *"Accident and injuries are minimised by using digital tools in my project"* as the benefits incurred from the implementation of digital tools. It might be that they are more likely to have been exposed to the latest developments in digital tools during their formative years in their careers. The outbreak of COVID-19 in 2020 substantially altered the working landscape across sectors. Goh, et al. (2023)'s study found out that the COVID-19 pandemic has sparked digital transformation in Malaysia's construction industry, with increased adoption of digital technologies surpassing pre-pandemic levels. They are increasingly relying on digital tools for project management, recognising their potential to enhance precision, efficiency, and safety. The pandemic underscored the importance of safety and risk mitigation, prompting these professionals to explore how technologies like IoT, RFID, and drones can facilitate remote monitoring, virtual inspections, and real-time data analysis to minimise accidents and injuries (Li, et al., 2022). They also observed how digital tools enable accurate design and measurement, reducing the need for physical presence on-site and addressing health concerns. Overall, adaptive professionals with this level of expertise are more likely to see the benefits of digital technologies in solving pandemic-related obstacles.

On top of that, certain group categories are also taken into account to enhance the comprehensiveness of the study. The findings revealed that respondents from architectural firms highly favour the benefits of CF13 – *"More innovative solutions are promoted by using digital tools in my project"*. Architects have a great responsibility in transforming client requirements into drawings and they rely heavily on creativity to develop innovative and attractive designs. They are at the forefront of BIM adoption because of their role in making critical design decisions (Aizat, et al., 2019). BIM helps architects to visualise, model, and evaluate designs more effectively by streamlining the design process. With the integration of AI and BIM, their capability to efficiently produce accurate 3D building models enables architects to prioritise design innovation and effortlessly generate alternative design layouts, thereby easing their workload.

Besides, safety benefits such as CF7 – "*Accident and injuries are minimised by using digital tools in my project*" and CF8 – "*My workers feel safer working with digital tools on my project*" are more preferred by respondents at managerial levels, including Assistant Manager/ Team Leader/ Directors/ CEO. According to Shafei, et al. (2024), organisations bear significant responsibility in selecting effective digital options to prevent hazardous construction sites and reduce accidents. Fatal accidents at construction sites can greatly interrupt operations, causing work stoppages for inspection and deteriorating the company's reputation. Directors or team leaders often have greater degrees of accountability within an organisation and are primarily responsible for the company's overall performance as well as safety outcomes. They must know the consequences of their decisions to ensure the organisation may fully utilise digital tools and cultivate new safety practices (Muktamar, et al., 2023).

Simultaneously, the findings also target the three major benefits with highest mean ranking as depicted in Table 4.8. CF6 – "*Precise design, measurement and documentation of my project are facilitated by using digital tools*" being ranked the highest is thus spotted as one of the outstanding benefits incurred from implementing Construction 4.0 digital tools. This indicates that respondents perceive significant value in the accuracy and efficiency gained from utilising these tools for project planning and documentation. The ability to achieve precise design and measurement improves overall project quality while reducing mistakes, resulting in better outcomes and higher satisfaction among stakeholders (Siriwardhana and Moehler, 2023). For instance, BIM enhances the reliability of cost and time estimates by generating a precise virtual building model, utilised throughout the design, planning, and construction phases (Alwashah, et al., 2024). This model allows consultants to visualise the structure in a simulated environment, identifying potential issues related to design. Furthermore, better planning for project scheduling and cost estimation during the early design phase is made feasible by the integration of time (4D) and cost (5D) components into BIM (Abioye, et al., 2021). Since huge data will be generated, cloud computing facilitates the storage and access of data generated throughout project life cycles by offering on-demand computer resources over the Internet. It plays a critical role in CPS, enabling centralised, shared, and scalable computing resources, enabling multiple users to access data and computation without separate licences (Aghimien, et al., 2022a). Besides, AI, BIM, cloud computing and immersive technologies such as AR and VR are transforming engineering design and planning (Okoro, et al., 2022). These tools improve project performance by making data collection, analysis, and storage easier before the commencement of construction work.

On the other hand, CF7 – *"Accident and injuries are minimised by using digital tools in my project"* and CF8 – *"My workers feel safer working with digital tools on my project"* are ranked the second and third place. Since both of these benefits are related to safety, it shows that construction participants nowadays are more concerned about safety issues in the industry. Different digital tools such as IoT (Bhattacharya and Momaya, 2021), and robotics and automation (Oke, et al., 2023a) adopted in construction may help to create a safer environment for workers to work. These novel technologies offer enhanced safety features by predicting and identifying hazards, along with continuous monitoring of health and safety performance on construction sites. According to Smallwood and Allen (2022), AR and VR are applauded for improving duties related to work inspection, data visualisation, and error detection on the job site. Moreover, AI is revolutionising safety and health in the construction sector by offering improved risk monitoring to worksite workers using visual algorithms. By automatically identifying and prioritising safety dangers on site using project and photo data, it offers an unbiased risk assessment (Shafei, et al., 2024). Not only that, the integration of RFID-based real-time tracking systems and sensor-based safety technologies during early design and planning phases enables automatic identification and mitigation of safety issues, thereby preventing accidents (Yap, et al., 2021).

4.10.2 Builders, Material Merchants and Equipment Suppliers Encounter More Barriers in Embracing to Construction 4.0

Based on Table 4.11, eight barriers exhibit significant differences among respondents' demographic characteristics. Consequently, it was discovered that builders, material merchants, and equipment suppliers are facing more challenging barriers in embracing Construction 4.0.

The respondents working for builder firms are more in consensus on DB12 – "*Low Interest and Market Demand*" and DB13 – "*Higher Requirement for Computing Device*" as barriers to the adoption of Construction 4.0 digital tools compared to those employed in consultant, supplier, subcontractor, or specialist companies. Builders actively involved in the building process will assign priority to urgent issues such as project profitability and client demand. They may believe that there is inadequate demand from clients for digital tools, or that current market conditions are not suitable for investing in such technology. Furthermore, they may encounter difficulties incorporating new technology into their established workflows (Tam, et al., 2024). Apart from that, builders are more likely to agree on the higher requirement for computing devices as barriers because they are regularly participating in project execution and are aware of Malaysia's hot and humid weather conditions. This finding aligns with the study by Alwashah, et al. (2024), who reported that builders' concerns about the increased requirement for computing equipment act as main barriers to transitioning towards Construction 4.0. In Malaysia's tropical climate, where temperatures are consistently hot and humid, there is a greater demand for computing equipment that can resist such conditions (Castelo, 2022). Hence, builders are cautious to engage in costly digital tools without clear client demand, as any damage might result in more time and money spent on repairs.

Building material merchants and equipment/ supply/ hiring/ renting business activities more inclined to consider DB7 – "*Lack of Research on Construction 4.0 Digital Tools*" and DB11 – "*Poor Connectivity Network*" as primary barriers for adopting digital tools due to several factors related to their business nature and their relatively limited exposure to digital tools. Their focus tends to be on physical goods and logistics rather than digital innovations. Their business operations, which often have established procedures, may encounter specific issues in inventory management, supply chain logistics, and customer interactions. Not only that, but they may also require specific digital solutions adapted to their specific requirements, which may not be widely available or thoroughly explored on the market (Tam, et al., 2024). The lack of research into digital tools that solve industry-specific difficulties can further reinforce their perception of this barrier. Besides, unlike consultancy and property development firms, material merchants and equipment suppliers have a vested interest in implementing digital technologies that integrate with their management systems. However, establishing a successful ICT environment to support employee efficiency is often overlooked, especially in remote construction sites lacking critical services such as power and communication. This can lead to operational inefficiencies, downtime, and maintenance issues, prompting these companies to prioritise reliable connectivity for smooth digital product integration and operation (Abioye, et al., 2021).

Meanwhile, it was also found that Director/ Managing Director/ CEO exhibit a stronger consensus regarding DB2 – *"Lack of Expertise and Skilled Workers"* and DB6 – *"Lack of Regulations and Standardisation"* as barriers of implementing Construction 4.0 digital tools compared to individuals holding positions as Junior, Senior Executives and Assistant Manager/ Manager/ Team Leader. These barriers could be attributed to their managerial position in deciding resource allocation, budget planning and company growth direction. According to Kraft, et al. (2022), directors must understand current technologies before making strategic decisions on selecting and implementing digital solutions. This enables them to accurately identify the specific skills required to effectively leverage digital tools within their companies. Other than that, directors who have a broader perspective in understanding how regulatory frameworks and standards influence industry practices should ensure that digital tools align with the organisation's needs and objectives (Cortellazzo, et al., 2019). They may know the importance of defined rules and legislation governing the adoption and use of digital tools in construction to ensure consistency, interoperability, and adherence to industry standards. The absence of regulations and standards raises major concerns, possibly leading to legal, operational, or reputational challenges because of noncompliance or inconsistent procedures. In short, directors act as resource allocator, managing resources assessing risks to mitigate the impacts of skill shortages and standardisation gaps, thus positioning the firm for long-term success in the Construction 4.0 era (Omari, et al., 2023; Chen, et al., 2024).

Following that, three primary barriers with the highest mean ranking are also covered to enhance the completeness of the study, as indicated in Table 4.10. It is unsurprising to observe that DB1 – *"High Implementation Cost"* is recognised as the most significant barrier faced when adopting Construction 4.0 digital tools. This is similar to the study by Almatari, et al. (2023) who noted that investment issues and high implementation cost obtained the highest ranked factor contributing to the slow adoption of digital tools in the Malaysian construction industry. In fact, this issues not only limited to Malaysia, but several studies have also underscored the influence of cost on the implementation of Construction 4.0 digital tools in Vietnam (Momade, et al., 2022), Nigeria (Oke, et al., 2023a) and even China (Zhao, et al., 2023). Any new technology adoption is always accompanied by concerns about costs. Cost issues are often classified into training expenses and the acquisition cost of specific software and equipment. The organisation needs to hire programmers and software developers, train their workers, and possibly form partnerships with companies that have the know-how to fully leverage these technologies in order to fully integrate digital tools (Adam, et al., 2020). Some of these digital tools require regular upgrades to maintain software efficiency, forcing organisations to consistently invest in security enhancements. Moreover, the significant costs of purchasing hardware and software for these advanced technologies creates challenges for stakeholders seeking to incorporate them into different phases of the building process. As elucidated by Lee, et al. (2022), the high investment costs of implementing Construction 4.0 can exceed the expected growth of an organisation, resulting in a financial deficit. The long-term payoff of digital technologies and the associated risk contribute to the construction industry's hesitancy in adopting them (Akunyumu, et al., 2021).

Besides, DB2 – *“Lack of Expertise and Skilled Workers”* ranks second in the overall ranking. Shortage of qualified workers to operate the technology creates a skills gap that hinders effective transformation due to the lack of workers with the competencies needed for the future. These discrepancies show a major mismatch between the skills needed by industry and the capabilities that are available, which affects productivity (Balogun, 2024). According to Abiyoke, et al. (2021), there is presently a lack of AI engineers competent enough to achieve major improvement in a variety of industries, including construction. Recruiting those with industry-specific experience for customised solutions is even more challenging. A case study done by Ahmed, et al. (2022) in Malaysia demonstrated that BIM adoption in the AEC sector is significantly hindered by complexity since simpler technologies are more likely to be adopted because they need less time to understand. The ability of the new and current workers to acquire the necessary skills may be impacted by insufficient training requirements. However, as indicated by the findings of Khudzari, et al. (2021), employees with a negative attitude may limit the adoption of digital tools, as some may undergo training but fail to implement the gained skills throughout the projects.

Moreover, DB9 – *"Lack of Government Support"* is rated third. Government plays a critical role in fostering the shift to Construction 4.0 by providing supervision, financial support, and regulations, as highlighted in various studies (Oke, et al., 2022; Okoro, et al., 2022). As a key client and regulator of the construction industry, governments heavily influence design, technology, and the adoption of best practices in terms of time, cost, quality and environmental performance. The government should conduct further research to ascertain the most suitable and realistic stage for technological implementation. Furthermore, Khudzari, et al. (2021) emphasised that aligning new digital tools with Malaysian standards and environmental considerations to ensure company compliance. These initiatives are the government's indirect role of supporting to ensure that Construction 4.0 is successfully incorporated into the construction industry. On the other hand, government financial aid or incentives are often seen as effective tools and as direct roles to promote the adoption of new technology (Jiang, et al., 2022). Ahmed, et al. (2022) discovered that the Malaysian government failed to offer any subsidies, tax reductions, or other incentives to encourage the use of digital technologies in projects. This shows that the Malaysian government's sluggish responsiveness to the technology demands of the construction sector leads to this barrier being ranked third in this research.

4.10.3 The Readiness of Construction 4.0 Digital Tools by Construction Industry Players

a) Malaysian Construction Industry is Not Ready for Construction 4.0

The implementation of Construction 4.0 relies on several factors and is impossible to rely solely on a single aspect for its success. The digital tools should be leveraged and spanned across various project phases, including planning, design, construction, and even operation and maintenance. It is noticed that the respondents have an awareness and willingness to adopt Construction 4.0 digital tools but are lagging in terms of executing them in the project. The Malaysian construction players are either partially or not fully harnessing the potential of digital tools in construction practices, as evident in Section 4.6 and 4.10.1.

It is affirmed as well in Table 4.5 where there is a weak correlation between the respondents' recommendation and adoption level of digital tools. This result underlines that the experience with digital tools in past projects does not guarantee their implementation in future projects. As asserted by Jones, et al. (2021), past achievements, such as swiftly integrating new technologies into existing workflows and procedures, are insufficient to ensure future success. Some Construction 4.0 tools' utilisation appears to be one-off rather than continuous (Akunyumu, et al., 2021). In other words, a lack of consistency and one-off-oriented or occasional mindset does not guarantee the ongoing commitment to integrating technology into industry practices.

Interestingly, there was no statistically significant difference between past adoption of IoT, Robotics and Automation Systems, Big Data, CPS and AI, and their recommended usage for future projects, as depicted in Table 4.5. This further explains the leveraging of technologies by companies mainly relies on other determining criteria such as the resources available and operating perspective. This underscores decision-making's diverse and context-specific nature, rather than exclusively relying on past experiences. Nevertheless, it cannot be denied that experiencing these technologies might be useful, but there are also additional considerations when adopting them in new projects. The inevitable aspects of the firm are the availability of resources, such as financial, technological, and human capital, which can have a substantial influence on the feasibility of using digital tools.

It is noticed that micro and small-sized companies are increasingly recognising the benefits of low-cost digital tools for improving project management. However, their ability to fully embrace these tools is impeded by limitations in research capacity and resources, encompassing funding and operational capabilities, as indicated in Table 4.15. Despite receiving some government funding, medium-sized firms struggle to adopt digital tools extensively, whereas large-sized companies lead the way due to greater resources and infrastructure. Considering that SMEs constitute over 60% of businesses in the Malaysian construction sector (Singaram, et al., 2023), their efforts to integrate digital tools into operations are constrained. Consequently, the overall adoption of these technologies remains limited, posing challenges to a seamless transition to Construction 4.0.

The situation is aggravated in the supply chain network especially the parties like building material merchants, and equipment supply/ hiring/ renting businesses. As reported in Table 4.16, none of these groups demonstrated any preference or inclination towards adopting digitalised methods. Reluctance or hesitance is expressed among these professionals to embrace digital tools and technologies as part of their practices or workflows. A similar situation is also evident in Table 4.15 where they face more challenging barriers to embracing Construction 4.0 digital tools. Building material merchants, equipment suppliers, and subcontractors are undermined by this transition due to the nature of their business operations. These stakeholders still resort to the traditional methods, with their focus mainly on tangible goods and logistic transportation, leading them to have limited exposure to digital technologies. As a result, they are more susceptible to perceiving barriers related to research and connectivity.

While Table 4.14 indicates builders acknowledge the benefits of digital tools, Zhao, et al. (2023) attribute this recognition to government and construction industry association pressure, resulting in heightened demands for adoption from contractors. However, builders’ practical implementation of these tools remains notably low. Builders with hands-on experience in construction sites emphasise immediate issues such as project profitability and client demand (Akunyumu, et al., 2021). Due to the harsh equatorial climate in Malaysia, it requires computing devices that can withstand high temperatures and humidity levels for effective use in on-site projects. However, the uncertainty of demand and the additional cost incurred for specialised requirements of these devices substantially jeopardise builders’ profitability. Ultimately, this may deter builders from investing in digital tools, and refuse to adopt Construction 4.0.

In conclusion, the construction industry is yet to ready towards Construction 4.0 due to several factors discussed above from various perspectives. The construction industry comprises diverse professionals and relying merely on the use of digital tools by certain professional groups or company sizes does not signify industry-wide readiness.

Table 4.14: Summary of Relationships Between the Benefits Incurred of Adopting Construction 4.0 Tools and the Attributes of Respondents

Code	Benefits	Demographic Information		Mean Rank
CF1	Time is saved by using the digital tools in my project.	-		
CF2	My project is completed earlier than the completion date by using digital tools.	-		
CF3	My project is executed within budget by using digital tools.	-		
CF4	My project becomes more cost-effective by using digital tools.	Working Experience	21 years and above	101.21
CF5	Quality standards of my project are maintained by using digital tools.	-		
CF6	Precise design, measurement and documentation of my project are facilitated by using digital tools.	Working Experience	6-10 years	92.50
CF7	Accident and injuries are minimised by using digital tools in my project.	Working Experience	6-10 years	90.35
		Position	AM/ Manager/ Team Leader	91.48
CF8	My workers feel safer working with digital tools on my project.	Professional	Builder	90.46
		Position	Directors/ Managing Directors/ CEO	90.06
CF9	Lesser resource waste is generated by using digital tools in my project.	-		
CF10	Conflict among stakeholders is reduced by using digital tools in my project.	-		
CF11	Communication and collaboration within my project are enhanced by using digital tools.	-		
CF12	Time and cost predictability of my project are increased by using digital tools.	-		
CF13	More innovative solutions are promoted by using digital tools in my project.	Professional	Architect	101.44
CF14	The exploration of new aesthetic possibilities is enabled by using digital tools in my project.	Professional	Builder	102.20
CF15	My project is properly managed by using digital tools.	Company Size	Micro (<5 people) & Small (5-30 people)	100.41
CF16	The layout and logistical planning of the site in my project are improved by using digital tools.	Company Size	Micro (<5 people) & Small (5-30 people)	100.98

Table 4.15: Summary of Relationships Between the Barriers of the Construction 4.0 Tools Implementation and the Attributes of Respondents

Code	Barriers	Demographic Information		Mean Rank
DB1	High Implementation Cost	-		
DB2	Lack of Expertise and Skilled Workers	Working Experience	11-20 years	89.50
		Position	Director/ Managing Director/ CEO	96.49
DB3	Resistance to Change	-		
DB4	Concerning on Data Security and Protection Issue	-		
DB5	Lack of Regulations and Standardisation	Position	Director/ Managing Director/ CEO	95.71
DB6	Lack of Awareness of the Benefits of Construction 4.0 Digital Tools	-		
DB7	Lack of Research on Construction 4.0 Digital Tools	Business Activities	Equipment Supply/ Hiring/ Renting Business	103.98
			Building Material Merchant	99.07
		Company Size	Micro & Small	107.23
DB8	Pertaining to Legal and Contractual Matters	-		
DB9	Lack of Government Support	-		
DB10	Fragmentated Nature of Construction Industry	-		
DB11	Poor Connectivity Network	Business Activities	Building Material Merchant	108.91
			Equipment Supply/ Hiring/ Renting Business	99.50
DB12	Low Interest and Market Demand	Professional	Builder	101.77
DB13	Higher Requirements for Computing Devices	Professional	Builder	96.66
DB14	Lack of Knowledge Management	-		

b) Property Development and Consultant Firms Use More Digital Methods over than Others

However, developers and consultants such as architects and quantity surveyors showed a stronger preference for digitalised methods over traditional methods, as reported in Table 4.16. To remain competitive and attract clients in the digital age, developers exhibit a preference for digitalised approaches, including the utilisation of digital tools of AR, VR and IoT. These technologies provide immersive experiences, improve project visualisation, enable remote collaboration, and boost marketing efforts, resulting in higher sales and client satisfaction (Hairuddin, et al., 2022). They also allow developers to digitally showcase properties, collect real-time data for better decision-making, and optimise construction processes for efficiency and cost-effectiveness. Therefore, by incorporating digital tools into their business plans, developers may differentiate themselves in the market, create innovation, and satisfy the changing wants of modern customers.

Apart from that, the construction consultants are key stakeholders in the built environment industry, contributing considerably to the inception and planning stages of building projects. These professionals favour digital methods since they are the experts in design, cost estimation, and quality assurance. Digital tools improve construction procedures, increase efficiency, and reduce errors in construction projects. They help in the early detection of clashes between building elements, allowing consultants to explore different alternatives to design and visualise complicated architectural concepts more effectively. Identifying clashes early on helps consultants avoid costly errors and rework during construction, resulting in significant time and resource savings. As a result, the designs generated are more feasible, with minimal discrepancies in quantity take-off.

Despite developers and consultants showing preferences for digitalised methods, the overall readiness of the entire construction industry for Construction 4.0 remains constrained when assessed comprehensively. They primarily employ digital tools during the planning and design stages of construction projects for varying purposes, demonstrating only a surface-level engagement with these technologies in the early stages. Hence, the incorporation of digital tools in construction projects seems to be partial.

Table 4.16: Summary of Pearson’s Chi-Square Test Results of the Respondents’ Preference Towards Digitalised Methods

Code	**Preference between Traditional and Digitalised**	**Demographic Information**		**Digitalised Method**	
				Frequency N	**Percentage %**
BTC1	Design or Modelling/ Measurement (Printed or CAD drawings / Microsoft Excel vs BIM)	-			
BTC2	Data Storage (Pendrive/ Email/ Hard disk vs Cloud Computing)	-			
BTC3	Data Generation (Analog sensors and gauges / Field notes / Camera vs IoT)	Business Nature	Property Development	39	81.30
		Working Experience	0-2 years	20	80.00
BTC4	Data Collection (Microsoft Excel / Field Notes / Camera/ Voice Recorder vs Big Data)	Working Experience	11-20 years	29	87.90
			21 years and above	21	87.50
BTC5	Monitoring construction activities (Microsoft Excel / Mobile devices / Manual Labour vs CPS)	-			
BTC6	Data Analysis (Microsoft Excel / SPSS vs AI)	-			
BTC7	Performing Construction Activities / Building, Demolition, Excavation, Material Handling (Heavy machine / hand tools vs Robotics and Automation)	Business Nature	Consultancy	33	80.50
		Professional	Quantity Surveyor	29	82.90
BTC8	Resources Management / Managing Materials, Equipment and Inventory (Barcode scanner / mobile devices vs RFID)	-			

Table 4.16 (Continued)

Code	**Preference between Traditional and Digitalised**	**Demographic Information**		**Digitalised Method**	
				Frequency N	**Percentage %**
BTC9	Simulation and Visualisation (Printed or CAD drawings vs AR & VR)	Business Nature	Property Development	47	97.90
		Professional	Architect	33	100.00
		Company Size	Medium (31-75 people)	63	98.40
BTC10	Prefabrication (Heavy machine/ Manual labour vs 3D printing)	Professional	Quantity Surveyor	26	74.30
BTC11	Transaction and Contract Management (Paper-based documents vs Blockchain)	-			

4.10.4 Strategy Diversity is Important to Holistic Barrier Resolution

To assess the effectiveness of strategies in addressing the various identified barriers, the Spearman correlation coefficient test was adopted. Overall, the results uncovered that there is a moderate to weak relations between the barriers and the strategies, as displayed in Table 4.13. This means that there is no single strategy that can solely address a specific barrier due to the barriers to implementing Construction 4.0 are complicated. They are impacted by a variety of factors, including company culture, resource restrictions, and technology readiness. As a result, confronting these barriers needs a holistic strategy that takes into account the collaboration between the various strategies in order to adapt to the different conditions of each organisation (Oke, et al., 2023a).

Among the results, there is a highest moderate relationship observed between the strategy of providing training and education to solve shortage of expertise and skilled workers issue, with a correlation coefficient of 0.472. Rather than possessing the perception that sending the workers to training is wasting time and money, the company should enhance their workforce’s skills and knowledge through training programs (Munianday, et al., 2023). For instance, one contributing factor to Singapore’s successful adoption of BIM in construction projects is the introduction of new training programs by the government, which were outlined as one of the five strategies in the second BIM roadmap (Jiang, et al., 2022). Likewise, Kissi, et al. (2022) found that offering incentives for staff training and retraining as the top strategy for overcoming barriers in integrating BIM as an emerging technology in construction. Hence, organisations who offer training and education to their employees are better equipped to cope with the issues caused by a skilled worker shortage.

However, there is a weak negative correlation between the financial support from the government and lack of research on Construction 4.0 digital tools. This outcome is not surprising by considering the findings of Kim and Park (2021) who had conducted a study to disclose the government funded R&D collaboration and its influence on SME performance in the Korean construction sector. It discovered that government R&D subsidies are frequently perceived as “free” money by receiving companies, particularly

SMEs in South Korea. It implies that their involvement in joint R&D projects may be motivated primarily by obtaining subsidies rather than improving technological expertise and competitiveness, potentially indicating a failure to meet the government’s primary goal.

In short, there is no one-size-fits-all solution, and multiple strategies are required to efficiently overcome the barriers to Construction 4.0 adoption. This is especially critical for micro and small-sized companies, builders and professionals within the supply chain network, who confront particularly tough obstacles. Everyone, including government, educational institutions, as well as stakeholders, must cooperate with the relevant authorities to address the barriers encountered. There should be a thorough study of the barriers before a proper strategy can be mapped out to channel the construction participants towards Construction 4.0.

4.11 Summary

This chapter summarises the data gathered from the questionnaire, covering respondent backgrounds, reliability analysis, their past project tool adoption, and recommendations for future usage, as well as their perceptions regarding benefits, barriers, and strategies. The data is analysed and further discussed to accomplish the research objectives.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter includes a complete summary of the research findings that are aligned with the research aims and objectives. It also discusses research implications, reflects on limitations, and offers recommendations for future studies.

5.2 Accomplishment of Research Objectives

Construction 4.0, evolving from the principles of Industry 4.0, is an emerging concept in the construction sector. With the Malaysian government actively endorsing policies aimed at transitioning the construction industry towards Construction 4.0, it becomes vital to assess industry players' responses to this transformative shift. This research delves into the readiness of construction players to embrace the transition to Construction 4.0, providing insight on their preparedness for adopting digital tools and innovative practices. Furthermore, the study highlights the significant benefits perceived by construction practitioners upon integrating Construction 4.0 digital tools into their projects. Moreover, it offers useful insights into the key barriers that undermine the widespread implementation of digital tools in construction projects, providing practical strategies for overcoming these barriers. Overall, the study successfully achieves its objectives by offering better understanding into the benefits, barriers and readiness associated with Construction 4.0 adoption in the construction industry, as summarised below:

5.2.1 Objective 1: To Identify the Benefits Incurred from Adopting Construction 4.0 Digital Tools

This research identified 10 benefits incurred from the adoption of various Construction 4.0 digital tools. These benefits were derived through a review of existing literature and subsequently analysed in the context of this research. The benefits will be covered from various aspects, including “Time Savings”, “Cost Savings”, “Quality Improvement”, “Safety Enhancement”, “Boosting

Sustainability”, “Collaboration and Communication Improvement”, “Increase Time and Cost Predictability”, “Promote Innovation”, “Enhance Project Management” and “Enhance Site Design and Logistical Planning”.

In summary, the findings concluded that the benefits incurred do not significantly vary across different categories of respondents. The benefits remain consistent regardless of the nature of the business, with no specific benefits catering to any particular profession. Instead, they are broadly applicable to all roles and positions within the construction industry. However, there are three groups of respondents which are builders, micro and small-sized companies and 6 to 10 years of work experience perceive slightly different on the benefits incurred. Builders managing construction sites acknowledge that digital tools contribute to a safer work environment and increase their competitiveness by exploring new aesthetic possibilities. Moreover, micro and small-sized firms are increasingly recognising the benefits of digital tools for project management as they begin to adopt more affordable options. Simultaneously, professionals with 6 to 10 years of experience, who were relatively new to their careers during the COVID-19 pandemic, appreciate the benefits of digital tools to enhance project productivity and ensure labour safety. Following that, there are three statements that possess the highest mean ranking, including “Precise design, measurement and documentation of my project are facilitated by using digital tools”, followed by “Accident and injuries are minimised by using digital tools in my project” and “My workers feel safer working with digital tools on my project”. These results highlight the most commonly recognised benefits gained by respondents through the implementation of Construction 4.0 digital tools in construction projects.

5.2.2 Objective 2: To Explore the Barriers of Implementing Construction 4.0 Digital Tools

This research also explored 14 barriers to implementing Construction 4.0 digital tools. These barriers were discovered through a literature review and further assessed in this research. The barriers consist of “High Implementation Cost”, “Lack of Expertise and Skilled Workers”, “Resistance to Change”, “Concerning on Data Security and Protection Issues”, “Lack of Regulations and Standardisation", "Lack of Awareness of the Benefits of Construction 4.0 Digital Tools", "Lack of Research on Construction 4.0 Digital Tools", "Pertaining to Legal and Contractual Matters", "Lack of Government Support", "Fragmented Nature of Construction Industry", "Poor Connectivity Network", "Low Interest and Market Demand", "Higher Requirements for Computing Devices" and "Lack of Knowledge Management".

The findings revealed that the respondents working for builders, building material merchants and equipment supply/ hiring/ renting firms are more inclined to acknowledge barriers in implementing Construction 4.0 digital tools. Builders who actively engage in construction site operations tend to recognise issues related to project profitability, which are connected to client demand and higher requirements for computing devices. Concurrently, building material merchants and equipment suppliers are more aligned in perceiving unreliable networks and limited exploration as barriers to implementing Construction 4.0 digital tools due to the nature of their business operations. In addition, it also found out that respondents at the managerial level, who have the authority to allocate resources and make decisions are concerned about the shortage of skilled labour and standardisation issues when applying digital tools in their organisations. Meanwhile, three barriers holding the highest mean ranking, including High Implementation Cost, Lack of Expertise and Skilled Workers and Lack of Government Support, were also pinpointed in this research.

5.2.3 Objective 3: To Infer the Readiness of Construction 4.0 Digital Tools by Construction Industry Players

In overall, the Malaysian construction industry players are not yet ready for Construction 4.0, as indicated by various factors identified in this study. While digital tools have been utilised in past projects, their future adoption appears uncertain. This may be attributed to the limited resources in companies, especially micro, small and medium-sized companies. Although these companies express a commitment to integrating low-cost digital tools, their implementation rates are insufficient for a successful transition to Construction 4.0.

The situation is exacerbated among builders, building material merchants and equipment suppliers, who show less enthusiasm to digitalised methods due to more challenging barriers such as limited research, poor connectivity networks, low interest and market demand and higher requirements for computing devices to embrace Construction 4.0 digital tools. Meanwhile, property development and consultant firms exhibit some preference for digital tools, focused on specialised tasks such as visualisation and clash detection. However, the restricted application of digital technologies, particularly in certain activities or phases, indicates partial adoption rather than comprehensive digitalisation.

As the construction industry operates as a complex network of different professionals and entities, relying exclusively on the adoption by one segment does not accurately represent the readiness for whole industry. Achieving readiness requires coordinated efforts across all industrial segments to fully embrace digital transformation. With some professions or companies left out, the whole construction industry cannot realise the achievement of Construction 4.0.

5.3 Research Implications

This research improves understanding of integration of digital tools in construction projects and helps professionals in grasping current adoption levels and transitioning towards Construction 4.0. It identifies effective digital tools, outlines their project benefits, explores adoption barriers, and proposes strategies for promoting the industry’s transition. Furthermore, the research findings also demonstrate that while construction players are aware, their readiness for the transition remains low.

Firstly, this study can provide significant insights to construction firms and serves as an alarm for all construction practitioners in Malaysia to prepare for the changing landscape of Construction 4.0 in their business. By emphasising both the benefits and barriers associated with adopting Construction 4.0 digital tools, this research stresses the importance of assessing readiness and strategizing effectively. It underscores the necessity of adopting digital tools, promoting innovation, and adapting to new industry norms in order to stay competitive and sustainable in the face of fast technological changes. Finally, this study enables construction professionals to proactively embrace Construction 4.0, promising their long-term survival and success in their careers.

Besides that, this research can make contributions to government agencies responsible for regulating digital transformation toward Construction 4.0 strategies in the construction industry. For instance, it helps CIDB and the Ministry of Works in creating long-term plans that ensure successful execution of the Construction 4.0 Strategic Plan and NCP 2023. By providing insights into the existing landscape and barriers of digital tools adoption, these findings help policymakers to develop legislative frameworks and incentives that foster a conducive environment for Construction 4.0. Governments can establish regulations that effectively address industry-specific difficulties and barriers to adoption through assessing the readiness of construction participants. This approach simplifies the development of regulations, standards, and guidelines that not only encourage the use of digital technology but also solve the particular barriers faced by stakeholders in the construction industry.

Moreover, this research can help to raise awareness among institutions about the need to update their curricula and provide new short courses on modern technologies such as BIM, AI and so on. This is to guarantee that students have the information and skills needed to prosper in the construction industry’s ever-changing environment by emphasiing the necessity of training young generations for the digital age. Introducing classes on cutting-edge technologies exposes students to upcoming Construction 4.0 trends, allowing them to stay ahead of the competition in the job market. Furthermore, by including these new concepts into their educational programs, universities may play a critical role in encouraging innovation and driving growth in the construction industry.

5.4 Research Limitations

Due to time constraints in gathering data, several groups, including building material merchants, equipment supply/ hiring/ renting businesses, and those with work experience of 0-2 years as well as 21 years and above, did not meet the minimum requirement of CLT. This may impact the findings of this research as it is insufficient to represent the mean value for these groups, thereby presenting one of the limitations of this research.

This research, conducted through quantitative approaches such as questionnaire surveys, faces various constraints in data collection. The reliability and precision of results are challenged due to the inability to verify respondents' identities as well as their knowledge of Construction 4.0 and its digital tools. Uncertainty arises regarding whether respondents possess the necessary knowledge and experience to provide meaningful insights. Even if respondents assert familiarity with Construction 4.0 concepts, their lack of hands-on experience with digital tools may affect response quality and induce biases. These biases, which result from personal preferences or limited understanding, can undermine the accuracy and validity of the findings.

Lastly, research findings based on theoretical ideas may not always apply well to specific situations or groups under study. The theories made may be based on assumptions that do not exactly reflect the real-world circumstances under consideration. Without the support of practical evidence, it is hard to draw solid conclusions, limiting how useful the research findings can be in real-life situations. This emphasises how crucial it is to have real-world evidence to support theoretical assumptions.

5.5 Research Recommendations

In future research, overcoming the limitation of sample size can be achieved by increasing the number of respondents in underrepresented groups. This helps to make meaningful comparisons between groups, resulting in more reliable statistical analyses. Therefore, allocating more time to collect sufficient data from various group categories is crucial. Since quantitative methods depend on large samples for reliability, gathering more data boosts the reliability of the findings. Hence, allocating more time to data collecting is imperative for ensuring the validity of future study results.

On the other hand, future research may employ a mixed research method. This approach integrates both quantitative and qualitative methods, leveraging the advantage of their respective strengths. While quantitative methods gather numerical data from large samples, qualitative approaches, such as interviews, offer the opportunity to delve deeper and obtain a more detailed viewpoint directly from interviewees. By striking a balance between the two approaches, researchers can mitigate the limitations of each method and achieve a more comprehensive understanding of the research topic. This method improves the robustness and validity of the research findings, providing more in-depth insights into the topic matter.

Moreover, researchers can better focus their efforts by narrowing their study scope to specific topics such as cultural and organisational readiness for Construction 4.0 adoption in future research. This targeted approach allows for a deeper exploration of key factors and dynamics within a certain area, leading to more accurate and insightful findings. Furthermore, a narrower scope enables researchers to employ more rigorous methodologies and analysis tools for specific topics, thereby enhancing the quality and reliability of the research outcomes. Finally, by performing a more focused and meticulous study, researchers can significantly contribute to the existing knowledge base on Construction 4.0 adoption, providing valuable insights for practitioners, policymakers, and academics in the field.

5.6 Summary

This final chapter presents an overview of the study’s background, outlines the achievements of the research objectives, and delves into the implications, limitations, and recommendations arising from this research.

REFERENCES

Abioye, S.O., Oyedele, L.O., Akanbi, L., Ajayi, A., Davila Delgado, J.M., Bilal, M., Akinade, O.O. and Ahmed, A., 2021. *Artificial intelligence in the construction industry: A review of present status, opportunities and future challenges*. *Journal of Building Engineering*, https://doi.org/10.1016/j.jobe.2021.103299.

Adam, V., Manu, P., Mahamadu, A.M., Dziekonski, K., Kissi, E., Emuze, F. and Lee, S., 2020. Building information modelling (BIM) readiness of construction professionals: the context of the Seychelles construction industry. *Journal of Engineering, Design and Technology*, 20(3), pp.823–840. https://doi.org/10.1108/JEDT-09-2020-0379.

Adekunle, S.A., Aigbavboa, C.O., Ejohwomu, O., Adekunle, E.A. and Thwala, W.D., 2021. *Digital transformation in the construction industry: a bibliometric review*. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-08-2021-0442.

Aghimien, D., Aigbavboa, C., Meno, T. and Ikuabe, M., 2021. Unravelling the risks of construction digitalisation in developing countries. *Construction Innovation*, 21(3), pp.456–475. https://doi.org/10.1108/CI-02-2020-0026.

Aghimien, D., Aigbavboa, C., Oke, A., Thwala, W. and Moripe, P., 2022a. Digitalization of construction organisations–a case for digital partnering. *International Journal of Construction Management*, 22(10), pp.1950–1959. https://doi.org/10.1080/15623599.2020.1745134.

Aghimien, D., Aigbavboa, C., Oke, A.E. and Aliu, J., 2022b. Delineating the people-related features required for construction digitalisation. *Construction Innovation*. https://doi.org/10.1108/CI-01-2022-0012.

Ahmed, K., 2024. *Kruskal Wallis Test*. [online] Available at: <https://www.simplilearn.com/tutorials/statistics-tutorial/spearmans-rank-correlation> [Accessed 3 April 2024].

Ahmed, S., 2019. *A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project Management*. *Organization, Technology and Management in Construction*, https://doi.org/10.2478/otmcj-2018-0012.

Ahmed, Y.A., Shehzad, H.M.F., Khurshid, M.M., Abbas Hassan, O.H., Abdalla, S.A. and Alrefai, N., 2022. Examining the effect of interoperability factors on building information modelling (BIM) adoption in Malaysia. *Construction Innovation*, 24(2), pp.606–642. https://doi.org/10.1108/CI-12-2021-0245.

Aizat, K., Jamal, A., Fadhil Mohammad, M., Hashim, N., Mohamed, M.R. and Ramli, M.A., 2019. Challenges of Building Information Modelling (BIM) from the Malaysian Architect's Perspective. *IConBEE2018*, [online] pp.1–5. https://doi.org/10.1051/matecconf/2019.

Akinradewo, O.I., Aigbavboa, C.O., Edwards, D.J. and Oke, A.E., 2022. A principal component analysis of barriers to the implementation of blockchain technology in the South African built environment. *Journal of Engineering, Design and Technology*, 20(4), pp.914–934. https://doi.org/10.1108/JEDT-05-2021-0292.

Akunyumu, S., Fugar, F.D.K., Adinyira, E. and Danku, J.C., 2021. *A review of models for assessing readiness of construction organisations to innovate*. *Construction Innovation*, https://doi.org/10.1108/CI-01-2020-0014.

Alaloul, W.S., Liew, M.S., Zawawi, N.A.W.A. and Kennedy, I.B., 2020. Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders. *Ain Shams Engineering Journal*, 11(1), pp.225–230. https://doi.org/10.1016/j.asej.2019.08.010.

Alcácer, V. and Cruz-Machado, V., 2019. *Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems*. *Engineering Science and Technology, an International Journal*, https://doi.org/10.1016/j.jestch.2019.01.006.

Ali, M.H., Issayev, G., Shehab, E. and Sarfraz, S., 2022. *A critical review of 3D printing and digital manufacturing in construction engineering*. *Rapid Prototyping Journal*, https://doi.org/10.1108/RPJ-07-2021-0160.

Ali, S.M., Lulseged, S. and Medhin, G., 2018. EMJ Series on Statistics and Methods: Normal Distribution and the Central Limit Theorem. *Ethiop Med J*, 56(3), pp.285–291.

Aliu, J. and Oke, A.E., 2023. Construction in the digital age: exploring the benefits of digital technologies. *Built Environment Project and Asset Management*, 13(3), pp.412–429. https://doi.org/10.1108/BEPAM-11-2022-0186.

Alizadehsalehi, S., Hadavi, A. and Huang, J., 2019. *Virtual Reality for Design and Construction Education Environment Life Cycle Cost Analysis for Bridges View project Scan to BIM Workflows View project*. [online] Available at: <https://www.researchgate.net/publication/328759208>.

Almatari, H.A.Q., Chan, M. and Masrom, M.A.N., 2023. Factors inhibiting the adoption of industrial revolution 4.0 in Malaysian construction industry. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-10-2022-0232.

Alwashah, Z., Sweis, G.J., Abu Hajar, H., Abu-Khader, W. and Sweis, R.J., 2024. Challenges to adopt digital construction technologies in the Jordanian construction industry. *Construction Innovation*. https://doi.org/10.1108/CI-03-2023-0056.

Andersson, R. and Eidenskog, M., 2023. Beyond barriers–exploring resistance towards BIM through a knowledge infrastructure framework. *Construction Management and Economics*. https://doi.org/10.1080/01446193.2023.2218498.

Apuke, O.D., 2017. Quantitative Research Methods : A Synopsis Approach. *Kuwait Chapter of Arabian Journal of Business and Management Review*, 6(11), pp.40–47. https://doi.org/10.12816/0040336.

Arowoiya, V.A., Oke, A.E., Aigbavboa, C.O. and Aliu, J., 2020. An appraisal of the adoption internet of things (IoT) elements for sustainable construction. *Journal of Engineering, Design and Technology*, 18(5), pp.1193–1208. https://doi.org/10.1108/JEDT-10-2019-0270.

Arowoiya, V.A., Oke, A.E., Ojo, L.D. and Adelusi, A.O., 2023. Driving Factors for the Adoption of Digital Twin Technology Implementation for Construction Project Performance in Nigeria. *Journal of Construction Engineering and Management*, 150(1). https://doi.org/10.1061/jcemd4.coeng-13659.

Ashraf, M., Fateh, M. and Mohamed, T., 2016. Cloud Based Storage Application as A Project Information Management Tool For Grade G5 Contractors in Selangor. *Infrastructure University Kuala Lumpur Research Journal*, [online] 4(1). Available at: <https://iukl.edu.my/rmc/wp-content/uploads/sites/4/2018/04/2.-Cloud-Based-Storage-Application-as-A-Project-Information-Management-Tool-For-Grade-G5-Contractors-in-Selangor.pdf> [Accessed 19 April 2024].

Atkinson, E., Spillane, J., Bradley, J. and Brooks, T., 2022. Challenges in the adoption of mobile information communication technology (M-ICT) in the construction phase of infrastructure projects in the UK. *International Journal of Building Pathology and Adaptation*, 40(3), pp.327–344. https://doi.org/10.1108/IJBPA-04-2021-0048.

Aureliano, F. dos S., Costa, A.A.F., Franklin Júnior, I., Alves, A.F., Rodrigues, R.A., Frogeri, R.F. and Portugal Júnior, P. dos S., 2019. Application of lean manufacturing in construction management. *International Journal for Innovation Education and Research*, 7(12), pp.536–544. https://doi.org/10.31686/ijier.vol7.iss12.2105.

Bagheri, B., Yang, S., Kao, H.A. and Lee, J., 2015. Cyber-physical systems architecture for self-aware machines in industry 4.0 environment. In: *IFAC-PapersOnLine*. pp.1622–1627. https://doi.org/10.1016/j.ifacol.2015.06.318.

Bajpai, A. and Misra, S.C., 2021. Barriers to implementing digitalization in the Indian construction industry. *International Journal of Quality and Reliability Management*, 39(10), pp.2438–2464. https://doi.org/10.1108/IJQRM-09-2020-0318.

Bajpai, A. and Misra, S.C., 2022. Evaluation of success factors to implement digitalization in the construction industry. *Construction Innovation*. https://doi.org/10.1108/CI-02-2022-0042.

Bajpai, A., Misra, S.C. and Kim, D.Y., 2023. Identification and assessment of risks related to digitalization in Indian construction: a quantitative approach. *Business Process Management Journal*, 29(4), pp.965–990. https://doi.org/10.1108/BPMJ-11-2022-0571.

Balali, V., Noghabaei, M., Heydarian, A. and Han, K., 2018. Improved Stakeholder Communication and Visualizations: Real-Time Interaction and Cost Estimation within Immersive Virtual Environments. American Society of Civil Engineers (ASCE). pp.522–530. https://doi.org/10.1061/9780784481264.051.

Balasubramanian, S., Shukla, V., Islam, N. and Manghat, S., 2021. Construction Industry 4.0 and Sustainability: An Enabling Framework. *IEEE Transactions on Engineering Management*. https://doi.org/10.1109/TEM.2021.3110427.

Balogun, T.B., 2024. Built environment professionals' perspective on digital technology skills. *Education and Training*. https://doi.org/10.1108/ET-08-2023-0309.

Banerjee, A. and Nayaka, R.R., 2022. *A comprehensive overview on BIM-integrated cyber physical system architectures and practices in the architecture, engineering and construction industry*. *Construction Innovation*, https://doi.org/10.1108/CI-02-2021-0029.

Begić, H. and Galić, M., 2021. *A systematic review of construction 4.0 in the context of the BIM 4.0 premise*. *Buildings*, https://doi.org/10.3390/BUILDINGS11080337.

Bello, S.A., Oyedele, L.O., Akinade, O.O., Bilal, M., Davila Delgado, J.M., Akanbi, L.A., Ajayi, A.O. and Owolabi, H.A., 2021. *Cloud computing in construction industry: Use cases, benefits and challenges*. *Automation in Construction*, https://doi.org/10.1016/j.autcon.2020.103441.

Bhattacharya, S. and Momaya, K.S., 2021. Actionable strategy framework for digital transformation in AECO industry. *Engineering, Construction and Architectural Management*, 28(5), pp.1397–1422. https://doi.org/10.1108/ECAM-07-2020-0587.

Bhawna and Gobind, &, 2015. Research Methodology and Approaches. *Journal of Research & Method in Education (IOSR-JRME)*, [online] 5(3), pp.48–51. https://doi.org/10.9790/7388-05344851.

Biswal, A., 2023. *What is a Chi-Square Test? Formula, Examples & Application*. [online] Available at: <https://www.simplilearn.com/tutorials/statistics-tutorial/chi-square-test> [Accessed 3 April 2024].

Bobbitt, Z., 2020. *How to Perform the Friedman Test in R*. [online] Available at: <https://www.statology.org/friedman-test-r/> [Accessed 3 April 2024].

Bock, T., 2015. *Construction Robotics enabling Innovative Disruption and Social Supportability*.

Boute, R.N., Gijsbrechts, J. and Van Mieghem, J.A., 2022. Digital Lean Operations: Smart Automation and Artificial Intelligence in Financial Services. In: *Springer Series in Supply Chain Management*. Springer Nature. pp.175–188. https://doi.org/10.1007/978-3-030-75729-8_6.

Branco, T., De Sá-Soares, F. and Rivero, A.L., 2017. Key Issues for the Successful Adoption of Cloud Computing. In: *Procedia Computer Science*. Elsevier B.V. pp.115–122. https://doi.org/10.1016/j.procs.2017.11.016.

Castelo, S.R.M.B., 2022. *The Importance of Digital Tools in a Nature-based Climate Adaptation Program in Malaysia: The Case of Penang Island*. [online] Available at: <https://penanginstitute.org/programmes/socioeconomics-and-statistics-programme/penang->.

Chen, K. and Xue, F., 2020. *The renaissance of augmented reality in construction: history, present status and future directions*. *Smart and Sustainable Built Environment*, https://doi.org/10.1108/SASBE-08-2020-0124.

Chen, Q., Adey, B.T., Haas, C. and Hall, D.M., 2020. Using look-ahead plans to improve material flow processes on construction projects when using BIM and RFID technologies. *Construction Innovation*, 20(3), pp.471–508. https://doi.org/10.1108/CI-11-2019-0133.

Chen, Q., García de Soto, B. and Adey, B.T., 2018. Construction automation: Research areas, industry concerns and suggestions for advancement. *Automation in Construction*, 94, pp.22–38. https://doi.org/10.1016/j.autcon.2018.05.028.

Chen, R. and Yang, B., 2022. Construction of an Intelligent Analysis Model for Website Information Based on Big Data and Cloud Computing Technology. *Discrete Dynamics in Nature and Society*, 2022. https://doi.org/10.1155/2022/7876119.

Chen, X., Chang-Richards, A.Y., Ling, F.Y.Y., Yiu, T.W., Pelosi, A. and Yang, N., 2024. Digital technology-enabled AEC project management: practical use cases, deployment patterns and emerging trends. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-09-2023-0962.

Chen, X., Chang-Richards, A.Y., Pelosi, A., Jia, Y., Shen, X., Siddiqui, M.K. and Yang, N., 2022. Implementation of technologies in the construction industry: a systematic review. *Engineering, Construction and Architectural Management*, 29(8), pp.3181–3209. https://doi.org/10.1108/ECAM-02-2021-0172.

Chen, X., Chang-Richards, A.Y., Yiu, T.W., Ling, F.Y.Y., Pelosi, A. and Yang, N., 2023. A multivariate regression analysis of barriers to digital technologies adoption in the construction industry. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-11-2022-1051.

Chia Kuang Lee, Min Si Chen, Nurhaizan Mohd Zainudin, Muhammad Ashraf Fauzi and Tien Choon Toh, 2022. Transformation of Industrial Revolution 4.0 in the Construction Industry: Understanding Drivers & Barriers with Dematel Algorithm. *International Journal of Industrial Management*, 16(1), pp.31–43. https://doi.org/10.15282/ijim.16.1.2022.9010.

Chowdhury, T., Adafin, J. and Wilkinson, S., 2019. Review of digital technologies to improve productivity of New Zealand construction industry. *Journal of Information Technology in Construction*, 24, pp.569–587. https://doi.org/10.36680/J.ITCON.2019.032.

Construction Industry Development Board (CIDB), 2020. *Construction 4.0 Strategic Plan (2021-2025)*. [online] Available at: <https://www.cidb.gov.my/eng/cr-4-0/> [Accessed 23 August 2023].

Construction Industry Development Board (CIDB), 2022. *Malaysia Building Information Modelling (BIM) Report 2021*.

Cooper, D.R. and Schindler, P.S., 2014. *Business Research Methods*. Twelfth ed. The McGraw-Hill Companies.

Correa, F.R., 2018. *Cyber-Physical Systems for Construction Industry*.

Cortellazzo, L., Bruni, E. and Zampieri, R., 2019. The role of leadership in a digitalized world: A review. *Frontiers in Psychology*, 10(AUG). https://doi.org/10.3389/fpsyg.2019.01938.

Craveiro, F., Duarte, J.P., Bartolo, H. and Bartolo, P.J., 2019. *Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0. Automation in Construction,* https://doi.org/10.1016/j.autcon.2019.03.011.

Creswell, J.W. and Creswell, J.D., 2018. *Research Design Qualitative, Quantitative, and Mixed Methods Approaches Fifth Edition*. 5th ed. United Sates of America: SAGE Publications.

Cui, R., Li, M. and Zhang, S., 2020. AI and Procurement. *Manufacturing and Service Operations Management*, 24(2), pp.691–706. https://doi.org/10.1287/msom.2021.0989.

Das, P., Perera, S., Senaratne, S. and Osei-Kyei, R., 2022. Paving the way for industry 4.0 maturity of construction enterprises: a state of the art review. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-11-2021-1001.

Delgado, J.M.D., Oyedele, L., Ajayi, A., Akanbi, L., Akinade, O., Bilal, M. and Owolabi, H., 2019. Robotics and automated systems in construction: Understanding industry-specific challenges for adoption. *Journal of Building Engineering*, 26. https://doi.org/10.1016/j.jobe.2019.100868.

Demirkesen, S. and Tezel, A., 2021. Investigating major challenges for industry 4.0 adoption among construction companies. *Engineering, Construction and Architectural Management*, 29(3), pp.1470–1503. https://doi.org/10.1108/ECAM-12-2020-1059.

Department of Statistics Malaysia, 2021. *National Occupational Accident 2021*. [online] Available at: <https://www.ilmia.gov.my/index.php/en/bda-noa> [Accessed 24 August 2023].

Department of Statistics Malaysia, 2023. *Gross Domestic Product First Quarter 2023*. [online] Available at: <https://www.dosm.gov.my/portal-main/release-content/c4a9dbc1-8b79-11ed-96a6-1866daa77ef9> [Accessed 24 August 2023].

Devadass, P., Heimig, T., Stumm, S., Kerber, E. and Brell-Cokcan, S., 2019. *Robotic Constraints Informed Design Process Abstract*. [online] Available at: <chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://papers.cumincad.org/data/works/att/acadia19_130.pdf> [Accessed 24 August 2023].

Diana, I., Aripin, M., Marinie, E., Zawawi, A. and Ismail, Z., 2019. Factors Influencing the Implementation of Technologies Behind Industry 4.0 in the Malaysian Construction Industry. *MATEC Web of Conferences*, [online] 266. https://doi.org/10.1051/matecconf/2019.

Dilakshan, S., Rathnasinghe, A.P. and Seneviratne, L.D.I.P., 2021. Potential of internet of things (Iot) in the construction industry. In: *World Construction Symposium*. Ceylon Institute of Builders. pp.445–457. https://doi.org/10.31705/WCS.2021.39.

Dobrucali, E., Demirkesen, S., Sadikoglu, E., Zhang, C. and Damci, A., 2022. Investigating the impact of emerging technologies on construction safety performance. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-07-2022-0668.

Dosumu, O.S. and Uwayo, S.M., 2023. Modelling the adoption of Internet of things (IoT) for sustainable construction in a developing economy. *Built Environment Project and Asset Management*, 13(3), pp.394–411. https://doi.org/10.1108/BEPAM-08-2022-0123.

Du, J., Shi, Y., Zou, Z. and Zhao, D., 2018a. CoVR: Cloud-Based Multiuser Virtual Reality Headset System for Project Communication of Remote Users. *Journal of Construction Engineering and Management*, 144(2). https://doi.org/10.1061/(asce)co.1943-7862.0001426.

Du, J., Zou, Z., Shi, Y. and Zhao, D., 2018b. Zero latency: Real-time synchronization of BIM data in virtual reality for collaborative decision-making. *Automation in Construction*, 85, pp.51–64. https://doi.org/10.1016/j.autcon.2017.10.009.

Ebekozien, A. and Aigbavboa, C., 2021. COVID-19 recovery for the Nigerian construction sites: The role of the fourth industrial revolution technologies. *Sustainable Cities and Society*, 69. https://doi.org/10.1016/j.scs.2021.102803.

Ebekozien, A., Aigbavboa, C. and Samsurijan, M.S., 2023. An appraisal of blockchain technology relevance in the 21st century Nigerian construction industry: perspective from the built environment professionals. *Journal of Global Operations and Strategic Sourcing*, 16(1), pp.142–160. https://doi.org/10.1108/JGOSS-01-2022-0005.

Ebekozien, A. and Samsurijan, M.S., 2022. Incentivisation of digital technology takers in the construction industry. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-02-2022-0101.

Eber, W., 2020. Potentials of artificial intelligence in construction management. *Organization, Technology and Management in Construction*, 12(1), pp.2053–2063. https://doi.org/10.2478/otmcj-2020-0002.

Economic Planning Unit, 2021. *National Fourth Industrial Revolution (4IR) Policy*. [online] Available at: <chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.ekonomi.gov.my/sites/default/files/2021-07/National-4IR-Policy.pdf> [Accessed 24 August 2023].

Elghaish, F., Matarneh, S., Talebi, S., Kagioglou, M., Hosseini, M.R. and Abrishami, S., 2021. Toward digitalization in the construction industry with immersive and drones technologies: a critical literature review. *Smart and Sustainable Built Environment*, 10(3), pp.345–363. https://doi.org/10.1108/SASBE-06-2020-0077.

El-Sayegh, S., Romdhane, L. and Manjikian, S., 2020. *A critical review of 3D printing in construction: benefits, challenges, and risks*. *Archives of Civil and Mechanical Engineering,* https://doi.org/10.1007/s43452-020-00038-w.

Esa, M.B., Ibrahim, F.S.B. and Kamal, E.B.M., 2020. Covid-19 pandemic lockdown: The consequences towards project success in malaysian construction industry. *Advances in Science, Technology and Engineering Systems*, 5(5), pp.973–983. https://doi.org/10.25046/aj0505119.

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

Fakher, R.A. and Anandh, K.S., 2022. An Exploratory Study to Utilize Construction 4.0 Technologies in Enhancing Communication to Get Quality Human Resources. In: *Lecture Notes in Civil Engineering*. Springer Science and Business Media Deutschland GmbH. pp.465–479. https://doi.org/10.1007/978-981-16-5839-6_41.

Fargnoli, M. and Lombardi, M., 2020. *Building information modelling (BIM) to enhance occupational safety in construction activities: Research trends emerging from one decade of studies*. *Buildings*, https://doi.org/10.3390/BUILDINGS10060098.

Fokaides, P.A., Apanaviciene, R., Černeckiene, J., Jurelionis, A., Klumbyte, E., Kriauciunaite-Neklejonoviene, V., Pupeikis, D., Rekus, D., Sadauskiene, J., Seduikyte, L., Stasiuliene, L., Vaiciunas, J., Valancius, R. and Ždankus, T., 2020. *Research challenges and advancements in the field of sustainable energy technologies in the built environment*. *Sustainability (Switzerland)*, https://doi.org/10.3390/su12208417.

Forcael, E., Ferrari, I., Opazo-Vega, A. and Pulido-Arcas, J.A., 2020. *Construction 4.0: A literature review*. *Sustainability (Switzerland)*, https://doi.org/10.3390/su12229755.

Gamil, Y., A. Abdullah, M., Abd Rahman, I. and Asad, M.M., 2020. Internet of things in construction industry revolution 4.0: Recent trends and challenges in the Malaysian context. *Journal of Engineering, Design and Technology*, 18(5), pp.1091–1102. https://doi.org/10.1108/JEDT-06-2019-0164.

Georgiadou, M.C., 2019. An overview of benefits and challenges of building information modelling (BIM) adoption in UK residential projects. *Construction Innovation*, 19(3), pp.298–320. https://doi.org/10.1108/CI-04-2017-0030.

Ghauri, P. and Gronhaugh, K., 2010. *Research Methods in Business Studies*. Fifth ed. United Kingdom: Cambridge University Press.

Ghosh, A., Edwards, D.J. and Hosseini, M.R., 2020. *Patterns and trends in Internet of Things (IoT) research: future applications in the construction industry*. *Engineering, Construction and Architectural Management*, https://doi.org/10.1108/ECAM-04-2020-0271.

Glen, S., 2024. *Cronbach's Alpha: Definition, Interpretation, SPSS*. [online] Statistics How To. Available at: <https://www.statisticshowto.com/contact/> [Accessed 4 April 2024].

Goh, C.S., Lee, S.S.H., Lee, S.S.H. and Goh, C.S., 2023. *An Investigation of The Implications Of Covid-19 For Digitalisation In The Malaysian Construction Industry*. [online] *Journal of Engineering Science and Technology*, Available at: <https://www.researchgate.net/publication/375025283>.

Gong, Z. and Wang, N., 2021. The driving process of technological innovation in construction: a firm-level CDM analysis. *Construction Innovation*, 22(2), pp.222–241. https://doi.org/10.1108/CI-12-2020-0194.

Gupta, A., 2023. *Spearman's Rank Correlation: The Definitive Guide To Understand*. [online] Available at: <https://www.simplilearn.com/tutorials/statistics-tutorial/spearmans-rank-correlation> [Accessed 3 April 2024].

Guray, T.S. and Kismet, B., 2022. VR and AR in construction management research: bibliometric and descriptive analyses. *Smart and Sustainable Built Environment*, 12(3), pp.635–659. https://doi.org/10.1108/SASBE-01-2022-0015.

Hairuddin, F.I., Abdul Rasam, A.R. and Razali, M.H., 2022. Development of a 3d cadastre augmented reality and visualization in malaysia. In: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*. International Society for Photogrammetry and Remote Sensing. pp.123–130. https://doi.org/10.5194/isprs-archives-XLVI-4-W3-2021-123-2022.

Hajirasouli, A., Banihashemi, S., Drogemuller, R., Fazeli, A. and Mohandes, S.R., 2022. *Augmented reality in design and construction: thematic analysis and conceptual frameworks*. *Construction Innovation*, https://doi.org/10.1108/CI-01-2022-0007.

Halim, M.I.A., Rusuli, M.S.C. and Yaziz, M.F.A., 2021. 2021_Halim et al_Attitudes, Awareness, Readiness and Barriers towards the Internet of Things. *Journal of Sustainable Management Studies*, 2(1), pp.7–15.

Hall, A.T., Durdyev, S., Koc, K., Ekmekcioglu, O. and Tupenaite, L., 2022. Multi-criteria analysis of barriers to building information modeling (BIM) adoption for SMEs in New Zealand construction industry. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-03-2022-0215.

Hatoum, M.B., Piskernik, M. and Nassereddine, H., 2020. *A Holistic Framework for the Implementation of Big Data throughout a Construction Project Lifecycle*.

Hossain, M.A. and Nadeem, A., 2019. Towards digitizing the construction industry: State of the art of construction 4.0. In: *ISEC 2019 - 10th International Structural Engineering and Construction Conference*. ISEC Press. https://doi.org/10.14455/isec.res.2019.184.

Hossain, M.A., Zhumabekova, A., Paul, S.C. and Kim, J.R., 2020. *A review of 3D printing in construction and its impact on the labor market*. *Sustainability (Switzerland),* https://doi.org/10.3390/su12208492.

Huimin, M., Wu, X., Yan, L., Huang, H., Wu, H., Xiong, J. and Zhang, J., 2018. Strategic plan of ‘Made in China 2025’ and its implementation. In: *Analyzing the Impacts of Industry 4.0 in Modern Business Environments*. IGI Global. pp.1–23. https://doi.org/10.4018/978-1-5225-3468-6.ch001.

Hwang, B.-G., Ngo, J. and Teo, J.Z.K., 2022. Challenges and Strategies for the Adoption of Smart Technologies in the Construction Industry: The Case of Singapore. *Journal of Management in Engineering,* 38(1). https://doi.org/10.1061/(asce)me.1943-5479.0000986.

Ibrahem, O.A., Varouqa, I., Ali, O., Ibrahim, I., Mohammed, A. and Farouq Varouqa, I., 2020. *Materials Management on Construction Sites Using RFID Technique*. [online] Available at: <www.ijstr.org>.

Ibrahim, F.S., Esa, M. and Rahman, R.A., 2021. The adoption of iot in the Malaysian construction industry: Towards construction 4.0. *International Journal of Sustainable Construction Engineering and Technology,* 12(1), pp.56–67. https://doi.org/10.30880/ijscet.2021.12.01.006.

Ibrahim, F.S.B., Ebekozien, A., Khan, P.A.M., Aigbedion, M., Ogbaini, I.F. and Amadi, G.C., 2022. Appraising fourth industrial revolution technologies role in the construction sector: how prepared is the construction consultants? *Facilities,* 40(7–8), pp.515–532. https://doi.org/10.1108/F-09-2021-0086.

Ikuabe, M., Aghimien, D.O., Aigbavboa, C. and Oke, A.E., 2020. *Exploring the Adoption of Digital Technology at the Different Phases of Construction Projects in South Africa 053 View project an assessment of environmental impacts of building construction activities View project*. [online] Available at: <https://www.researchgate.net/publication/340116122>.

Islam, M.R., 2018. Sample size and Its role in Central Limit Theorem (CLT). *Computational and Applied Mathematics Journal,* [online] 4(1), pp.1–7. Available at: <http://www.aascit.org/journal/camj>.

Ismail, S.A., Bandi, S. and Maaz, Z.N., 2018. An Appraisal into the Potential Application of Big Data in the Construction Industry. *International Journal of Built Environment and Sustainability,* 5(2). https://doi.org/10.11113/ijbes.v5.n2.274.

Iyer, K.C., Kumar, R. and Singh, S.P., 2020. Understanding the role of contractor capability in risk management: a comparative case study of two similar projects. *Construction Management and Economics,* 38(3), pp.223–238. https://doi.org/10.1080/01446193.2019.1590614.

Jākobsone, M., 2022. *Germany - Digital Strategy 2025*. [online] Federal Ministry for Economic Affairs and Energy. Available at: <https://digital-skills-jobs.europa.eu/en/actions/national-initiatives/national-strategies/germany-digital-strategy-2025> [Accessed 24 August 2023].

El Jazzar, M., Schranz, C., Urban, H. and Nassereddine, H., 2021. *Integrating Construction 4.0 Technologies: A Four-Layer Implementation Plan*. *Frontiers in Built Environment*, https://doi.org/10.3389/fbuil.2021.671408.

Jazzar, M. El, Urban, H., Schranz, C. and Nassereddine, H., 2020. Construction 4.0: A roadmap to shaping the future of construction. In: *Proceedings of the 37th International Symposium on Automation and Robotics in Construction, ISARC 2020: From Demonstration to Practical Use - To New Stage of Construction Robot*. International Association on Automation and Robotics in Construction (IAARC). pp.1314–1321. https://doi.org/10.22260/isarc2020/0180.

Jelodar, M.B. and Shu, F., 2021. Innovative use of low-cost digitisation for smart information systems in construction projects. *Buildings*, 11(7). https://doi.org/10.3390/buildings11070270.

Jiang, R., Wu, C., Lei, X., Shemery, A., Hampson, K.D. and Wu, P., 2022. *Government efforts and roadmaps for building information modeling implementation: lessons from Singapore, the UK and the US*. *Engineering, Construction and Architectural Management*, https://doi.org/10.1108/ECAM-08-2019-0438.

Jiang, W., Ding, L. and Zhou, C., 2020. Cyber physical system for safety management in smart construction site. *Engineering, Construction and Architectural Management*, 28(3), pp.788–808. https://doi.org/10.1108/ECAM-10-2019-0578.

Jilcha Sileyew, K., 2020. Research Design and Methodology. In: *Cyberspace*. IntechOpen. https://doi.org/10.5772/intechopen.85731.

Jones, M.D., Hutcheson, S. and Camba, J.D., 2021. Past, present, and future barriers to digital transformation in manufacturing: A review. *Journal of Manufacturing Systems*, 60, pp.936–948. https://doi.org/10.1016/j.jmsy.2021.03.006.

Jussila, J.J., Porkka, P., Jussila, J. and Suominen, A., 2008. *Using Friedman Test for Creating Comparable Group Results of Nonparametric Innovation Competence Data*. [online] Available at: <https://www.researchgate.net/publication/200021578>.

Kabir, S.M.S., 2016. *Introduction to Research Chapter-1*. [online] Available at: <https://www.researchgate.net/publication/325846733>.

Kamaruddeen, A.M., Sung, C.F. and Wahi, W., 2020. A study on factors causing cost overrun of construction projects in Sarawak, Malaysia. *Civil Engineering and Architecture*, 8(3), pp.191–199. https://doi.org/10.13189/cea.2020.080301.

Kamaruddin, S.S., Mohammad, M.F. and Mahbub, R., 2016. Barriers and Impact of Mechanisation and Automation in Construction to Achieve Better Quality Products. *Procedia - Social and Behavioral Sciences*, 222, pp.111–120. https://doi.org/10.1016/j.sbspro.2016.05.197.

Kang, K., Liu, X., Jiang, Y., Lee, K.K.H., Wan, S.K.W., Huang, G.Q. and Zhong, R.Y., 2022. Blockchain opportunities for construction industry in Hong Kong: a case study of RISC and site diary. *Construction Innovation*. https://doi.org/10.1108/CI-08-2021-0153.

Kariuki, I.G., Alkizim, A. and Kivaa, T., 2021. Adoption of Internet of Things in The Construction Industry: A Comparative Case Study of Construction and Manufacturing Industries in Kenya. *Africa Habitat Review Journal*, [online] 15(1). Available at: <http://uonjournals.uonbi.ac.ke/ojs/index.php/ahr>.

Karmakar, A. and Delhi, V.S.K., 2021. *Construction 4.0: What we know and where we are headed? Journal of Information Technology in Construction*, https://doi.org/10.36680/j.itcon.2021.028.

Kasim, N., Sarpin, N., Noh, H.M., Zainal, R., Mohamed, S., Manap, N. and Yahya, M.Y., 2019. Automatic Materials Tracking Practices Through RFID Implementation in Construction Projects. *MATEC Web of Conferences*, [online] 266(2019). https://doi.org/10.1051/matecconf/2019.

Khudzari, F., Rahman, R.A. and Ayer, S.K., 2021. Factors Affecting the Adoption of Emerging Technologies in the Malaysian Construction Industry. In: *IOP Conference Series: Earth and Environmental Science*. IOP Publishing Ltd. https://doi.org/10.1088/1755-1315/641/1/012006.

Kim, S. and Park, K.C., 2021. Government funded R&D collaboration and it’s impact on SME’s business performance. *Journal of Informetrics*, 15(3). https://doi.org/10.1016/j.joi.2021.101197.

Kissi, E., Aigbavboa, C. and Kuoribo, E., 2022. Emerging technologies in the construction industry: challenges and strategies in Ghana. *Construction Innovation*, 23(2), pp.383–405. https://doi.org/10.1108/CI-11-2021-0215.

Klinc, R. and Turk, Ž., 2019. Construction 4.0 – Digital Transformation of One of the Oldest Industries. *Economic and Business Review*, 21(3). https://doi.org/10.15458/ebr.92.

Kor, M., Yitmen, I. and Alizadehsalehi, S., 2021. An investigation for integration of deep learning and digital twins towards Construction 4.0. *Smart and Sustainable Built Environment*, 12(3), pp.461–487. https://doi.org/10.1108/SASBE-08-2021-0148.

Kothari, C.R., 2004. Research Methodology Methods and Techniques. pp.1–418.

Kowalski, M., Lee, Z.W.Y. and Chan, T.K.H., 2021. Blockchain technology and trust relationships in trade finance. *Technological Forecasting and Social Change*, 166. https://doi.org/10.1016/j.techfore.2021.120641.

Kozlovska, M., Klosova, D. and Strukova, Z., 2021. *Impact of industry 4.0 platform on the formation of construction 4.0 concept: A literature review*. *Sustainability (Switzerland)*, https://doi.org/10.3390/su13052683.

Kraft, C., Lindeque, J.P. and Peter, M.K., 2022. The digital transformation of Swiss small and medium-sized enterprises: insights from digital tool adoption. *Journal of Strategy and Management*, 15(3), pp.468–494. https://doi.org/10.1108/JSMA-02-2021-0063.

Kumar, B. and Cheng, J.C.P., 2010. *Cloud Computing and its Implications for Construction IT*.

Kuzdikbay, N. and Nadeem, A., 2022. *Evaluating Industry 4.0 Implementation Barriers in the Construction Industry of Kazakhstan*.

Lamprecht, C. and Guetterman, T.C., 2019. Mixed methods in accounting: a field based analysis. *Meditari Accountancy Research*, 27(6), pp.921–938. https://doi.org/10.1108/MEDAR-11-2018-0403.

Lau, S.E.N., Aminudin, E., Zakaria, R., Saar, C.C., Roslan, A.F., Hamid, Z.A., Zain, M.Z.M., Maaz, Z.N. and Ahamad, A.H., 2021. Talent as a Spearhead of Construction 4.0 Transformation: Analysis of Their Challenges. *IOP Conference Series: Materials Science and Engineering*, 1200(1), p.012025. https://doi.org/10.1088/1757-899x/1200/1/012025.

Lau, S.E.N., Zakaria, R., Aminudin, E., Chang Saar, C., Abidin, N.I.A., Roslan, A.F., Abd Hamid, Z., Mohd Zain, M.Z. and Lou, E., 2019. Review: Identification of roadmap of fourth construction industrial revolution. In: *IOP Conference Series: Materials Science and Engineering*. Institute of Physics Publishing. https://doi.org/10.1088/1757-899X/615/1/012029.

Lawal, K. and Rafsanjani, H.N., 2022. *Trends, benefits, risks, and challenges of IoT implementation in residential and commercial buildings*. *Energy and Built Environment*, https://doi.org/10.1016/j.enbenv.2021.01.009.

Lekan, A., Clinton, A., Fayomi, O.S.I. and James, O., 2020. Lean thinking and industrial 4.0 approach to achieving construction 4.0 for industrialization and technological development. *Buildings*, 10(12), pp.1–27. https://doi.org/10.3390/buildings10120221.

Lew, Y.L., Toh, T.C., Lim, K.L., Yan, F.Y.Y. and Yow, L.P., 2019. A study on the constraints of implementing Information and Communication Technology (ICT) in Malaysian Construction Industry. In: *IOP Conference*

Series: Earth and Environmental Science. Institute of Physics Publishing. https://doi.org/10.1088/1755-1315/385/1/012005.

Li, J., Bian, Y., Guan, J. and Yang, L., 2023. Construction and Application of Cloud Computing Model for Reciprocal and Collaborative Knowledge Management. *Computers, Materials and Continua*, 75(1), pp.1119–1137. https://doi.org/10.32604/cmc.2023.035369.

Li, J., Greenwood, D. and Kassem, M., 2019. Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Automation in Construction*, 102, pp.288–307. https://doi.org/10.1016/j.autcon.2019.02.005.

Li, Y., Sun, H., Li, D., Song, J. and Ding, R., 2022. Effects of Digital Technology Adoption on Sustainability Performance in Construction Projects: The Mediating Role of Stakeholder Collaboration. *Journal of Management in Engineering*, 38(3). https://doi.org/10.1061/(asce)me.1943-5479.0001040.

Lim, M.L.W., Wong, S.Y. and Ding, C.S., 2023. Challenges of industrial revolution 4.0: quantity surveying students' perspectives. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-07-2022-0636.

Madanayake, U.H. and Egbu, C., 2019. *Critical analysis for big data studies in construction: significant gaps in knowledge*. *Built Environment Project and Asset Management*, https://doi.org/10.1108/BEPAM-04-2018-0074.

Mahmood, S., Awang, Z., Abdel Rahman Kmeil, F. and Jakada, A.H., 2021. Participation of Local Youth Workers in Construction Industry and Strategies for Improvement: A Study in Kelantan and Terengganu. *International Journal of Academic Research in Business and Social Sciences*, 11(2). https://doi.org/10.6007/ijarbss/v11-i2/8225.

Malik, A., Sharma, S., Batra, I., Sharma, C., Kaswan, M.S. and Garza-Reyes, J.A., 2023. Industrial revolution and environmental sustainability: an analytical interpretation of research constituents in Industry 4.0. *International Journal of Lean Six Sigma*. https://doi.org/10.1108/IJLSS-02-2023-0030.

Malomane, R., Musonda, I. and Okoro, C.S., 2022. The Opportunities and Challenges Associated with the Implementation of Fourth Industrial Revolution Technologies to Manage Health and Safety. *International Journal of Environmental Research and Public Health*, 19(2). https://doi.org/10.3390/ijerph19020846.

Mantha, B.R.K. and de Soto, B.G., 2019. Cyber security challenges and vulnerability assessment in the construction industry. Periodica Polytechnica Budapest University of Technology and Economics. pp.29–37. https://doi.org/10.3311/ccc2019-005.

Maqsoom, A., Zulqarnain, M., Irfan, M., Ullah, F., Alqahtani, F.K. and Khan, K.I.A., 2023. Drivers of, and Barriers to, the Adoption of Mixed Reality in the Construction Industry of Developing Countries. *Buildings*, 13(4). https://doi.org/10.3390/buildings13040872.

Maskuriy, R., Selamat, A., Ali, K.N., Maresova, P. and Krejcar, O., 2019. Industry 4.0 for the construction industry-How ready is the industry? *Applied Sciences (Switzerland)*, 9(14). https://doi.org/10.3390/app9142819.

Ministry of Works, 2021. *National Construction Policy 2030 (NCP 2030)*. [online] Available at: <https://www.kkr.gov.my/sites/default/files/2022-10/Dasar-Pembinaan-Negara-NCP2030.pdf> [Accessed 4 April 2024].

Moffatt, S., 2015. Contextualizing Scientific Research Methodologies. [online] 5(6), pp.52–57. https://doi.org/10.9790/7388-05615257.

Mohd Nawi, M.N., Baluch, N. and Bahauddin, A.Y., 2014. Impact of fragmentation issue in construction industry: An overview. In: *MATEC Web of Conferences*. EDP Sciences. https://doi.org/10.1051/matecconf/20141501009.

Momade, M.H., Durdyev, S., Van Tam, N., Shahid, S., Mbachu, J. and Momade, Y., 2022. Factors influencing adoption of construction technologies in Vietnam’s residential construction projects. *International Journal of Building Pathology and Adaptation*. https://doi.org/10.1108/ijbpa-03-2022-0048.

Moon, S., Ham, N., Kim, S., Hou, L., Kim, J.H. and Kim, J.J., 2020. Fourth industrialization-oriented offsite construction: case study of an application to an irregular commercial building. *Engineering, Construction and Architectural Management*, 27(9), pp.2271–2286. https://doi.org/10.1108/ECAM-07-2018-0312.

Moshood, T.D., Adeleke, A.Q., Nawanir, G., Ajibike, W.A. and Shittu, R.A., 2020. International Journal of Recent Technology and Engineering (IJRTE). *International Journal of Recent Technology and Engineering (IJRTE)*, [online] 9(1), pp.1627–1634. https://doi.org/10.35940/ijrte.A2564.059120.

Muktamar, A.B., Bachtiar, A., Guntoro, G., Riyantie, M. and Ridwan, N., 2023. The Role of Leadership in Digital Transformation Management in Organisations. *Jurnal Minfo Polgan*, 12(1), pp.1306–1314. https://doi.org/10.33395/jmp.v12i1.12731.

Munianday, P., A. Rahman, R. and Esa, M., 2023. Case study on barriers to building information modelling implementation in Malaysia. *Journal of Facilities Management*, 21(4), pp.511–534. https://doi.org/10.1108/JFM-10-2021-0132.

Nagy, O., Papp, I. and Szabó, R.Z., 2021. Construction 4.0 organisational level challenges and solutions. *Sustainability (Switzerland)*, 13(21). https://doi.org/10.3390/su132112321.

Neuman, W.L., 2014. *Social Research Methods: Qualitative and Quantitative Approaches*. Seventh ed.

Newman, C., Edwards, D., Martek, I., Lai, J., Thwala, W.D. and Rillie, I., 2021. Industry 4.0 deployment in the construction industry: a bibliometric literature review and UK-based case study. *Smart and Sustainable Built Environment*, 10(4), pp.557–580. https://doi.org/10.1108/SASBE-02-2020-0016.

Ngo, J. and Hwang, B.-G., 2022. Critical Project Management Knowledge and Skills for Managing Projects with Smart Technologies. *Journal of Management in Engineering*, 38(6). https://doi.org/10.1061/(asce)me.1943-5479.0001095.

Nicole, W.Z.Z., Wah, L.W., Yee, W.S. and Soon, W.K., 2022. Impact of Performance and Barriers towards Industrial Revolution 4.0 Implementation in Malaysian Construction Projects. *Malaysian Journal of Sustainable Environment*, 9(1), p.243. https://doi.org/10.24191/myse.v9i1.17302.

Niedoba, T., Surowiak, A., Hassanzadeh, A. and Khoshdast, H., 2023. Evaluation of the Effects of Coal Jigging by Means of Kruskal–Wallis and Friedman Tests. *Energies*, 16(4). https://doi.org/10.3390/en16041600.

Oesterreich, T.D. and Teuteberg, F., 2016. *Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry*. *Computers in Industry*, https://doi.org/10.1016/j.compind.2016.09.006.

Oke, A.E., Aliu, J., Fadamiro, P., Akanni, P., Jamir Singh, P.S. and Shaharudin Samsurijan, M., 2023a. Unpacking the strategies to promote the implementation of automation techniques in the construction industry. *Construction Innovation*. https://doi.org/10.1108/CI-12-2022-0332.

Oke, A.E., Aliu, J., Fadamiro, P., Jamir Singh, P.S., Samsurijan, M.S. and Yahaya, M., 2023b. Robotics and automation for sustainable construction: microscoping the barriers to implementation. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-12-2022-0275.

Oke, A.E., Aliu, J., Onajite, S. and Simeon, M., 2022. Success factors of digital technologies (DT) tools adoption for sustainable construction in a developing economy. *Construction Innovation*. https://doi.org/10.1108/CI-08-2022-0207.

Oke, A.E. and Arowoiya, V.A., 2021a. Critical barriers to augmented reality technology adoption in developing countries: a case study of Nigeria. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-12-2020-0519.

Oke, A.E. and Arowoiya, V.A., 2021b. Evaluation of internet of things (IoT) application areas for sustainable construction. *Smart and Sustainable Built Environment*, 10(3), pp.387–402. https://doi.org/10.1108/SASBE-11-2020-0167.

Oke, A.E., Kineber, A.F., Akindele, O. and Ekundayo, D., 2023c. Determining the stationary barriers to the implementation of radio frequency identification (RFID) technology in an emerging construction industry. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-07-2022-0348.

Oke, A.E., Kineber, A.F., Albukhari, I. and Dada, A.J., 2021a. Modeling the robotics implementation barriers for construction projects in developing countries. *International Journal of Building Pathology and Adaptation*. https://doi.org/10.1108/IJBPA-06-2021-0093.

Oke, A.E., Kineber, A.F., Al-Bukhari, I., Famakin, I. and Kingsley, C., 2021b. Exploring the benefits of cloud computing for sustainable construction in Nigeria. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-04-2021-0189.

Okedara, K., Ejohwomu, O. and Chan, P., 2020. Ethics and Stakeholder Engagement for Industry/Construction 4.0: A Systematic Review. In: *The Construction Industry in the Fourth Industrial Revolution*. Springer International Publishing. pp.577–587. https://doi.org/10.1007/978-3-030-26528-1_59.

Okoro, C.S., Nnaji, C. and Adediran, A., 2022. Determinants of immersive technology acceptance in the construction industry: management perspective. *Engineering, Construction and Architectural Management*, 30(7), pp.2645–2668. https://doi.org/10.1108/ECAM-06-2021-0476.

Okpo, H., Ikediashi, D. and Dania, A., 2023. Influence of digitalisation adoption level on construction project delivery in Nigeria. *Frontiers in Engineering and Built Environment*. https://doi.org/10.1108/febe-01-2023-0008.

Olanrewaju, O.I., Babarinde, S.A., Chileshe, N. and Sandanayake, M., 2021. Drivers for implementation of building information modeling (BIM) within the Nigerian construction industry. *Journal of Financial Management of Property and Construction*, 26(3), pp.366–386. https://doi.org/10.1108/JFMPC-12-2019-0090.

Olatunde, N.A., Gento, A.M., Okorie, V.N., Oyewo, O.W., Mewomo, M.C. and Awodele, I.A., 2022. Construction 4.0 technologies in a developing economy: awareness, adoption readiness and challenges. *Frontiers in Engineering and Built Environment*, 3(2), pp.108–121. https://doi.org/10.1108/febe-08-2022-0037.

Olsson, N.O.E., Shafqat, A., Arica, E. and Økland, A., 2019. 3d-printing technology in construction: Results from a survey. In: *Emerald Reach Proceedings Series*. Emerald Group Holdings Ltd. pp.349–356. https://doi.org/10.1108/S2516-285320190000002044.

Omari, R. Al, Sweis, G., Abu-Khader, W. and Sweis, R., 2023. Barriers to the Adoption of Digitalization in the Construction Industry: Perspectives of Owners, Consultants, and Contractors. [online] https://doi.org/10.5130/AJCEB.

Onososen, A.O., Musonda, I., Onatayo, D., Tjebane, M.M., Saka, A.B. and Fagbenro, R.K., 2023. Impediments to Construction Site Digitalisation Using Unmanned Aerial Vehicles (UAVs). *Drones*, 7(1). https://doi.org/10.3390/drones7010045.

Osei-Asibey, D., Ayarkwa, J., Adinyira, E., Acheampong, A. and Amoah, P., 2021. Roles and Responsibilities of Stakeholders towards Ensuring Health and Safety at Construction Site. *Journal of Building Construction and Planning Research*, 09(01), pp.90–114. https://doi.org/10.4236/jbcpr.2021.91008.

Osunsanmi, T.O., Aigbavboa, C.O., Emmanuel Oke, A. and Liphadzi, M., 2020. Appraisal of stakeholders' willingness to adopt construction 4.0 technologies for construction projects. *Built Environment Project and Asset Management*, 10(4), pp.547–565. https://doi.org/10.1108/BEPAM-12-2018-0159.

Oyedele, A., Owolabi, H.A., Oyedele, L.O. and Olawale, O.A., 2020. Big data innovation and diffusion in projects teams: Towards a conflict prevention culture. *Developments in the Built Environment*, 3. https://doi.org/10.1016/j.dibe.2020.100016.

Patel, M. and Patel, N., 2019. Exploring Research Methodology Review Article: Review Article. *International Journal of Research and Review*, 6(3), pp.48–55.

Perera, S., Jin, X., Samaratunga, M. and Gunasekara, K., 2023. Drivers and Barriers to Digitalization: A Cross-Analysis of the Views of Designers and Builders in the Construction Industry. *Journal of Information Technology in Construction*, 28, pp.87–106. https://doi.org/10.36680/j.itcon.2023.005.

Perrier, N., Bled, A., Bourgault, M., Cousin, N., Danjou, C., Pellerin, R. and Roland, T., 2020. *Construction 4.0: A survey of research trends*. *Journal of Information Technology in Construction*, https://doi.org/10.36680/J.ITCON.2020.024.

V Prabhakar, V., Belarmin Xavier, C.S. and Abubeker, K.M., 2023. A Review on Challenges and Solutions in the Implementation of Ai, IoT and Blockchain in Construction Industry. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.03.535.

Proctor-Parker, C. and Stopforth, R., 2021. Radio frequency identification (RFID) stock control and geo-location data system from a moving vehicle. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-10-2021-0548.

Public Works Department (PWD), 2020. *Pelan Strategik Jabatan Kerja Raya Malaysia 2021 - 2025*. [online] Malaysia. Available at: <https://www.jkr.gov.my/sites/default/files/documents/PELAN_STRATEGIK_JKR_2021-_2025.pdf> [Accessed 1 April 2024].

Queirós, A., Faria, D. and Almeida, F., 2017. European Journal of Education Studies Strengths and Limitations of Qualitative and Quantitative Research Methods. *European Journal of Education Studies*, [online] 3(9). https://doi.org/10.5281/zenodo.887089.

Rachmawati, T.S.N. and Kim, S., 2022. *Unmanned Aerial Vehicles (UAV) Integration with Digital Technologies toward Construction 4.0: A Systematic Literature Review*. *Sustainability (Switzerland)*, https://doi.org/10.3390/su14095708.

Rafiq, W., Musarat, M.A., Altaf, M., Napiah, M., Sutanto, M.H., Alaloul, W.S., Javed, M.F. and Mosavi, A., 2021. Life cycle cost analysis comparison of hot mix asphalt and reclaimed asphalt pavement: A case study. *Sustainability (Switzerland)*, 13(8). https://doi.org/10.3390/su13084411.

Rane, S.B. and Narvel, Y.A.M., 2019. Re-designing the business organization using disruptive innovations based on blockchain-IoT integrated architecture for improving agility in future Industry 4.0. *Benchmarking*, 28(5), pp.1883–1908. https://doi.org/10.1108/BIJ-12-2018-0445.

Reynoso Vanderhorst, H.D., Heesom, D., Suresh, S., Renukappa, S. and Burnham, K., 2022. Barriers and cost model of implementing unmanned aerial system (UAS) services in a decentralised system: case of the Dominican Republic. *Construction Innovation*. https://doi.org/10.1108/CI-08-2021-0155.

Ribeiro, D.B., Coutinho, A. dos R., Satyro, W.C., Campos, F.C. de, Lima, C.R.C., Contador, J.C. and Gonçalves, R.F., 2022. The DAWN readiness model to assess the level of use of Industry 4.0 technologies in the construction industry in Brazil. *Construction Innovation*. https://doi.org/10.1108/CI-05-2022-0114.

Rugg, D., 2010. An Introduction to Triangulation.

Safa, M., Baeza, S. and Weeks, K., 2019. Incorporating Blockchain technology in construction management. *Strategic Direction*, 35(10), pp.1–3. https://doi.org/10.1108/SD-03-2019-0062.

Safura Zabidin, N., Belayutham, S. and Khairil Izam Che Ibrahim, C., 2021. Awareness and Barriers of Industry 4.0 and Education 4.0 between Construction Players and Academicians in Malaysia. *JOURNAL OF*

TECHNOLOGY MANAGEMENT AND BUSINESS, [online] 8(2), pp.26–37. https://doi.org/10.30880/jtmb.2021.08.02.003.

Sajjad, M., Hu, A., Waqar, A., Falqi, I.I., Alsulamy, S.H., Bageis, A.S. and Alshehri, A.M., 2023. Evaluation of the Success of Industry 4.0 Digitalization Practices for Sustainable Construction Management: Chinese Construction Industry. *Buildings*, 13(7). https://doi.org/10.3390/buildings13071668.

Saka, A.B. and Chan, D.W.M., 2020. *Adoption and implementation of building information modelling (BIM) in small and medium-sized enterprises (SMEs): a review and conceptualization*. *Engineering, Construction and Architectural Management*, https://doi.org/10.1108/ECAM-06-2019-0332.

Salkin, C., Oner, M., Ustundag, A. and Cevikcan, E., 2018. *Springer Series in Advanced Manufacturing Industry 4.0: Managing The Digital Transformation*. [online] Springer International Publishing Switzerland. https://doi.org/https://doi.org/10.1007/978-3-319-57870-5_1.

Salkind, N.J., 2006. *Exploring research*. Pearson.

Santos, C., Mehrsai, A., Barros, A.C., Araújo, M. and Ares, E., 2017. Towards Industry 4.0: an overview of European strategic roadmaps. *Procedia Manufacturing*, 13, pp.972–979. https://doi.org/10.1016/j.promfg.2017.09.093.

Saunders, M., Lewis, P. and Thornhill, A., 2016. *Research Methods for Business Students*. Seventh ed.

Sawhney, A., Riley, M. and Irizarry, J., 2020. *Construction 4.0; An Innovation Platform for the Built Environment; First Edition*. https://doi.org/10.1201/9780429398100-1.

Schober, P. and Schwarte, L.A., 2018. Correlation coefficients: Appropriate use and interpretation. *Anesthesia and Analgesia*, 126(5), pp.1763–1768. https://doi.org/10.1213/ANE.0000000000002864.

Sekaran, U. and Bougie, R., 2016. *Research Methods for Business A Skill-Building Approach*. [online] Available at: <www.wileypluslearningspace.com>.

Senanayake, S.M.A.H., Gunawardana, P.A.M., Perera, B.A.K.S. and Rajaratnam, D., 2023. Examining the potential use of augmented reality in construction cost management tools and techniques. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-10-2022-0512.

Sepasgozar, S.M.E., 2021. *Differentiating digital twin from digital shadow: Elucidating a paradigm shift to expedite a smart, sustainable built environment*. *Buildings*, https://doi.org/10.3390/buildings11040151.

Shafei, H., Radzi, A.R., Algahtany, M. and Rahman, R.A., 2022. *Construction 4.0 Technologies and Decision-Making: A Systematic Review and Gap Analysis*. *Buildings*, https://doi.org/10.3390/buildings12122206.

Shafei, H., Rahman, R.A. and Lee, Y.S., 2024. Evaluating Construction 4.0 technologies in enhancing safety and health: case study of a national strategic plan. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-08-2023-0330.

Shang, G., Low, S.P. and Lim, X.Y.V., 2023. Prospects, drivers of and barriers to artificial intelligence adoption in project management. *Built Environment Project and Asset Management*. https://doi.org/10.1108/BEPAM-12-2022-0195.

Singaram, L.R., Zakaria, R., Munikanan, V., Wahi, N., Aminudin, E., Sahamir, S.R., Redzuan, A.A., Gara, J., Zulkarnaini, M.F. and Khalid, R., 2023. Pre-investigation on adaptation of construction 4.0 multi criteria business model by SME contractors in Malaysia. *Cleaner Engineering and Technology,* 15. https://doi.org/10.1016/j.clet.2023.100662.

Siriwardhana, S. and Moehler, R., 2023. *Mastering the skills of Construction 4.0: a review of the literature using science mapping*. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-03-2023-0045.

Smallwood, J. and Allen, C., 2022. Practitioners' perceptions of the potential impact of Industry 4.0 on construction health and safety. *Journal of Engineering, Design and Technology*, 21(2), pp.486–501. https://doi.org/https://10.1108/JEDT-11-2021-0635.

Statsenko, L., Samaraweera, A., Bakhshi, J. and Chileshe, N., 2023. *Construction 4.0 technologies and applications: a systematic literature review of trends and potential areas for development*. *Construction Innovation*, https://doi.org/10.1108/CI-07-2021-0135.

Su, J., Sheng, Z., Leung, V.C.M. and Chen, Y., 2019. Energy Efficient Tag Identification Algorithms for RFID: Survey, Motivation and New Design. *IEEE Wireless Communications*, 26(3), pp.118–124. https://doi.org/10.1109/MWC.2019.1800249.

Szafranko, E., 2017. Decision problems in management of construction projects. In: *IOP Conference Series: Materials Science and Engineering*. Institute of Physics Publishing. https://doi.org/10.1088/1757-899X/251/1/012048.

Taber, K.S., 2018. The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, 48(6), pp.1273–1296. https://doi.org/10.1007/s11165-016-9602-2.

Talla, A. and McIlwaine, S., 2022. Industry 4.0 and the circular economy: using design-stage digital technology to reduce construction waste. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-03-2022-0050.

Van Tam, N., Toan, N.Q. and Van Phong, V., 2024. Investigating potential barriers to construction digitalization in emerging economies: A study in Vietnam. *International Journal of Information Management Data Insights*, 4(1), p.100226. https://doi.org/10.1016/j.jjimei.2024.100226.

Tang, S., Shelden, D.R., Eastman, C.M., Pishdad-Bozorgi, P. and Gao, X., 2019. *A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends*. *Automation in Construction*, https://doi.org/10.1016/j.autcon.2019.01.020.

Tanga, O.T., Aigbavboa, C.O., Akinradewo, O.I., Thwala, D.W. and Onyia, M., 2021. Construction Digitalisation Tools In South African Construction Industry: An Added Advantage. *IOP Conference Series: Materials Science and Engineering*, 1107(1), p.012230. https://doi.org/10.1088/1757-899x/1107/1/012230.

Tanko, B.L., Essah, E.A., Elijah, O., Zakka, W.P. and Klufallah, M., 2023. *Bibliometric analysis, scientometrics and metasynthesis of Internet of Things (IoT) in smart buildings*. *Built Environment Project and Asset Management*. https://doi.org/10.1108/BEPAM-11-2022-0179.

Tariq, J. and Gardezi, S.S.S., 2023. *Study the delays and conflicts for construction projects and their mutual relationship: A review*. *Ain Shams Engineering Journal*, https://doi.org/10.1016/j.asej.2022.101815.

Tay, Y.W.D., Panda, B., Paul, S.C., Noor Mohamed, N.A., Tan, M.J. and Leong, K.F., 2017. 3D printing trends in building and construction industry: a review. 12(3), pp.261–276. https://doi.org/https://doi.org/10.1080/17452759.2017.1326724.

Tehrani, B.M., BuHamdan, S. and Alwisy, A., 2022. Robotics in industrialized construction: an activity-based ranking system for assembly manufacturing tasks. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-02-2022-0143.

Toyin, J.O. and Mewomo, M.C., 2022. An investigation of barriers to the application of building information modelling in Nigeria. *Journal of Engineering, Design and Technology*, 21(2), pp.442–468. https://doi.org/10.1108/JEDT-10-2021-0594.

Turner, C.J., Oyekan, J., Stergioulas, L. and Griffin, D., 2021. Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities. *IEEE Transactions on Industrial Informatics*, 17(2), pp.746–756. https://doi.org/10.1109/TII.2020.3002197.

Uhomoibhi, J.O., Onime, C.E. and Wang, H., 2019. A study of developments and applications of mixed reality cubicles and their impact on learning. *International Journal of Information and Learning Technology*. https://doi.org/10.1108/IJILT-02-2019-0026.

Wahab, A., Wang, J., Shojaei, A. and Ma, J., 2022. A model-based smart contracts system via blockchain technology to reduce delays and conflicts in construction management processes. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-03-2022-0271.

Wang, K., Guo, F., Zhang, C. and Schaefer, D., 2022. From Industry 4.0 to Construction 4.0: barriers to the digital transformation of engineering and construction sectors. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-05-2022-0383.

Wang, M., Wang, C.C., Sepasgozar, S. and Zlatanova, S., 2020. *A systematic review of digital technology adoption in off-site construction: Current status and future direction towards industry 4.0*. *Buildings*, https://doi.org/10.3390/buildings10110204.

Wayne, T., Chai, C.S., Wong, S.S.L., Lim, F.L., Goh, K.C. and Abidin, N.I., 2023. Evaluation of Digital's Role in Sustainable Built Environment. *Pertanika Journal of Science and Technology*, 31(3), pp.1335–1351. https://doi.org/10.47836/pjst.31.3.13.

Weerapperuma, U.S., Rathnasinghe, A.P., Jayasena, H.S., Wijewickrama, C.S. and Thurairajah, N., 2023. A knowledge framework for blockchain-enabled smart contract adoption in the construction industry. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-01-2023-0012.

Wilson, J.R. and Sharples, S., 2015. *Evaluation of human work*.

Wilts, H., Garcia, B.R., Garlito, R.G., Gómez, L.S. and Prieto, E.G., 2021. Artificial intelligence in the sorting of municipalwaste as an enabler of the circular economy. *Resources*, 10(4). https://doi.org/10.3390/resources10040028.

Xu, Y., Chong, H.Y. and Chi, M., 2023. Modelling the blockchain adoption barriers in the AEC industry. *Engineering, Construction and Architectural Management*, 30(1), pp.125–153. https://doi.org/10.1108/ECAM-04-2021-0335.

Yahya, M.Y., Hui Yin, L., Binti Md Yassin, A., Omar, R., Orbintang anak Robin, R. and Kasim, N., 2019. The Challenges of the Implementation of Construction Robotics Technologies in the Construction. *MATEC Web of Conferences*, [online] 266(2019), pp.1–5. https://doi.org/10.1051/matecconf/2019.

Yan, T.W. and Kah, S., 2018. Building Information Modelling in Small and Medium Enterprieses (SMES) within Malaysian Construction Sector: Implementation, Barriers, and Solutions. *Faculty of Engineering and Quantity Surveying*, [online] 2(1). Available at: <http://eprints.intimal.edu.my/1333/1/vol2_2018_1.pdf> [Accessed 20 April 2024].

Yan, Z., Wang, S., Ma, D., Liu, B., Lin, H. and Li, S., 2019. Meteorological factors affecting pan evaporation in the Haihe River Basin, China. *Water (Switzerland)*, 11(2). https://doi.org/10.3390/w11020317.

Yap, J.B.H., Lee, K.P.H. and Wang, C., 2021. Safety enablers using emerging technologies in construction projects: empirical study in Malaysia. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-07-2021-0379.

You, Z. and Feng, L., 2020. Integration of Industry 4.0 Related Technologies in Construction Industry: A Framework of Cyber-Physical System. *IEEE Access*, 8, pp.122908–122922. https://doi.org/10.1109/ACCESS.2020.3007206.

Yousif, O.S., Zakaria, R., Wahi, N., Aminudin, E., Abdul Tharim, A.H., Gara, J.A., Liyana Umran, N.I., Khalid, R. and Ismail, N., 2022. Monitoring the Construction Industry towards a Construction Revolution 4.0. *International Journal of Sustainable Development and Planning*, 17(2), pp.633–641. https://doi.org/10.18280/ijsdp.170228.

Zabidin, N.S., Belayutham, S. and Che Ibrahim, C.K.I., 2023. The knowledge, attitude and practices (KAP) of Industry 4.0 between construction practitioners and academicians in Malaysia: a comparative study. *Construction Innovation*. https://doi.org/10.1108/CI-05-2022-0109.

Zaher, M., Greenwood, D. and Marzouk, M., 2018. Mobile augmented reality applications for construction projects. *Construction Innovation*, 18(2), pp.152–166. https://doi.org/10.1108/CI-02-2017-0013.

Zaia, Y.Y., Adam, S.M. and Abdulrahman, F.H., 2023. Investigating BIM level in Iraqi construction industry. *Ain Shams Engineering Journal*, 14(3). https://doi.org/10.1016/j.asej.2022.101881.

Zhang, Z. and Min, H., 2020. Analysis on the Construction of Personalized Physical Education Teaching System Based on a Cloud Computing Platform. *Wireless Communications and Mobile Computing*, 2020. https://doi.org/10.1155/2020/8854811.

Zhao, Y., Hao, S., Chen, Z., Zhou, X., Zhang, L. and Guo, Z., 2023. Critical factors influencing the internet of things technology adoption behavior of construction companies: evidence from China. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-01-2023-0045.

Zulu, S.L., Saad, A., Ajayi, S., Unuigbe, M. and Dulaimi, M., 2023. A thematic analysis of the organisational influences on digitalisation in construction firms. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-10-2022-0513.

APPENDICES

Appendix A: Questionnaire

ASSESSING THE READINESS OF MALAYSIAN CONSTRUCTION INDUSTRY TOWARDS CONSTRUCTION 4.0

Dear Sir / Madam,
I am Chia Chi Wei, a final year undergraduate student pursuing a Bachelor of Science (Honours) Quantity Surveying at the Department of Surveying, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman (UTAR).

I am conducting a survey regarding my Final Year Project titled "**Assessing the Readiness of Malaysian Construction Industry towards Construction 4.0**". This research investigates the adoption of Construction 4.0 digital tools in the Malaysian construction industry.

This questionnaire is divided into FIVE (5) sections which will take approximately 10 – 15 minutes to complete. Your response to this questionnaire will significantly contribute to achieving the research aim. All information provided is strictly confidential and used solely for academic purposes.

If you have any queries, please do not hesitate to contact me at chiweii0101@1utar.my.

Thank you for your participation and have a nice day.

Regards,
Chia Chi Wei
Bachelor of Science (Honours) Quantity Surveying
Universiti Tunku Abdul Rahman

Section A: Respondent's Background

1) Which of the following best describes your company's business activities?

☐ Property Development
☐ Consultancy
☐ Contracting Business
☐ Building Material Merchant
☐ Equipment Supply/Hiring/Renting Business
☐ Others, please specify

2) What is your professional?

☐ Architect
☐ Engineer
☐ Quantity Surveyor
☐ Builder
☐ Supplier/ Subcontractor/ Specialist
☐ Others, please specify

3) Years of working experience in the construction industry.

☐ 0-2 years
☐ 3-5 years
☐ 6-10 years
☐ 11-20 years
☐ 21 years and above

4) What is your current position in the organisation?

☐ Junior Executive
☐ Senior Executive
☐ Assistant Manager/ Manager/ Team Leader
☐ Director/ Managing Directors/ CEO

5) What is your company size?

☐ Less than 5 people
☐ 5 – 30 people
☐ 31 – 75 people
☐ More than 75 people

Section B: Types of Construction 4.0 Digital Tools

6) To what extent these Construction 4.0 digital tools are implemented in your **current / past** construction project?

(1=Never Adopt, 2=Seldom Adopt, 3=Sometimes Adopt, 4=Frequently Adopt, 5=Always Adopt)

		1	**2**	**3**	**4**	**5**
1	Building Information Modelling (BIM)	☐	☐	☐	☐	☐
2	Cloud Computing	☐	☐	☐	☐	☐
3	Internet of Things (IoT)	☐	☐	☐	☐	☐
4	Big Data	☐	☐	☐	☐	☐
5	Cyber-Physical System (CPS)	☐	☐	☐	☐	☐
6	Artificial Intelligence (AI)	☐	☐	☐	☐	☐
7	Robotics and Automation Systems	☐	☐	☐	☐	☐
8	Radio Frequency Identification (RFID)	☐	☐	☐	☐	☐
9	Augmented Reality (AR) / Virtual Reality (VR)	☐	☐	☐	☐	☐
10	3D Printing	☐	☐	☐	☐	☐
11	Blockchain	☐	☐	☐	☐	☐

7) How likely you will suggest the company adopt the following Construction 4.0 digital tools in your **future** projects?

(1=Extremely Unlikely, 2=Unlikely, 3=Neutral, 4=Likely, 5=Extremely Likely)

		1	**2**	**3**	**4**	**5**
1	Building Information Modelling (BIM)	☐	☐	☐	☐	☐
2	Cloud Computing	☐	☐	☐	☐	☐
3	Internet of Things (IoT)	☐	☐	☐	☐	☐
4	Big Data	☐	☐	☐	☐	☐
5	Cyber-Physical System (CPS)	☐	☐	☐	☐	☐
6	Artificial Intelligence (AI)	☐	☐	☐	☐	☐
7	Robotics and Automation Systems	☐	☐	☐	☐	☐
8	Radio Frequency Identification (RFID)	☐	☐	☐	☐	☐

9	Augmented Reality (AR) / Virtual Reality (VR)	☐	☐	☐	☐	☐
10	3D Printing	☐	☐	☐	☐	☐
11	Blockchain	☐	☐	☐	☐	☐

8) What is your preference between Traditional Method vs Construction 4.0 tools when it comes to the following activities?

	Traditional Method	**Construction 4.0 Tools**
Design or Modelling/ Measurement (Printed or CAD drawings / Microsoft Excel vs BIM)		
Data Storage (Pendrive/ Email/ Hard disk vs Cloud Computing)		
Data Generation (Analog sensors and gauges / Field notes / Camera vs IoT)		
Data Collection (Microsoft Excel / Field Notes / Camera / Voice Recorder vs Big Data)		
Monitoring construction activities (Microsoft Excel / Mobile devices / Manual Labour vs CPS)		
Data Analysis (Microsoft Excel / SPSS vs AI)		
Performing Construction Activities / Building, Demolition, Excavation, Material Handling (Heavy machine / hand tools vs Robotics and Automation)		
Resources Management / Managing Materials, Equipment and Inventory (Barcode scanner / mobile devices		

vs RFID)		
Simulation and Visualisation (Printed or CAD drawings vs AR & VR)		
Prefabrication (Heavy machine/ Manual labour vs 3D printing)		
Transaction and Contract Management (Paper-based documents vs Blockchain)		

Section C: Benefits of Implementing Construction 4.0 Digital Tools

9) To what extent do you agree the benefits incurred to my construction project due to Construction 4.0 digital tools?

(1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree)

		1	**2**	**3**	**4**	**5**
1	Time is saved by using the digital tools in my project.	☐	☐	☐	☐	☐
2	My project is completed earlier than the completion date by using digital tools.	☐	☐	☐	☐	☐
3	My project is executed within budget by using digital tools.	☐	☐	☐	☐	☐
4	My project becomes more cost-effective by using digital tools.	☐	☐	☐	☐	☐
5	Quality standards of my project are maintained by using digital tools.	☐	☐	☐	☐	☐
6	Precise design, measurement and documentation of my project are facilitated by using digital tools.	☐	☐	☐	☐	☐
7	Accident and injuries are minimised by using digital tools in my project.	☐	☐	☐	☐	☐
8	My workers feel safer working with digital tools on my project.	☐	☐	☐	☐	☐

9	Lesser resource waste is generated by using digital tools in my project.	☐	☐	☐	☐	☐
10	Conflict among stakeholders is reduced by using digital tools in my project.	☐	☐	☐	☐	☐
11	Communication and collaboration within my project are enhanced by using digital tools.	☐	☐	☐	☐	☐
12	Time and cost predictability of my project are increased by using digital tools.	☐	☐	☐	☐	☐
13	More innovative solutions are promoted by using digital tools in my project.	☐	☐	☐	☐	☐
14	The exploration of new aesthetic possibilities is enabled by using digital tools in my project.	☐	☐	☐	☐	☐
15	My project is properly managed by using digital tools.	☐	☐	☐	☐	☐
16	The layout and logistical planning of the site in my project are improved by using digital tools.	☐	☐	☐	☐	☐

Section D: Barriers of Implementing Construction 4.0 Digital Tools

10) To what extent do you agree the following undermines the implementation of Construction 4.0 digital tools?

(1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree)

		1	**2**	**3**	**4**	**5**
1	High Implementation Cost	☐	☐	☐	☐	☐
2	Lack of Expertise and Skilled Workers	☐	☐	☐	☐	☐
3	Resistance to Change	☐	☐	☐	☐	☐
4	Concerning on Data Security and Protection Issue	☐	☐	☐	☐	☐
5	Lack of Regulations and Standardisation	☐	☐	☐	☐	☐
6	Lack of Awareness of the Benefits of Construction 4.0 Digital Tools	☐	☐	☐	☐	☐

7	Lack of Research on Construction 4.0 Digital Tools	☐	☐	☐	☐	☐
8	Pertaining to Legal and Contractual Matters	☐	☐	☐	☐	☐
9	Lack of Government Support	☐	☐	☐	☐	☐
10	Fragmentated Nature of Construction Industry	☐	☐	☐	☐	☐
11	Poor Connectivity Network	☐	☐	☐	☐	☐
12	Low Interest and Market Demand	☐	☐	☐	☐	☐
13	Higher Requirements for Computing Devices	☐	☐	☐	☐	☐
14	Lack of Knowledge Management	☐	☐	☐	☐	☐

Section E: Strategies to Improve the Implementation of Construction 4.0 Digital Tools

11) To what extent do you agree the following fosters the implementation of Construction 4.0 digital tools?

(1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree)

		1	**2**	**3**	**4**	**5**
1	Financial Support from Government	☐	☐	☐	☐	☐
2	Training and Education	☐	☐	☐	☐	☐
3	Increase Awareness of Construction	☐	☐	☐	☐	☐
4	Early Technology Involvement	☐	☐	☐	☐	☐
5	Regulations and Policies by Government	☐	☐	☐	☐	☐
6	Guidelines by Professional Bodies	☐	☐	☐	☐	☐