EXAMINE DIGITAL ECOSYSTEM IN THE MALAYSIAN CONSTRUCTION SUPPLY-CHAIN

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

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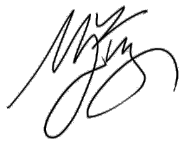
DECLARATION

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

Signature : 

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **" EXAMINE DIGITAL ECOSYSTEM IN THE MALAYSIAN CONSTRUCTION SUPPLY-CHAIN "** was prepared by **LOW MING CHI** 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.

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ABSTRACT

Digital ecosystem is a complex network of interlinked companies, where people make use of digital devices and application software on a secured platform to exchange digital content. The National Construction Policy in Malaysia aims to establish a conducive infrastructure development ecosystem and targeted digitalizing half of the industry's cycle by 2030. This research examines the current state of digital ecosystem in the Malaysian construction supply-chain and explores its underpinning issues. Four key constituents of the digital ecosystem namely device, network, content, and application are synthesized from the literature reviewed. 41 close-ended questionnaire statements embracing the four key constituents were constructed to explore the availability of digital infrastructure in construction organizations. Another 40 statements were used to assess the digital knowledge and talent of the construction community. Three open-ended questions were included for the respondents to share the subjective issues in digitalization encounters. The quantitative data collected from 200 respondents have undergone reliability analysis, Friedman test, Chi-square test and Kruskal-Wallis H test generalized the significant findings that social collaboration applications are more prevalent in the organization and the construction community is more competent with social collaboration application than smart technologies. The construction supply-chain faced seven (7) major digitalization issues of high network latency, lack of digital knowledge and skills, inadequate digital infrastructure, intricate software and technology, immature common data environment, expensive software subscription fees, and fixed cultural mindset. These findings offer a snapshot of the current digital ecosystem in the Malaysian construction supply-chain which enable the industry practitioners to preempt the issues; regulators to facilitate the industry by developing alleviation policies, permit researchers to conduct further investigation and educational institutions to improve the related course curriculum.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

RICS	Royal Institution of Chartered Surveyors
UK	United Kingdom
US	United States
D-COM	Digital Compliance
ITM	Construction Industry Transformation Map
DfMA	Design for Manufacturing and Assembly
IDD	Integrated Digital Delivery
BIM	Building Information Modelling
CDE	Common Data Environment
UAS	Unmanned Aeriel System
CMMS	Computerized Maintenance Management System
BEMS	Building Energy Management Systems
BAS	Building Automation System
RFID	Radio Frequency Identification
GPS	Global Positioning System
WLAN	Wireless Local Area Network
IoT	Internet of Things
Wi-Fi	Wireless Fidelity
IOS	Iphone Operating System
DWG	AutoCAD Drawing File
CAD	Computer-aided Design
AI	Artificial Intelligence
AR	Augmented Reality
VR	Virtual Reality
UV	Ultraviolet
CLT	Central Limit Theorem
SPSS	Statistical Package for Social Sciences
CCTV	Close Circuit Television

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

The construction sector is always being viewed adversely within the ecosystem of more cutting-edge and futuristic fields. It is a sleeping behemoth on the edge of extinction since it has not changed from the practises of the twentieth century. These cautions were served as a wake-up call, underlining the significance of technological advancement in propelling the sector forward. RICS (2022) suggests that digitization can disrupt every stage of the project delivery life cycle, from design to construction to the creation of social value.

From a global outlook, RICS is pushing for a "restart, reset, and reinvention" of the construction industry so that the "ecosystem of connected digital twins" can be established (RICS, 2020). The Construction Innovation Hub of United Kingdom (UK) has collaborated with Cardiff University's Digital Compliance (D-COM) Network to create a "digital ecosystem" to aid the industry in its efforts to simplify the regulatory landscape for construction firms, drive greater levels of compliance, and reduce the administrative and financial burden associated with failing to meet rules and standards. In the United States (US), it was found that only 11% of the construction companies have the ability to swiftly manage their digital assets, while 89% strongly agreed that using digital technology may boost overall efficiency to the workforce and reduce stress (OpenAsset, 2021). China has revealed a plan to advance digital development until 2035, with the aim of creating a “digital China” that will serve as a crucial catalyst for Chinese-style modernization and a significant pillar for gaining new advantages in global competition (Shen, 2023). Apart from that, 40% of construction companies in Australian and New Zealand plan to establish a digital transformation roadmap, facilitated by Victoria University’s innovative technologies (Building Connection, 2022; Angebrandt, 2023). Singapore’s Building Construction Authority (2022) launched the Construction Industry Transformation Map (ITM) in 2017 to create an advanced and integrated sector through widespread adoption of leading technologies, with a focus on implementing Design for Manufacturing and Assembly (DfMA) and Integrated Digital Delivery (IDD).

In addition, Malaysia has launched the National Construction Policy 2030 seeking to foster sustainable construction practises and ambitious new concepts interlinked with global initiatives for a more sustainable future (Ministry of Works, 2022). The government is committed to establish a conducive infrastructure development ecosystem in addressing future challenges faced by the construction sector. By 2030, at least half of the industry's cycle, including procurement and monitoring, should be digitalized, according to the new policy framework (Construction Policy 2030).

1.2 Problem Statement

Despite accounting for 13% of the global GDP, the construction ecosystem has experienced a modest annual productivity growth of only 1% over the last 20 years (Ribeirinho et al., 2020). The sluggish adoption of cutting-edge digital construction technology and tools by the construction sector is causing fragmentation (Keskin, Salman and Ozorhon, 2020). In view of that, the construction community needs to have clearer picture of the landscape of digital ecosystem in the industry in order to align with the national policy in fully digitized ecosystem of the construction industry by 2030.

There is limited research related to the digital ecosystem in the construction supply-chain. Most of the studies are not in the construction context. For examples, digital ecosystems, digital business ecosystems, and digital platforms are becoming popular studies among researchers as a means of gaining a deeper comprehension of digitalization (Boudreau, 2011; Reuver et al., 2018). Boley and Chang (2007) studied the collaboration between digital ecosystems semantically, but the research is limited to e-business only. Selander, Henfridsson and Svahn (2013) conducted digital ecosystem case study focus only on Sony Ericsson, the mobile device manufacturer. Valdez-De-Leon (2019) published the digital ecosystem design criteria. In the construction context, Pulkka et al. (2016) mainly focused on introducing and developing the concept of the ecosystem within the construction industry and investigating how ecosystem characteristics impact value creation in construction networks. Keskin, Salman, and Ozorhon's (2020) used the airport project as a case study to examine the effects of BIM adoption on the construction technology ecosystem, specifically focused on fostering the collaboration between major stakeholders in large-scale infrastructure projects. While Sawhney and Odeh's (2021) study of the digital ecosystem in the construction industry is more concerned with providing an overview of ecosystems and platforms as well as analysing the significance of the digital ecosystem within the construction 4.0 framework, it lacks elaboration of delivery process of the construction supply-chain. Hence, this study attempts to bridge the gap between the digital ecosystem and Malaysian construction supply-chain.

1.3 Research Aim

The research aims to examine the digital ecosystem in the Malaysian construction supply-chain, particularly from the perspective of the different business activities and professionals of the construction community in Malaysia.

1.4 Research Objectives

The following research objectives have been formulated to achieve the research aim:

i. To explore the essentials of digital ecosystem in the construction supply-chain in general.

ii. To assess the current state of digital ecosystem in the Malaysian construction supply-chain which include the infrastructure available in the construction related activities and talent and knowledge available among the construction community.

iii. To infer the digital ecosystem and the underpinning issues of the Malaysian construction supply-chain.

1.5 Research Method

A general comprehension of digital ecosystem worldwide was investigated through review of the published literature. A conceptual framework of the digital ecosystem is established, particularly on the essentials components from parts of the digital ecosystem (Figure 2.2). The framework was used to develop the questionnaire survey (Figure 3.1). The questionnaire survey will be analyzed descriptively and inferentially through Cronbach's alpha reliability test, Friedman test, Chi-square test and Kruskal-Wallis H test (Section 4.3 - 4.6). Figure 1.1 illustrates the detail of this research approaches and the respective research objectives.

Aim: To examine the digital ecosystem in the Malaysian construction supply-chain, particularly from the perspective of the different business activities and professionals of the construction community in Malaysia.		
Objective 1: To explore the essentials of digital ecosystem in the construction supply-chain in general.	**Objective 2:** To assess the current state of digital ecosystem in the Malaysian construction supply-chain which include the infrastructure available in the construction related activities and talent and knowledge available among the construction community.	**Objective 3:** To infer the digital ecosystem and the underpinning issues of the Malaysian construction supply-chain.

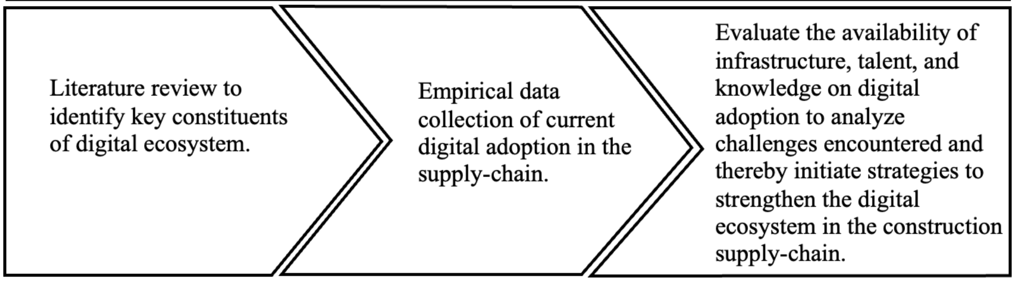

Figure 1.1: Research Plan

1.6 Research Scope

This research was conducted in Malaysia, the field data were collected with a questionnaire survey from the local construction community involved in the diverse process of the construction supply-chain. There are no specific limitations or qualifications for the respondents other than the participants must be part of the construction community.

1.7 Report Structure

This research comprises of five chapters namely; Introduction, Literature Review, Methodology and Work Plan, Result and Discussion, and Conclusion and Recommendations. The following paragraphs provide an overview of each chapter.

Chapter 1 presents the digital ecosystem as a wide variety of entities interacting with one another through digital means. The problem statement addresses that there is still a lack of research studies on the digital ecosystem in the construction supply-chain. The research aim and objectives are outlined. The research method is briefly described and illustrated. The statistical analysis method is listed. The research scope which is targeted to the Malaysian construction community only is declared.

Chapter 2 explains the description of the ecosystem from different contexts and the discoveries of four key constituents forming the digital ecosystem. Subsequently, this chapter reviews the published literature and documentation about the digital ecosystem. This chapter further provides insight into the digital ecosystem in the delivery process of the construction supply-chain. A conceptual framework showing the relationship between the variables used to infer the digital ecosystem landscape in the Malaysian construction supply-chain is presented in the last section of this chapter.

Chapter 3 justifies both the quantitative and qualitative research methodology adopted in this research. The chapter elucidates the rationale of the questionnaire design and its structure which comprises closes-ended questions and open-ended questions. A random sampling method is adopted. Cochran's central limit theorem is assumed to justify the average sample sizes. In addition, the statistical analysis methods and tests which included Cronbach's alpha reliability test, Friedman test, Chi-square test and Kruskal-Wallis H test are adopted for data analysis to obtain discernable results. The chapter concludes by addressing the research ethics to ensure the confidentiality of information provided by the respondents and appreciation for their contribution in answering the questionnaire survey.

Chapter 4 reports the research's results and discusses the findings. The chapter summarises the demographic information of the 200 respondents. The questionnaire construct is tested reliably. Furthermore, the digital infrastructure available in the construction organization and digital knowledge and talent are compared across different respondents' company business activities, profession and years of working experience. The industrial practitioners' sharings are organized and shown graphically to enable visualization of digitalization's issues, challenges and improvement strategies. Discussions are derived by comparing the findings with the literature reviewed.

Chapter 5 concludes that social collaboration applications are more prevalent in the organization and the construction community is more competent with them than smart technologies. The accomplishment of the research aim and objectives are presented with the evidence available in the preceding chapters. In addition, this chapter examines the research’s implications for industrial practitioners to alleviate the digitalization issues, regulators to develop policies, and academia to conduct further research and improve course curriculum. It ends with a reflection on the research's limitations and provides recommendations for future research on similar subjects.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Tansley (1935) defined ecosystem as the entire system, which consists of the organism complex and physical factors that comprise the biome's "environment" or "habitat." Even though the definition was proposed 80 years ago, it still holds up. In biological context, according to Elizabeth and Martin (2006), an ecosystem is a loosely connected, domain-clustering habitat in which each species conserves the environment for its own benefit. In social science, Moore (1993) defines an ecosystem as a group of actors and artefacts organised around a central platform. Over the years, the phrase ecosystem has become the buzzword beyond biome and as a system which drives the competitive strategy of organizations (Jacobides, Cennamo and Gawer, 2018). The interconnected network is where the evolution strike.

This chapter is structured into six sections. This introduction (Section 2.1) explains ecosystem with its context and provides a birdeye view of the chapter. It is following by section 2.2, which presents the overview of construction ecosystem. Section 2.3 explains the definition of digital ecosystem and its key constituents. Section 2.4 discusses the incorporation of key constituents along the construction delivery processes. Section 2.5 illustrates a conceptual framework of the digital ecosystem landscape in the Malaysian construction supply-chain.

2.2 Construction Ecosystem

The construction industry has developed the concept of an "ecosystem" to describe its interconnected hardware, software, people, information flows, and communication (Keskin, Salman and Ozorhon, 2020). The term "construction ecosystem" as described by Pulkka et al. (2016) refers to the entirety of the construction industry, including all phases from initial planning and design to construction, maintenance, and eventual demolition.

A study by McKinsey & Company revealed that over $10 billion was invested in construction technology between 2011 and 2018, with the fastest-growing phases being construction and operation and maintenance. Several technologies such as 3D printing, drones, virtual and augmented reality, modularization, robots, digital twin technology, AI and analytics, supply chain optimisation, and marketplaces are already being employed in the construction ecosystem (Blanco et al., 2018). According to Jamie (2021), drones are already being used by construction businesses to improve inspection times, cut costs, and increase productivity and safety on job sites. Certain AI-focused startups are gaining momentum and threatening non-traditional market entrants. Due to the lack of existing data strategies, resources and processes, AI will grow slowly in the near future. Marketplace startups for buying and selling construction goods are growing in popularity and can improve construction productivity, competitive bidding, and supply-chain optimization, but are currently limited to North America. Conversely, real-time sensing technologies have yet to find widespread adoption and use in actual building projects (Rao et al., 2022). Ibrahim, Simpeh and Adebowale (2023) found that wearable safety device adoption was mostly hampered by cost, leaving construction organizations feeling helpless about high startup costs, salaries for skilled workers, and maintenance expenses.

Oughton, Amaglobeli and Moszoro (2023)'s report has recently highlighted the need to invest $418 billion worldwide in digital infrastructure. Blanco et al. (2018) underlined fragmentation as the major issue for firms seeking technology solutions because many older organizations use legacy systems and other information-collection methods. Further, digital talent is also a concern for construction ecosystem, as the talent investment could doubles digitalization success (Blanco et al., 2018). Siddiqui, Abdekhodaee, and Thaheem (2022) emphasized that expertise and familiarity with drafting software (AutoCAD, Revit, or etc.) and structural design software systems that lead to technical solutions is highly valued in the construction industry. The digital literacy is more prevalent among younger construction workers than their older counterparts (Zulu, Saad, and Gledson, 2023). The lack of new digital leaders, mindsets, and flexible leadership styles can severely impact change and transformation (Kane et al., 2016). Therefore, the complex problems arising from the projected worsening of the skilled labor shortage require innovative solutions (Blanco et al., 2018).

According to Chai (2017), slow but steady digitalization progress can be seen in the Malaysian construction sector. It is essential for the Malaysian construction sector to address the growing knowledge gap in the specialized field of talent concerns as Construction 4.0 gains momentum (Lau et al., 2021). To achieve this, companies should implement intraorganizational digital training, like digital workshops and meetings which can help young construction employees get up to speed faster on digital tools (Koseoglu et al., 2019). Besides, digital training to upskill and acquire the inputs of senior workers is also essential (Olanipekun and Sutrisna, 2021). Industry bodies and authorities can offer grants, bonuses, and subsidies to encourage owners and contractors to utilise digital solutions and train the next generation (Agarwal, Chandrasekaran and Sridhar, 2016).

2.3 What is Digital Ecosystem ?

Gartner Research defines a digital ecosystem as an interdependent set of firms, people, and things that share standardized digital platforms to attain mutually beneficial goals, such as financial gain, innovation, common interest, and value creation (Osborne et al., 2022). Valdez-De-Leon (2019) describes a digital ecosystem as "loose networks of interacting organizations that are digitally connected, enabled by modularity, and impacted by one another's products." Nonetheless, Hadzic and Dillion (2008) describe a digital ecosystem as a complex ecosystem characterized by the diverse objectives of its digitally connected participants. In addition, Gloria, Marlien, and Adele (2016) defined a digital ecosystem as a network of digital communities comprised of interconnected, interrelated, and interdependent digital species, such as stakeholders, institutions, and digital devices located in a digital environment, that interacts as a functional unit and are linked through actions, information, and transaction flows. The digital ecosystem provides a unique potential to make public domain works accessible to everyone, not just through shared access but also through the possibility of third-party reuse in the form of digital libraries. Paradoxically, the "digital" character of the digital environment acts as a tool for individuals to construct or even self-construct. Eaton et al. (2011) determined that a digital ecosystem consists of a platform that serves as the ecosystem's core and upon which others can add modules that expand the platform's service potential. In addition, it consists of diverse social actors who construct the platform and its modules, as well as a regulatory framework with rules that bind these heterogeneous actors together. The introduction of digitalization into the construction ecosystem has instilled a culture of innovation in the sector.

The aforesaid definitions of the ecosystem and digital ecosystem published in the literature reviewed are refined here to synthesize a working definition of the digital ecosystem in this paper:

A complex network of interlinked companies, digital devices, applications and people cooperating on a secured platform with the presence of trust in attaining the same goal.

2.3.1 Key Constituents of Digital Ecosystem

The key constituents of a digital ecosystem included in the above working definition are device, network, application and content. The full potential of a digital ecosystem can only be unlocked when each component of this structure has been mastered. If any of these components is lacking or has not been thoroughly considered, the organization will have difficulty reaping the full benefits of operating in the digital realm. Device compatibility and content quality alone will not suffice as a digital solution. It must address the interconnected nature of the digital world. The firm may create a complete digital solution by considering the requirements of the ecosystem in each of the four elements (Sawhney, Riley and Irizarry, 2020). Specific examples are provided for each of the key constituents as shown in Table 2.1.

Table 2.1: Four Key Constituents of Digital Ecosystem

Key Constituents	**Specific Examples**	**Previous Research**
Device	Computer Tablet Smartphone Smart Glasses	Stanton (2022), Sawhney, Riley and Irizarry (2020), Perrier et al. (2020), Jamie

Table 2.1 (Continued)

	Smart Helmet Smart Boot Power Gloves Drones Smart Camera Laser Scanner Robotics Unmanned machineries	(2021)
Network	4G 5G WiFi IoT	IBM Institute (2019), Perrier et al. (2020), Tang et al. (2019), Holslin and Gates (2023)
Application	BIM 360 Common Data Environment (CDE) Navisworks AutoCAD Revit PrimaVera Microsoft Excel Microsoft Project Mircosoft Word Cubicost Google Drive OneDrive WhatsApp Email Unmanned Aeriel System (UAS) Computerized Maintenance Management System (CMMS) Building Energy Management Systems (BEMS) Building Automation System (BAS)	Chen and Ho (2021), Autodesk (2023), Bozorgi et al. (2019), Perrier et al. (2020), Hosseini (2018), Tobias (2017), Bughin, Chui and Pollak (2013), Deloitte (2013), Glodon (2023)

Table 2.1 (Continued)

	Additive Manufacturing System	
	E-Payment System	
	Big Data Analytics	
	E-procurement System	
	RFID	
	GPS	
Content	Text	Mullan (2021)
	Audio	
	Images and Photos	
	Videos	
	Location	

(a) Device

A digital device such as a PC, tablet or smartphone acts as a physical interface between the business and its customers. Other devices adopted in the construction sector include communication devices, wearable devices, monitoring devices, and construction devices. Communications devices are any hardware that sends and receive data, instructions, and information. Wearable devices are used to keep construction workers safe. It includes smart glasses, smart helmets, smart boots, and power gloves (Sawhney, Riley and Irizarry, 2020). Monitoring devices such as drones, cameras and robot dogs are used to inspect and keep tabs on the construction site's status (Jamie, 2021; Stanton, 2022). Construction devices such as laser scanners (3D printing technology), robots and unmanned machinery are used to streamline construction and address the shortage of qualified workers (Perrier et al., 2020).

(b) Network

A device needs a network to connect to the web and the rest of the digital world. Broadband internet, WiFi, sensor networks, and private networks are a few of the many types of network connectivity commonly available today (Tang et al., 2019). Network connectivity allows electronic communications. The operator will not be able to receive data from the device if its interoperability is disrupted due to a poor internet connection (GSM Association, 2014). The Internet of

Things (IoT) is a network that connects physical items and things, collects data from them in the form of images and videos, and promotes human contact. WiFi is a network that depends on radio signals as opposed to hardwired connections to connect devices, such as personal computers, in a single physical place. Today, 4G mobile broadband networks are widely accessible (Perrier et al., 2020). In comparison to 4G, 5G is planned to offer higher data transfer rates (up to 20 Gbps peak and 100 Mbps average), larger traffic capacities, and lower latency. It can handle more information and serve several functions (Holslin and Gates, 2023).

(c) Application

Application refers to any type of system, program, or software that is installed on a device and operates on that device to provide the user with access to the network and its content. Examples are company-specific software or hardware; the infrastructure behind providing personalized care to an individual or group of people including social media platforms or a website on the internet. Application software is a computer program meant to perform a set of coordinated functions, tasks, or activities for the user's benefit. BIM360 and the common data environment are combined as a digital platform for a digital ecosystem (Perrier et al., 2020). AutoCAD executes customized routines for creating, modifying, and processing DWG files. Using Naviswork, designers may open and merge 3D models, move freely in and out of the scene, and analyze the model in real-time using a variety of annotation, redlining, perspective, and measurement tools (Chen and Ho, 2021). Revit is a commercial BIM program that gives designers access to highly detailed 3D models for creation, modification, and evaluation (Autodesk, 2023). Planning and scheduling tools like Primavera and Microsoft Project are also commonly employed in the modern construction sector. Microsoft Excel and Microsoft Word are used for drafting documents like bills of quantities, tender documents, certificates of payment, and contracts. In addition, Cubicost are commonly used by quantity surveyors for cost estimating purposes (Glodon, 2023). According to McKinsey & Company’s report, the prevalent social technologies that are commonly employed include videoconferencing, social networking, and collaborative editing (Bughin, Chui and Pollak, 2013). It is becoming common for modern projects to rely on synchronous collaboration platforms such as online meetings, teleconferencing and audio conferencing software, and instant messaging (Hosseini, 2018). High collaboration and innovative employees use digital collaboration tools like instant messaging and video conferencing at a rate 50% greater than their peers (Deloitte, 2013). The drone technology used for real-time surveillance is called an Unmanned Aerial System (UAS). Computer-based control systems like Computerized Maintenance Management System (CMMS), Building Energy Management Systems (BEMS), and Building Automation System (BAS) regulate and track building operations. In order to print three-dimensional objects, a laser scanner robotics system uses additive manufacturing technology. The adoption of blockchain-based electronic payment solutions expanded significantly (Perrier et al., 2020). On the other hand, RFID and GPS may be implanted into wearable technology and machinery to follow their whereabouts in real-time (Bozorgi et al., 2019).

(d) Content

Content refers to the actual data or information that can be sent to the user. Anything from just words to audio to still or moving pictures is included. They contain both dynamic and static content. The five main types of digital content are video, audio, images, visual stories and text. Formatted digital content is stored on digital media or analog storage. For instance, it includes broadcast, streaming, file-based information, weather forecast and GPS maps (Mullan, 2021).

2.4 Digital Ecosystem in the Construction Supply-chain

The construction supply-chain consists of a diverse group of interest parties and stakeholders working together in the delivery process. Figure 2.2 encompasses the four constituents of the digital ecosystem in the context of the construction process starting from design, procurement, manufacturing, logistics, site assembly, on-site execution, until operation and maintenance.

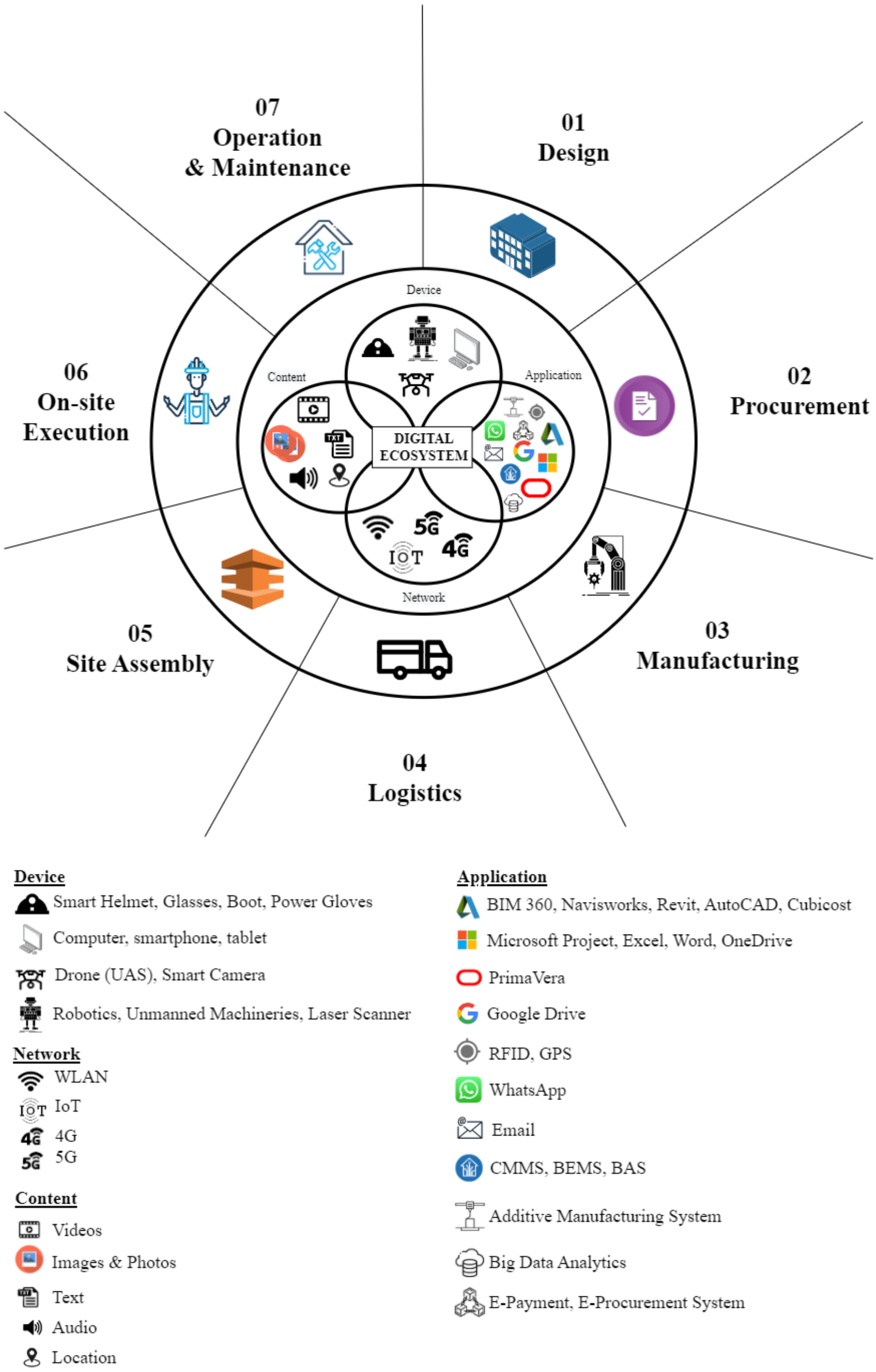

Figure 2.1: Four Constituents of Digital Ecosystem Encompassed in the Construction Process

2.4.1 Design

During the design process, the design team collects design requirement data using devices that connect to reliable Wi-Fi. The design team use application software such as AutoCAD and Revit to produce digital content in the forms of 3D models and CAD drawings (Tobias, 2017). Other application software such as BIM360 is used by architects and engineers to create a digital twin of a building in the digital ecosystem. Navisworks is used for clash detection, construction simulation or quantification of the BIM model. The social and email platforms are the common communication media among the design team. The application of Microsoft Team, Zoom or Skype enabled remote meetings. In addition, application of cloud drives such as OneDrive and Google Drive facilitated sharing of documents between the design teams (RICS, 2020). All the application cited above are made possible with the internet to send and receive content within the network.

2.4.2 Procurement

During the procurement process, the construction management team uses network-connected devices to estimate quantities, compile tender and contract documents, and develop a project planning schedule. These digital contents are created using application software such as Cubicost, Microsoft Word, Microsoft Excel, PrimaVera, and Microsoft Project. Gmail act as the formal communication tool used to inform the successfully awarded contractors. On the other hand, blockchain application can be used to make the ledger of purchases visible for those with access permissions, and to provide a way to verify the receipt of an order. Smart contracts can automate repeat orders, streamline the invoicing processes, and mitigate the risk of fraudulent transactions (Perera et al., 2021). All the applications mentioned above are enabled by the internet's ability to send and receive data within the network.

2.4.3 Manufacturing

The additive manufacturing building components can be 3D-printed straight from BIM models without the need for human intervention. This application allows the production of building components in the Industrial Building System (IBS), thereby eliminating the moulding and demoulding process and saving up to 60% on formwork and labour (Zhong et al., 2017). Application software such as Netfabb can be used to read CAD models and create 3D-printable models to streamline the additive manufacturing workflow. Solid Edge is another application software that can be used in 3D design, simulation, computer-aided manufacturing, and data management (Siemens, 2023). The aforementioned applications are made possible by the internet's ability to send and receive digital content within the network, allowing a substantial amount of customizable and modularized manufacturing processes to occur in the construction supply-chain.

2.4.4 Logistics

At the operational level of the logistics process, analytic tools with network connectivity can organise the material flows (acquisition, storage, and transportation) to the automated warehouse to transform the conventional logistics. Through the application of 4D BIM simulation, logistical transportation waste on construction sites can be reduced. Advanced technological applications such as Internet of Things (IoT), artificial intelligence (AI), and Big Data enable smart logistics to just-in-time delivery, particularly when factories are located far from construction sites (Ding et al., 2013). The application software such as NetSuite can be utilised to organise the efficient transportation, receiving, and storage of incoming inventory. The digital content generated, such as the components' geolocation data, enables rapid procurement and prevents unscheduled downtime in network environment.

2.4.5 Site Assembly

During the site assembly phase, the manufacturers ship all the LEGO-like elements to the site and assemble there. In a complex assembly, the site workers wear smart devices like Wi-Fi connected-smart glasses, helmet and power gloves powered by AR to assemble the prefabricated building components (Deloitte, 2022). Robotics can be used to automate assembly tasks such as fastening, joining, sorting, identifying, feeding, tool changing, inspecting, tracing, and dispensing glue, sealant, and grease. Site personnel and robots work together to reduce unnecessary wastage and increase total output (Remtec Automation, 2022). Real-time content updates allow the project team to track the progress of the task more accurately. The workers' data captured by the smart devices will reflect the workers' health condition and their efficiencies level (Perera et al., 2021). The application software such as Assemble can be used to transform a BIM model into a construction-ready model that is easily decomposable into applicable scopes of assembly work. BIM360 enable updated digital content into the project information system through internet within the supply-chain network (Autodesk, 2023).

2.4.6 On-site Execution

The project team is able to utilize sensors and mobile devices with reliable network connection to gather real-time digital content during the on-site execution process to improve communication and coordination on the construction site (Tang et al., 2019). The personal wearable devices such as smart helmet, glasses, boot, and power gloves with implanted RFID provide warnings about the temperature, overheating, and UV radiation as well as the equipment's movement to the site operatives. Drones can be used to inspect the construction process (Jamie, 2021). Drone footage and IoT sensor monitoring using key performance indicators offer automated, real-time status updates and daily decision-making cycles (Blanco et al., 2018). The content gathered by these sensors was relayed to the operator of the machine via displays in the helmet or even the worker's smartphone, allowing for more precise and productive operation (Perera et al., 2021). The application software like Procore can be used to facilitate communication between office and site-based team (Mitchell, 2023). In addition, the project team use application software such as BIM360 Build to enhance quality, eliminate rework, and monitor project progress.

2.4.7 Operation and Maintenance

The high-tech devices of sensors and cutting-edge smart gadgets with stable network connectivity will collect digital content, such as actual energy consumption data of the building in the operation phase of the building. The application such as the Building Automation System (BAS), Building Energy Management Systems (BEMS), Computerized Maintenance Management System (CMMS), and security systems can be used by the facility managers to keep tabs on consumption, conduct analysis on performance, run simulations on energy consumption, make predictions and visualise data in 3D model. All the applications mentioned above are enabled by the internet's ability to send and receive digital content within the network to enhance effectiveness of maintenance planning (RICS, 2020).

2.5 Proposed Conceptual Framework

Four key constituents of the digital ecosystem that are heavily relied on by the Malaysian construction supply-chain were identified through the literature review. Figure 2.2 revealed the conceptual framework of the digital ecosystem landscape in the Malaysian construction supply-chain. The organization's digital infrastructure, talent and knowledge of the construction community and nature of the Malaysian construction industry are manipulated to infer the current digital ecosystem landscape in the Malaysian construction supply-chain.

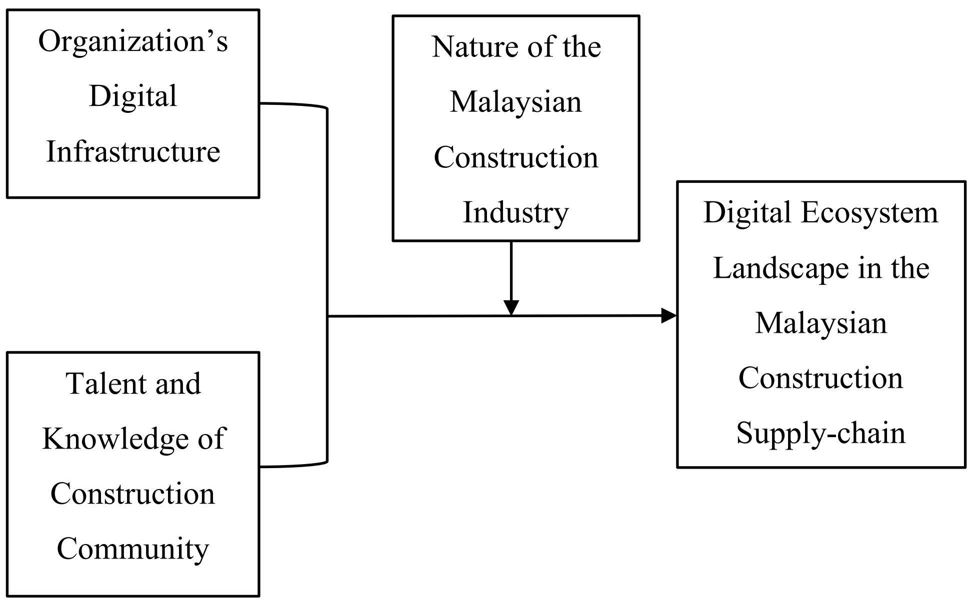

Figure 2.2: Conceptual Framework of Digital Ecosystem Landscape in the Malaysian Construction Supply-chain

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter presents the research methodology executed and the research approach in Section 3.2. It continues to outline the formulation of both close-ended and open-ended questions in the questionnaire design, as well as the targeted samples. Next, Section 3.3 evaluates the screening of the questionnaire through the pilot test. In addition, Section 3.4 discusses the approaches for tabulating, organizing, and analyzing the obtained data through Cronbach's alpha reliability test, Friedman test, Chi-square test, and Kruskal-Wallis H test. Section 3.5 addresses the issues of research ethics.

3.2 Research Approach

This research adopted a mixed method approach and field data were collected by questionnaire survey. The triangulation of qualitative and quantitative data yields deeper insights beyond the information solely provided by either quantitative or qualitative data (Creswell and Creswell, 2018). The questionnaire consists of both close-ended questions and open-ended questions. Quantitative analysis was adopted for the close-ended questions while qualitative analysis was used to analyze the open-ended questions. Invitation to the questionnaire survey was sent via LinkedIn, email, personal contacts and other social media platforms. The questionnaire was available in the Google Forms from December 2022 to April 2023. Additional detail regarding the design and structure of the questionnaire are explained in the next section.

3.2.1 Questionnaire Design

The questionnaire structure was separated into closed-ended questions and open-ended questions. Closed-ended questions comprise Section A and Section B which sought to explore the availability of digital infrastructure in the construction organizations and the digital talents and knowledge among the construction community respectively. Open-ended questions are established in Section C to discover the challenges and issues encountered by the construction community in digitalization and seek out possible strategies to improve the digital ecosystem. Section D stipulates the demographic data. The four key constituents (device, network, application and content) illustrated in Figure 2.1 was used to develop the questionnaire as depicted in Figure 3.1.

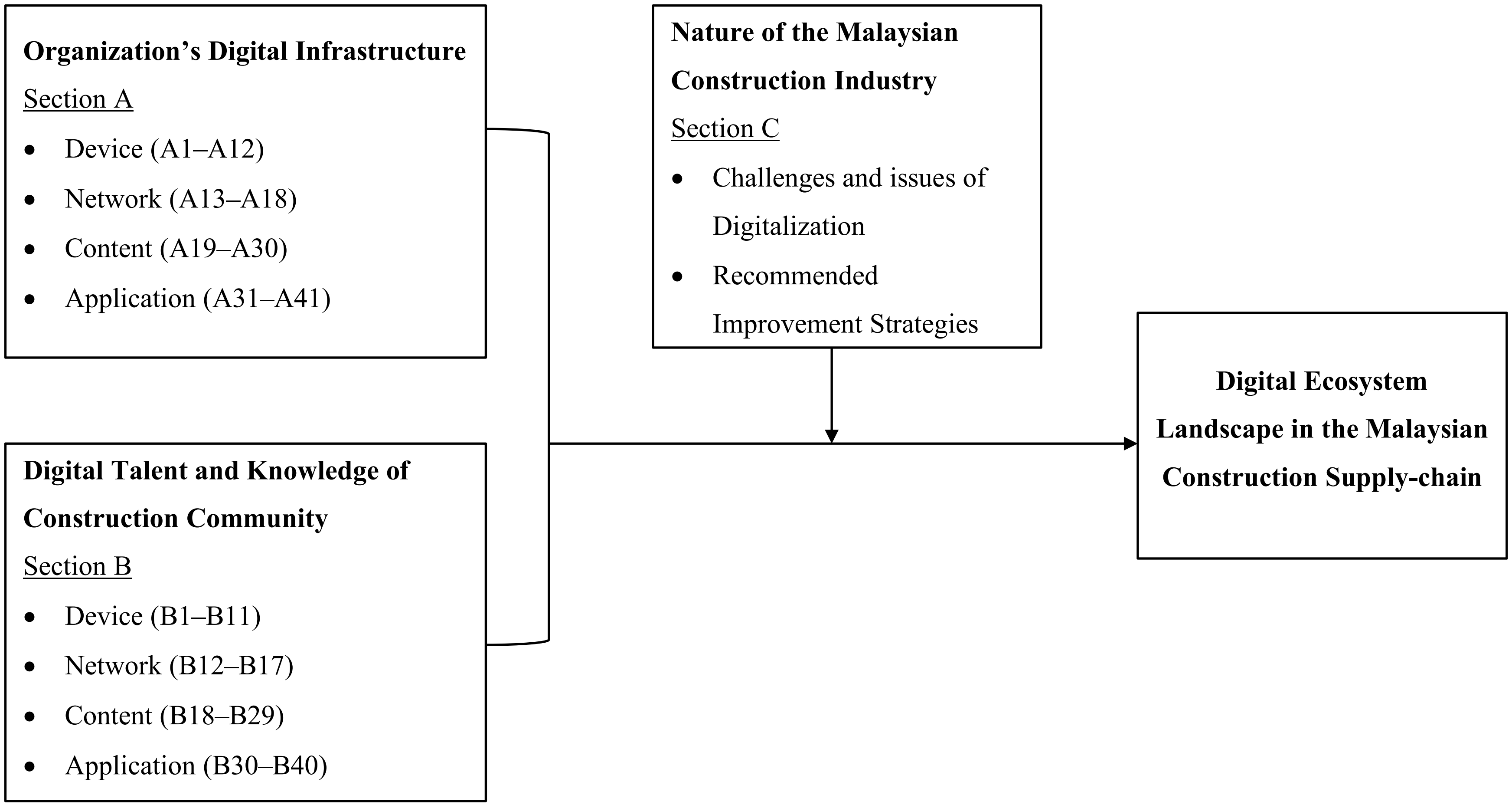

Figure 3.1: Questionnaire Design

(a) Closed-ended Questions

Section A of the questionnaire consists of 41 statements related to the availability of the digital infrastructure in the construction organization. Section B consists of 40 self-assessed statements related to the digital talent and knowledge. All the statements are related to the four key constituents of digital ecosystem synthesized from the literature reviewed. The respondents are expected to make a choice on the five point Likert scale. In Section A, the respondents are expected to make a choice of 'strongly disagree', 'disagree', 'neutral', 'agree', and 'strongly agree'; wherease they need to rate their competencies level from 'fundamental awareness', 'novice', 'intermediate', 'advanced', to 'expert' in Section B. The following Table 3.1 shows the breakdown of questionnaire's statements in Section A and B corresponding to each of the four key constituents of digital ecosystem. The detail of Section A and B are included as Appendix A at the end of this research.

Table 3.1: Statements Summary for Section A and B

Constituents of Digital Ecosystem	No. of Statement		References
	Section A	Section B	
Device	12	11	Alderton, 2021 CIOB, 2019, GoCodes, 2022, WaveScan, 2022
Network	6	6	Farr, 2021, Ibrahim, Esa and Rahman, 2021
Application	11	11	Budiac, 2019, RICS, 2020
Content	12	12	Mahat et al., 2022

(b) Open-ended Questions

Section C was designed as open-ended questions for the respondent to share their ideas and experience on an optional basis. This section comprised three questions as shown in Table 3.2.

Table 3.2: Formulation of Questions in Section C

Ref. code	Questions
C1	What do you think the challenges of the digitalization in the construction industry are?
C2	Have you experienced any issues in digitalization? Please share your experiences / examples.
C3	What would you suggest to improve the digital ecosystem in the construction industry?

(c) Demographic Information

Section D collected the respondent's biodata as illustrated in Table 3.3. The respondent's attributes are analyzed to prove the five hypotheses formulated in Section 3.4.

Table 3.3: Demographic data collected in Section D

Ref. code	Respondent’s Attributes
D1	Company’s business activities
D2	Profession
D3	Years of Working experience

3.2.2 Sampling Design

The rationale for the sampling strategy, sample size, and targeted respondents are detailed in the following sections.

3.2.3 Sampling Strategy

This research adopted random sampling to collect data from the construction community in the Malaysian construction supply-chain. The only qualification to participate in the survey is the respondents must be part of the construction supply-chain. Since the sample is sufficiently large and each construction community has an equal chance of being selected, it can be used to imply representativeness (Kumar, 2011).

3.2.4 Sample Size

This research adopted Central Limit Theorem (CLT) to determine the average sample size needed. The CLT highlights that with a sample size of 30 or more, the closer its distribution will resemble the normal distribution (Saunders, Lewis and Thornhill, 2016). Therefore, CLT was applied to this research for a comparison of subgrouping, such as the digital infrastructure available in the organization and digital knowledge and talent among the construction community. It is estimated that an average of 150 samples are required with consideration of five categories of respondents' attributes.

3.2.5 Targeted Respondents

The targeted respondents for this research are construction practitioners who works in Malaysia. They are from a wide array of business organisations, professions, age and educational backgrounds.

3.3 Pilot Test

The questionnaire has undergone a pilot test before officially being distributed to the construction community. The minimum number of respondents required for a pilot test is ten (Fink, 2013). A total of eight responses were received from the quantity surveying students, reflecting that the overall questionnaire is easy to understand. Since no questions were found vague and no further suggestions are given for improvement, the questionnaire was fine to be released.

3.4 Data Analysis

Quantitative analysis was conducted by using the Statistical Package for Social Sciences (SPSS) to analyze the collected data with Cronbach's alpha reliability test, Friedman test, Chi-square test and Kruskal-Wallis H test. On the other hand, content analysis was adopted to classify the qualitative data into codes, summarise the codes into categories, and then use a frequency table to determine how often certain challenges, issues, and strategies appear (Fellow and Liu, 2015). The biodata of the respondents are used to test the following hypothesis:

Table 3.4: Research Hypothesis

Item	Hypothesis (H) and Null Hypothesis (H_0)
H1a	The availability of digital infrastructure is different with respect to the different business activities of the organization in the construction supply-chain.
$H_0$1a	The availability of digital infrastructure is indifferent with respect to the different business activities of the organization in the construction supply-chain.
H1b	The availability of digital infrastructure is different with respect to the different professional backgrounds.
$H_0$1b	The availability of digital infrastructure is indifferent with respect to the different professional backgrounds.
H2a	The levels of digital talent and knowledge of different construction actors are different with respect to their organization's business activities.
$H_0$2a	The levels of digital talent and knowledge of different construction actors are indifferent with respect to their organization's business activities.
H2b	The levels of digital talent and knowledge of different construction actors are different with respect to their professional backgrounds.
$H_0$2b	The levels of digital talent and knowledge of different construction actors are indifferent with respect to their professional backgrounds.
H2c	The levels of digital talent and knowledge of different construction actors are different with respect to their years of experience in the industry.
$H_0$2c	The levels of digital talent and knowledge of different construction actors are indifferent with respect to their years of experience in the industry.

3.4.1 Cronbach's Alpha Reliability Test

The internal consistency of all the statements in Sections A and B were evaluated using Cronbach's alpha reliability test. If the value of alpha is equal to or greater than 0.7, it indicates that the survey results are reliable (Cortina, 1993).

3.4.2 Descriptive Statistics

Descriptive statistics such as frequency, percentages, mean rank and mode were applied to provide an overview of the results (Sekaran and Bougie, 2016). Frequency distribution was used to express the respondents' demographic information. Also, the results of open-ended questions about the nature of the Malaysian construction industry were presented graphically.

3.4.3 Inferential Statistics

(a) Friedman Test

Friedman test was adopted to test for the differences between the four constituents of the digital ecosystem (device, network, application and content) in the relevant sections of Chapter 4 as shown in Table 3.5 (Cohen, Manion and Morrison, 2018).

Table 3.5: Purposes of Friedman Test

Purposes of Friedman Test	Sections
To test the significant difference between the mean ranks of the digital infrastructure available in the organization (A1-A41).	4.4
To test the significant difference between the mean ranks of the digital knowledge and talent among the construction community (B1-B40).	4.5

(b) Chi-Square Test

This goodness-of-fit was used to show the randomness of the results obtained by comparing the observed and expected frequencies in the relevant sections of Chapter 4 as shown in Table 3.6. In order to derive valid findings, the asymptotic significance of less than 0.05 is considered the result is significant.

Table 3.6: Purposes of Chi-square Test

Purposes of Chi-square Test	Sections
To compare the observed and expected frequencies in the self-evaluated digitalization status in organization level and industrial level.	4.6.1

(c) Kruskal-Wallis H Test

Kruskal-Wallis H test is used to test the five hypotheses listed in Table 3.4. This test determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable as indicated in Table 3.7 (Kruskal and Wallis, 1952).

Table 3.7: Hypothesis Testing

Hypothesis	Independent Variable	Dependent Variable
1a	Digital infrastructure available in the organization (A1-A41)	Company's business activities (D1)
1b	Digital infrastructure available in the organization (A1-A41)	Respondents' Profession (D2)
2a	Digital talent and knowledge (B1-B40)	Company's business activities (D1)
2b	Digital talent and knowledge (B1-B40)	Respondents' Profession (D2)
2c	Digital talent and knowledge (B1-B40)	Years of working experience (D3)

3.5 Research Ethics

Participation in the questionnaire survey is entirely voluntary, and respondents are free to withdraw at any time. The respondents are assured that their information will be kept strictly private and confidential, and will not be disclosed without their consent. The information, which may contain personal data, will be used solely for this research. The respondents are advised to review the consent of participation and UTAR privacy notice before submitting the questionnaire survey.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The online version of the questionnaire elucidated in Chapter 3 was posted in Google Forms from December 2022 to April 2023, a total of 250 invitations to participate in the questionnaire survey were sent through LinkedIn, e-mail and personal contacts. 200 valid responses were received as of 12th April 2023. It is equivalent to 80%. The details of the respondents' backgrounds are featured in Section 4.2. The coefficient of reliability indicates high internal consistency of the questionnaire constructs and the details of reliability test results are reported in Section 4.3. Section 4.4 presents the digital infrastructure available in the construction organization and Section 4.5 analyses the digital knowledge and talent among the construction community. Section 4.6 summarises the responses to open-ended questions in the questionnaire survey which provide more insights into the current digital ecosystem in the Malaysian construction supply-chain. The last section discussed the key findings of the study in the context of published literature.

4.2 Respondents' Background

Table 4.1 summarised the detailed profiling information of the 200 respondents who participated in the questionnaire survey. Majority of the respondents (39.5%) are working in the consultant firms, and 29% of the respondents are quantity surveyors by profession. Almost three quarters of the respondents (71.5%) with working experience of up to five years while others are more than six years which includes six of them with more than 20 years of experience in the construction industry.

Table 4.1: Demographic Information of the Respondents (N = 200)

Demographic Characteristics	**Frequency *(n)***	**Percentage (%)**
Company's Business Activities		
Property Development	35	17.5

Table 4.1 (Continued)

Consultancy	79	39.5
Contracting Business	50	25.0
Building Material or Equipment Merchants	33	16.5
Others	3	1.5
Profession		
Architect	37	18.5
Civil & Structural Engineer	44	22.0
M & E Engineer	40	20.0
Quantity Surveyor	58	29.0
Builder	11	5.5
Other	10	5.0
Working Experience		
Less than 2 years	81	40.5
2 – 5 years	62	31.0
6 – 10 years	36	18.0
11 – 20 years	15	7.5
More than 20 years	6	3.0

4.3 Reliability Analysis

Table 4.2 lists the reliability coefficient (Cronbach's Alpha value) of the digital infrastructure available in the construction organization (Section A in the Questionnaire), digital knowledge and talent among the construction community (Section B in the Questionnaire) and their respective sub-components together with their number of items in the questionnaire. All the reliability coefficients (Cronbach's Alpha value) are higher than 0.75 which indicates internal consistency of the related statements in the relevant sections of the questionnaire constructs.

Table 4.2: Realibility Coefficient (Cronbach's Alpha) of Internal Consistency Test of Questionnaire Constructs

Section of Questionnaire	Number of Items	Cronbach's Alpha
Section A: Digital Infrastructure	**41**	**0.947**
Device (A1-A12)	12	0.879
Network (A13-18)	6	0.786
Application (A19-A29)	11	0.873
Content (A30-A41)	12	0.947
Section B: Digital Knowledge and Talent	**40**	**0.950**
Device (B1-B11)	11	0.861
Network (B12-B17)	6	0.761
Application (B18-B28)	11	0.860
Content (B29-B40)	12	0.975

4.4 Digital Infrastructure Available in the Construction Organizations

Among the four constituents of the digital ecosystem, 'Application' is mostly available in the organization. It follows by 'Content' and 'Network'. The 'Device' is the least available. The results of the Friedman test indicate there is a statistically significant difference between the mean ranks of the organization's digital infrastructure, χ^2 (3) = 134.31, ρ = 0.000 (Table 4.3).

Table 4.3: Digital Infrastructure Available in the Construction Organization

Digital Infrastructure	Mean Rank	Chi-Square	Asymp. Sig.
Application (A19-A29)	2.92	134.31	0.000
Content (A30-A41)	2.83		
Network (A13-A18)	2.63		
Device (A1-A12)	1.63		

Table 4.4 extracts the five mostly available and three rarely available digital infrastructures in the organization. The details results of all 41 items of the survey are included in Appendix B. A close examination of the results reveals that email, social chatting platforms, virtual meeting platforms, cloud drives and

4G mobility are the most applications available in the construction organization. Whereas smart wearables, smartphones and tablets are rarely provided by the organization. All these results are statistically significant with $\chi^2 = 1590.72$, $\rho < 0.05$ as shown in the following Table 4.4.

Table 4.4: Mostly Available and Rarely Available Digital Infrastructure in the Construction Organization (Extracts of Appendix B)

Ref Code	**Statements**	**Mean Rank**	**Chi-Square**	**Asymp. Sig.**
Mostly Available Digital Infrastructure			1590.72	0.000
A27	We communicate through email. (email)	29.81		
A26	We communicate through WhatsApp, WeChat or any other communication software. (Social chatting platforms)	29.42		
A25	We conduct virtual meetings via Microsoft Team, Google Hangouts, Zoom, Skype, or etc. (Virtual meeting platforms)	28.76		
A24	We use Google drive, OneDrive, or etc. to share and store project information. (Cloud drives)	26.65		
A15	We have access to 4G network. (4G mobility)	26.12		
Rarely Available Digital Infrastructure				
A12	We provide smart wearables (Eg: smart helmet or AR/VR smart glasses) to our workers. (Smart wearables)	12.23		
A4	My organization provides smartphone to employees. (Smartphones)	12.12		

Table 4.4 (Continued)

A1	My organization provides tablet to employees. (Tablets)	10.54

4.4.1 Contracting Business Use More Drone while Building Material or Equipment Merchants Provide Smartphones to Their Employees

Table 4.5 displays significant differences obtained from the hypothesis testing of null hypothesis (1a) in Table 3.7, "The distribution of availability of digital infrastructure is the same across categories of business activities". This hypothesis was tested using the Kruskal-Wallis H test, as described in Section 3.4.3. The rejected null hypothesis reveals that building material or equipment merchants *provide smartphone to employees* (Mean Rank = 119.32) more often than property development, consultancy and contracting business. Meanwhile, contracting business *use drone for site inspections* (Mean Rank = 119.06) more significant than others.

Table 4.5: Significant Result of Hypothesis Testing in Digital Infrastructure Available in the Organization According to Company's Business Activities

No	Rejected Null Hypothesis	Mean Rank				Sig.
		Property Development	Consultancy	Contracting Business	Building Material or Equipment Merchants	
A4	My organization provides smartphone to employees.	110.07	85.80	98.70	119.32	0.015
A6	We use drone for site inspections.	110.37	86.61	119.06	86.20	0.003

4.4.2 M&E Engineers are Provided with More Digital Infrastructure than Other Professionals

Table 4.6 displays significant differences obtained from the hypothesis testing of null hypothesis (1b) in Table 3.7, “The distribution of availability of digital infrastructure is the same across categories of profession”. This hypothesis was tested using the Kruskal-Wallis H test, as described in Section 3.4.3. The rejected null hypothesis reveals that M&E engineers *utilize AutoCAD to create 2D and 3D project drawings* (Mean Rank = 106.85) and *facilitation tools for building maintenance works (Eg: CMMS, BEMS or BAS)* (Mean Rank = 110.03) more often than other professionals. However, C&S engineers *use Revit to model building information in 3D* (Mean Rank = 99.19) more frequently than other professionals.

Table 4.6: Significant Result of Hypothesis Testing in Digital Infrastructure Available in the Organization Between Profession

No	Rejected Null Hypothesis	Mean Rank				Sig.
		Architect	C&S Engineer	M&E Engineer	Quantity Surveyor	
A21	We use Revit to model building information in 3D	98.89	99.19	95.14	73.81	0.029
A22	We utilize AutoCAD to create 2D and 3D project drawings	93.61	90.72	106.85	75.53	0.017
A28	We utilize facilitation tools for building maintenance works (Eg: CMMS, BEMS or BAS)	85.57	90.57	110.03	78.59	0.023

4.5 Digital Knowledge and Talent among the Construction Community

Among the four constituents of the digital ecosystem, the construction community poses the highest digital competency in ‘Network’. It follows by ‘Content’ and ‘Application’. The least competency goes to ‘Device’. The results of the Friedman test indicate there is a statistically significant difference between the mean ranks of digital knowledge and talent among the construction community, χ^2 (3) = 136.47, ρ = 0.000 (Table 4.7).

Table 4.7: Digital Knowledge and Talent among the Construction Community

Digital Knowledge and Talent	Mean Rank	Chi-Square	Asymp. Sig.
Network (B12-B17)	2.95	136.47	0.000
Content (B29-B40)	2.82		
Application (B18-B28)	2.61		
Device (B1-B11)	1.63		

Table 4.8 extracts the five construction community areas with the highest digital competence and the three areas with the lowest digital competence. The details results of all 40 items of the survey are included in Appendix C. A close examination of the results reveals that the majority of the construction community poses high digital competence in five areas including the use of social chatting platforms, email, virtual meeting platforms, laptops and cloud drives. In contrast, they are least competent in three areas including the use of wireless sensors, smart wearables and autonomous heavy equipment. All these results are statistically significant with χ^2 = 2346.80, ρ < 0.05 as shown in the following Table 4.8.

Table 4.8: High and Low Digital Competence Areas of the Construction Community (Extracts of Appendix C)

Ref Code	Statements	Mean Rank	Chi-Square	Asymp. Sig.
High Digital Competence			2346.80	0.000
B25	I can communicate with my team through WhatsApp, WeChat, or any other communication software. (Social chatting platforms)	29.16		
B26	I can communicate with my team through email. (email)	28.92		
B24	I can conduct virtual meetings with my team via Microsoft Team, Google Hangouts, Zoom, Skype, or etc. (Virtual meeting platforms)	28.53		
B2	I use laptop to execute my work. (laptops)	27.65		
B23	I can use Google drive, OneDrive, or etc. to share and store project information. (Cloud drives)	27.38		
Low Digital Competence				
B10	I use wireless sensor for building inspections. (Wireless sensors)	11.86		
B11	I wear smart wearables (eg: smart helmet or AR/VR smart glasses) while working on-site. (Smart wearables)	10.28		

Table 4.8 (Continued)

B7	I can remotely control the heavy equipment implanted with multiple sensors on site. (Autonomous heavy equipment)	10.27

4.5.1 Consultant is the Most Digital Competent in AutoCAD

Table 4.9 displays significant differences obtained from the hypothesis testing of null hypothesis (2a) in Table 3.7, "The distribution of the levels of digital talent and knowledge of construction actor is the same across categories of business activities. This hypothesis was tested using the Kruskal-Wallis H test, as described in Section 3.4.3. The rejected null hypothesis reveals that consultants are more proficient than others at *using PC to execute the work* (Mean Rank = 109.74) and *utilizing AutoCAD to create 2D and 3D project drawings* (Mean Rank = 110.55). Also, contracting business are more capable of *communicating with the team through email* (Mean Rank = 107.62) than others.

Table 4.9: Significant Result of Hypothesis Testing in Digital Talent and Knowledge According to Company's Business Acitvities

No	Rejected Null Hypothesis	Mean Rank				Sig.
		Property Development	Consultancy	Contracting Business	Building Material or Equipment Merchant	
B3	I use PC to execute my work.	94.77	109.74	103.13	71.52	0.006
B21	I can utilize AutoCAD to create 2D and 3D project drawings.	101.46	110.55	90.10	82.23	0.044
B26	I can communicate with my team through email.	105.87	100.33	107.62	75.47	0.029

4.5.2 Engineer is the most Digital Competent while Quantity Surveyor is the most Expertise in Estimation Software

Table 4.10 displays significant differences obtained from the hypothesis testing of null hypothesis (2b) in Table 3.7, "The distribution of the levels of digital talent and knowledge of construction actor is the same across categories of profession. This hypothesis was tested using the Kruskal-Wallis H test, as described in Section 3.4.3. The rejected null hypothesis reveals that C&S engineers' competency of *remotely controlling the drone to capture images for site inspections and topographical survey* (Mean Rank = 97.07) are more advanced than other professions. In addition, M&E engineers are more proficient than others in *conducting remote site CCTV monitoring* (Mean Rank = 100.04) and *utilizing the facilitation tool for building maintenance works (Eg: CMMS, BEMS or BAS)* (Mean Rank = 97.97). Also, architects are more knowledgeable in *utilizing AutoCAD to create 2D and 3D project drawings* (Mean Rank = 99.83) as compared to others. Besides, quantity surveyors' competency to *export the estimation done in different software (Eg: Cubicost or CostX, etc.) to pdf for e-tendering usage* (Mean Rank = 106.95) are greater than others.

Table 4.10: Significant Result of Hypothesis Testing in Digital Talent and Knowledge between Profession

No	**Rejected Null Hypothesis**	**Mean Rank**				**Sig.**
		Architect	**C&S Engineer**	**M&E Engineer**	**Quantity Surveyor**	
B5	I can remotely control the drone to capture images for site inspections and topographical survey	69.42	97.07	95.28	84.98	0.031
B6	I can conduct remote site CCTV monitoring.	71.86	95.00	100.04	81.65	0.030
B21	I can utilize AutoCAD to create 2D and 3D project drawings.	99.83	95.50	90.85	69.70	0.005
B27	I can utilize the facilitation tool for building maintenance works (Eg: CMMS, BEMS or BAS).	69.75	96.68	97.97	83.19	0.042
B28	I can export the estimation done in different software (Eg: Cubicost or CostX, etc.) to pdf for e-tendering usage.	66.24	85.99	78.62	106.95	<0.001

4.5.3 Construction Community with 2 to 5 Years of Working Experience is the most Proficient in Utilizing Facial Recognition Device

Table 4.11 displays significant differences obtained from the hypothesis testing of null hypothesis (2c) in Table 3.7, "The distribution of the levels of digital talent and knowledge of construction actor is the same across categories of years of working experience. This hypothesis was tested using the Kruskal-Wallis H test, as described in Section 3.4.3. The rejected null hypothesis reveals that those with 2 to 5 years of experience are more capable than others at *analyzing the workforce data captured by the facial recognition camera device* (Mean Rank = 101.05).

Table 4.11: Significant Result of Hypothesis Testing in Digital Talent and Knowledge According to Years of Working Experience

No	Rejected Null Hypothesis	Mean Rank			Sig.
		Less than 2 years	2 to 5 Years	6 to 10 Years	
B9	I can analyze the workforce data captured by the facial recognition camera device.	89.16	101.05	72.86	0.026

4.6 Nature of the Malaysian Construction Industry

4.6.1 Self-evaluated Digitalization Status

(a) In the Organization Level

Majority (41%) of the respondents rate the digitalization status of their organization higher than those rated lower (17%) than the mode. The mode of the rating is 43%. These results are statistically significant in the Chi-square test with $\chi^2 = 125.60$, $\rho < 0.05$.

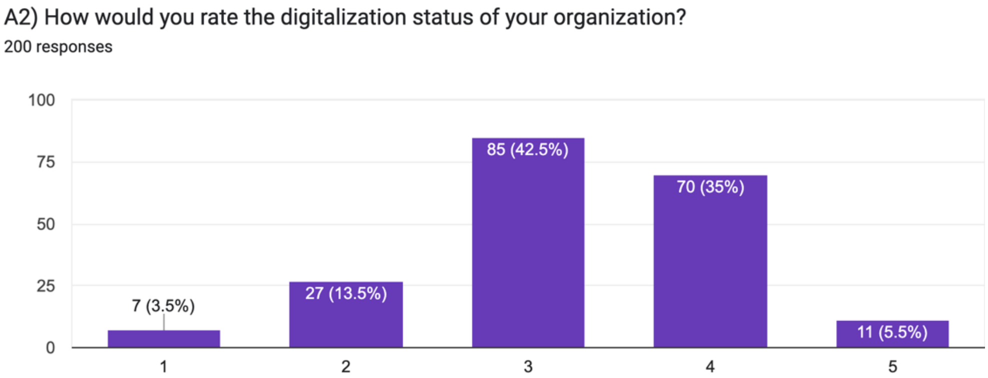

Figure 4.1: Digitalization Status of Construction Organization

(b) In the Industrial Level

Majority (35%) of the respondents rate the present digitalization status of the construction industry higher than those rate lower (20%) than the mode. The mode of the rating is 45%. These results are statistically significant in the Chi-square test with $\chi^2 = 117.05$, $\rho < 0.05$.

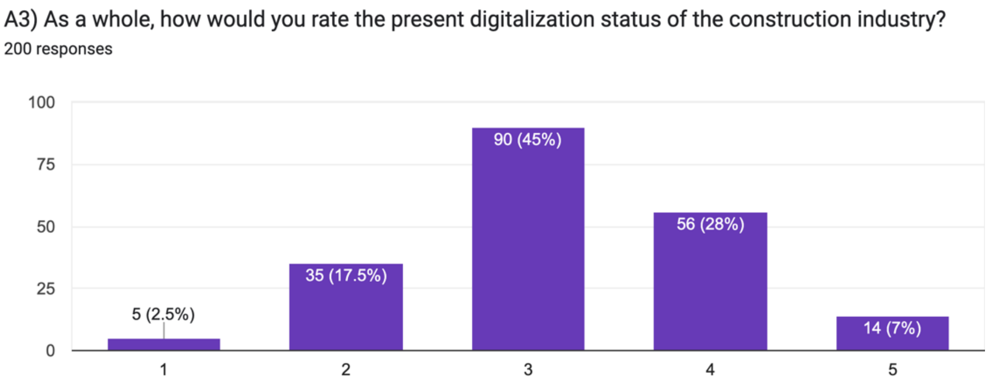

Figure 4.2: Digitalization Status of Construction Industry

4.6.2 Top Nine Challenges of Digitalization in the Construction Industry

Among the total of 187 replies to the open-ended question regarding the challenges of digitalization in the construction industry, a third (33.69%) of the respondents perceived high cost to be the major challenge, followed by conventional team structure (16.04%), traditional mindset and reluctance to change (13.37%), insufficient digital talent (11.23%), limited network connectivity (8.02%), difficult in implementation (7.49%), inadequate training (4.81%), restricted data security (3.21%), and insufficient digital infrastructure (2.14%) (Figure 4.3).

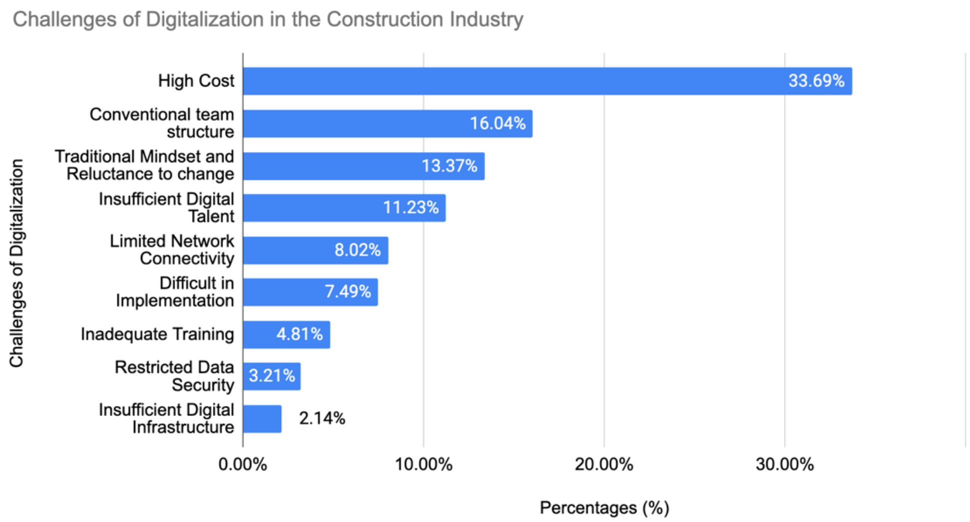

Figure 4.3: Top Nine Challenges of Digitalization in the Construction Industry

4.6.3 Top Seven Issues Encountered in Digitalization

Among the total of 95 replies to the open-ended question regarding the issues encountered in digitalization, one-fifth (21.05%) of the respondents revealed that the high network latency and lacking of digital knowledge and skills are the issues they mostly experience. It was then followed by inadequate digital infrastructure (16.84%), intricate software and technology same as immature common data environment (11.58%), expensive software subscription fees (9.47%), and lastly the fixed cultural mindset (8.42%) (Figure 4.4).

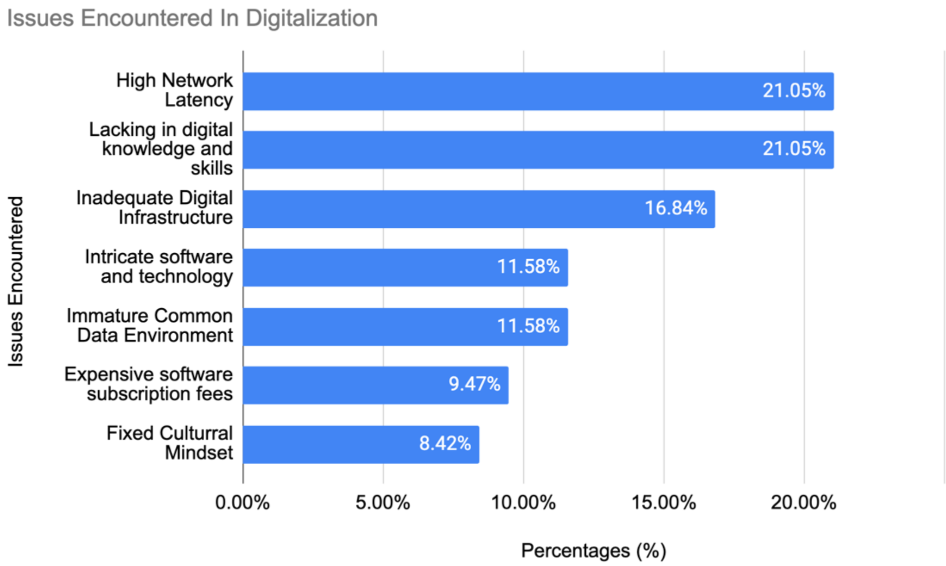

Figure 4.4: Top Seven Issues Encountered By Construction Community in Digitalization

4.6.4 Top Seven Recommended Strategies to Improve Digital Ecosystem

There is a total of 150 recommendations received on the open-ended question regarding the strategies to improve the digital ecosystem in the Malaysian construction supply-chain. Figure 4.5 revealed that more than a quarter (26%) of the respondents recommend conducting workshops and training programs, follows by upgrading digital infrastructure and investing in relevant software (21.33%), initiating government financial assistance or incentives (19.33%), encouraging integrated collaboration (10.67%), set out digital government policies (9.33%), widen network coverage (7.33%), and lastly to incorporate digital technology into educational course structure (6%).

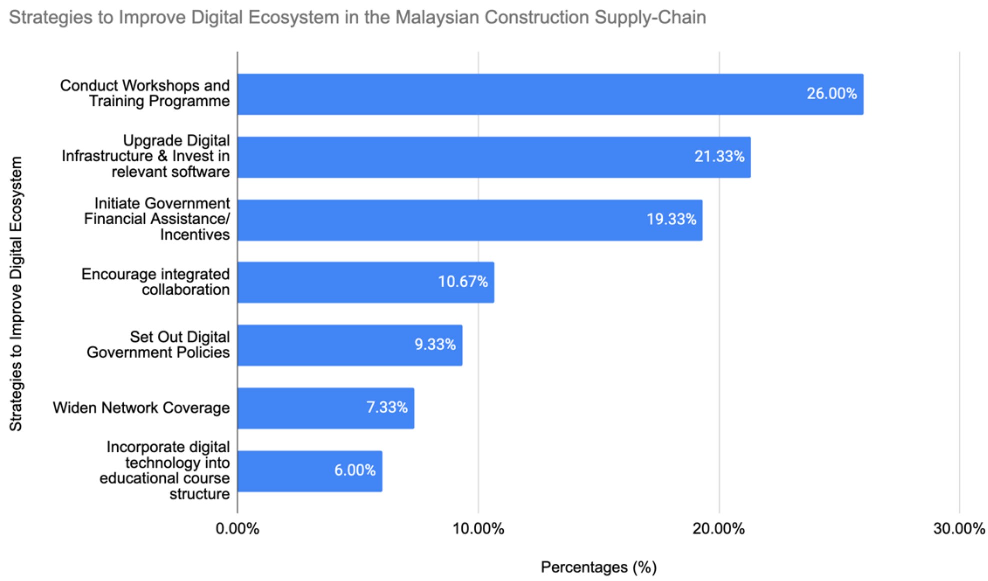

Figure 4.5: Top Seven Strategies to Improve Digital Ecosystem in the Malaysian Construction Supply-chain

4.7 Discussion

In a nutshell, seven generalizable findings can be derived from the survey results. Two findings each from the digital infrastructure currently available in the construction organization and digital talent and knowledge poses by the construction community. Another three are from the saturated findings summarised in the open-ended questions.

4.7.1 Digital Infrastructure Currently Available in the Organization

(a) Social Collaboration Applications Outstrip Smart Technologies

The finding from Section 4.4 revealed that most of the organizations are utilizing the social collaboration applications such as email, social chatting platforms, virtual meeting platforms, cloud storage and 4G mobile network throughout the construction cycle. This indicates that the employees are digitally collaborated, which is in line with the report of McKinsey & Company included in Section 2.3.5, whereby videoconferencing, social networking, and collaborative editing are the prevailing technologies that are frequently utilized (Bughin, Chui and Pollak, 2013). The organization often conduct virtual meetings via Microsoft Team, Google Hangouts, Zoom, Skype, or other online platform. According to Hosseini (2018) mentioned in Section 2.3.5, the use of synchronous collaboration platforms like online meetings, teleconferencing and audio conferencing tools, and instant messaging to complete modern projects is becoming the norm. They also use cloud storage like Google Drive and OneDrive to share and store project information. It is in line with RICS (2020)'s report reviewed in Section 2.4.1 that the cloud drives could facilitate sharing of documents between the design teams. Also, most of the organizations have access to 4G network. It supports the literature reviewed in Section 2.3.3 that the 4G mobile networks that are enabled with broadband technology have become extensively accessible (Perrier et al., 2020). On the other hand, it's noticeable that the site workers are rarely equipped with smart wearables. The result is contrasted with the literature review, in which Deloitte (2022) mentioned that the site workers are wearing AR smart devices in complicated assembly (Section 2.4.5). Also, most of the organizations do not provide their employees with smartphones or tablets, except building material or equipment merchants.

(b) Engineers Working in Contracting Business have More Accessibility to the Digital Infrastructure

The finding from Sections 4.4.1 and 4.4.2 indicated that M&E engineer get used to AutoCAD to create 2D and 3D project drawings. Besides, they are often utilizing facilitation tools such as CMMS, BEMS or BAS for building maintenance works. It concurs with the literature reviewed in Section 2.4.7 stating that real energy consumption data is gathered throughout the building's operation phase with the use of maintenance applications (RICS, 2020). Besides, C&S engineers agreed that they use revit to model building information in 3D. It affirms Tobias (2017)'s report reviewed in Section 2.4.1 which stated engineering businesses frequently employ AutoCAD and Revit in designing building.

Besides, contracting business are consistently the best at utilizing drone for site inspections. Jamie (2021) observed that the companies in the construction industry are already making use of drones to speed up the inspection process, decrease costs, and boost productivity and safety on building sites (Section 2.2).

4.7.2 Digital Talent and Knowledge Poses by Construction Community

(a) Digital Competency in Social Collaboration Application Surpass Smart Technical Skills

The construction community normally use the laptop to execute their work and they are highly competent in utilizing the social collaboration application (email, WhatsApp, WeChat, Microsoft Team, Google Hangouts, Zoom, Skype, Google Drive, OneDrive, etc.) provided by their organization according to the survey result analyzed in Section 4.5. Deloitte (2013) affirmed that the high-collaboration and innovative employees use digital collaboration tools like instant messaging and video conferencing at a rate 50% greater than their peers as mentioned in Section 2.3.5. However, it was found that the construction community is less proficient in remotely controlling the heavy equipment implanted with multiple sensors on site. Moreover, they seldom wear smart wearables such as smart helmets and VR or AR glasses while working on-site. Not only that, they also lack competence in utilizing wireless sensors for building inspections. It concurs with Rao et al. (2022)'s survey stressed in Section 2.2 that the utilization of real-time sensing technologies in building projects has not yet achieved extensive adoption.

(b) Consultant and Contractor's Engineer with Two to Five Years of Working Experience are Digitally Smarter

The finding from Sections 4.5.1 to 4.5.3 indicated that the employees in the contracting business are expertise to communicate with the project team through email while consultants use PC to execute their work. Overall, Engineers are deemed to be digitally smarter in the field of remotely controlling the drone to capture images for site inspections and topographical surveys. They can conduct remote site CCTV monitoring. Besides, they are capable of utilizing the facilitation tool for building maintenance works (Eg: CMMS, BEMS or BAS). Furthermore, consultant architect is far more competent in utilizing AutoCAD to create 2D and 3D project drawings. It concurs with the emphasis of Siddiqui, Abdekhodaee and Thaheem (2022) in Section 2.2 that expertise and familiarity with drafting software (AutoCAD, Revit, etc.) and structural design software systems that lead to technical solutions are highly valued in the construction industry. Apart from that, quantity surveyors are proficient in exporting the estimation done in different software (Eg: Cubicost or CostX, etc.) to pdf for e-tendering usage. In terms of years of working experience, it was found that those with 2 to 5 years of experience in the industry are more digitally competent. They are more proficient in analyzing the workforce data captured by the facial recognition camera device. It supports the claim made by Zulu, Saad and Gledson (2023) as reviewed in Section 2.2 that younger construction workers have higher levels of digital literacy than their older counterparts.

4.7.3 Snapshot on Digital Ecosystem in Malaysian Construction Supply-Chain

There are more respondents rate the digitalization status of their organization and construction industry higher than the mode than those who rate lower. It concurs that the Malaysian construction sector is slowly but steadily embracing digitalisation as stated in Section 2.2 (Chai, 2017). The open-ended findings from the construction practitioners have provide a snapshot on the current landscape of digital ecosystem in the Malaysian construction supply-chain as discussed in the following subsections.

(a) High Cost Remains as the Major Challenges of Digitalization

High upfront costs are the major challenges that hindered the organization from shifting towards digitalization (Figure 4.3). Equip the employees with the technology required high capital outlay. It corroborates with the literature reviewed in Section 2.2 which highlights that wearable safety device adoption was mostly hampered by cost, leaving construction organizations feeling helpless about high startup costs, salaries for skilled workers, and maintenance expenses (Ibrahim, Simpeh and Adebowale, 2023).

In addition, conventional team structure is the second challenge. Majority of the organizations managed by elder generations were mired in digitalization, indicating that they struggled to explore new opportunities while simultaneously clinging to outdated traditional working styles. This finding corroborates with Blanco et.al (2018)'s findings discussed in Section 2.2 that many older organizations use legacy systems and other information-collection methods.

Apart from that, traditional mindset and reluctance to change are the third challenge. It is further emphasized by Kane et al. (2016) that the lack of new digital leaders, mindsets, and flexible leadership styles can severely impact change and transformation indicated in Section 2.2.

(b) High Network Latency Remains as the Main Concern in Digitalization

High network latency is the foremost issue encountered in digitalization (Figure 4.4). The operator will not be able to receive data from the device if its interoperability is disrupted due to a poor internet connection as mentioned in Section 2.3.3 (GSM Association, 2014). Hence, the digital infrastructures are not been fully exploited.

Moreover, the lack of digital knowledge and skills among construction practitioners in utilizing digital infrastructure has created an ability gap. This issue concurred with the findings discussed in Section 4.7.2. It corroborates McKinsey & Company's report reviewed in Section 2.2, emphasizing that digital talent is a major concern for executives across industries, as the talent investment could doubles digitalization success. The complex problems arising from the projected worsening of the skilled labor shortage require innovative solutions (Blanco et al., 2018). It reveals that the construction industry is extremely in need of digital talents to push the industry forward.

Nonetheless, most of the organizations are providing inadequate digital infrastructure to their employees such as outdated software with frequent technical issues. This issue concurred with the findings discussed in Section 4.7.1. It differs from Blanco et al. (2018)'s findings indicated in Section 2.2 that 3D printing, drones, virtual and augmented reality, modularization, robots, digital twin technology, AI and analytics, supply chain optimization, and marketplaces are already being employed in the construction ecosystem.

(c) Workshop and Training Programme are Vital to Improve Digital Ecosystem

Conducting workshops and training programs is the most effective way to improve the digital ecosystem in the Malaysian construction supply-chain. It corroborates with the literature reviewed in Section 2.2, where Koseoglu et al. (2019) emphasized that intra-organizational digital training, like digital workshops and meetings, can help young construction employees get up to speed faster on digital tools. Olanipekun and Sutrisna (2021) distinguished the need for digital training in enhancing digital skills and acquiring the input of senior workers. It is further recognized by (Lau et al., 2021) that the Malaysian construction sector needs to address the growing knowledge gap in the specialized field of talent concerns as Construction 4.0 gains momentum.

Moreover, upgrading digital infrastructure and investing in relevant software is the second effective strategy. It is consistent with Oughton, Amaglobeli and Moszoro (2023)'s report discussed in Section 2.2 which has recently highlighted the need to invest $418 billion worldwide in digital infrastructure.

Further, initiating government financial assistance or incentives is the third effective strategy. As reviewed in Section 2.2, McKinsey & Company mentioned that the industry bodies and authorities can offer grants, bonuses, and subsidies to encourage owners and contractors to utilize digital solutions and train the next generation (Agarwal, Chandrasekaran and Sridhar, 2016).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In summary, the construction organization's digital infrastructure is outstripped by the social collaboration application more than other digital technologies. As a result, the talent and knowledge of the construction community are more competent in digital social collaboration applications than in other digital skills. The following Section 5.2 elaborate more on this conclusion. In addition, Section 5.3 highlights the implications of this research to the construction industry, the regulators and the academics respectively. However, it is acknowledged that this research is not free from flaws or shortcomings, Section 5.4 reflects the limitation of this research. Consequently, several recommendations for future research on similar topics are identified in Section 5.5.

5.2 Accomplishment on Research Aim and Objectives

In a nutshell, the accomplishment of the aim and objectives of this research can be observed with the following justifications.

Research Objective 1: To explore the essentials of digital ecosystem in the construction supply-chain in general

The four key constituents namely device, network, application and content are identified to characterize the landscape of digital ecosystem in the construction supply-chain through literature reviews, standard documents and organizational reports. To digitize the construction supply-chain, these four key constituents were encompassed into each of the construction processes starting from the design, procurement, manufacturing, logistics, site assembly, on-site execution to operation and maintenance. It forms the landscape of digital ecosystem in the construction supply-chain as depicted in Figure 2.1.

Research Objective 2: To assess the current state of digital ecosystem in the Malaysian construction supply-chain which include the infrastructure available in the construction related activities and talent and knowledge available among the construction community

The results and findings of the questionnaire survey disclosed that the digital infrastructure currently available in the construction organization are the social collaboration applications including email, WhatsApp, WeChat, Microsoft Team, Google Hangouts, Zoom, Skype, Google Drive and OneDrive. Also, 4G is available to most organizations. However, smart wearables are rarely available. Besides, the engineers are exposed to more specialized softwares such as Revit, AutoCAD, CMMS, BEMS and BAS, whereas contracting business leads the way in using drones for site inspections.

In terms of digital knowledge and talent, the findings revealed that the engineers in contracting business are digitally smarter in remotely controlling drone, conducting remote site CCTV monitoring, and utilizing the building maintenance facilitation tool (Eg: CMMS, BEMS or BAS). Architects are more proficient with AutoCAD while quantity surveyors are more competent with the estimation software (Eg: Cubicost or CostX, etc.). Younger construction workers with two to five years of experience have higher levels of digital literacy. However, the industry faces a shortage of digital talent and lack of proficiency in utilizing wireless sensors devices and smart wearables.

Research Objective 3: To infer the digital ecosystem and the underpinning issues of the Malaysian construction supply-chain

Overall, the Malaysian construction supply-chain is catching up in embracing digitalisation. Social collaboration applications are more prevalent within the organization and the construction community is more competent with them as compared to smart technologies. The underpinning issues discovered are lack of advanced digital infrastructure, digital talents shortage and high network latency. It infers that the construction organization has not yet fully prepared themselves to work in a comprehensive digital ecosystem. These issues can be addressed by upgrading the digital infrastructure and investing in relevant software. Also, construction organization should held more intra-organization digital training and support their employees in the external digital training.

Reseach Aim: To examine the digital ecosystem in the Malaysian construction supply-chain, particularly from the perspective of the different business activities and professionals of the construction community in Malaysia

In conclusion, social collaboration applications are more prevalent in the organization and the construction community is more competent with them than smart technologies. The crucial actions are required to address the issues of high cost, network latency, lack of advance digital infrastructure, and digital talent shortage to outperform in the construction supply-chain. Figure 5.1 summarised the conclusion of this research.

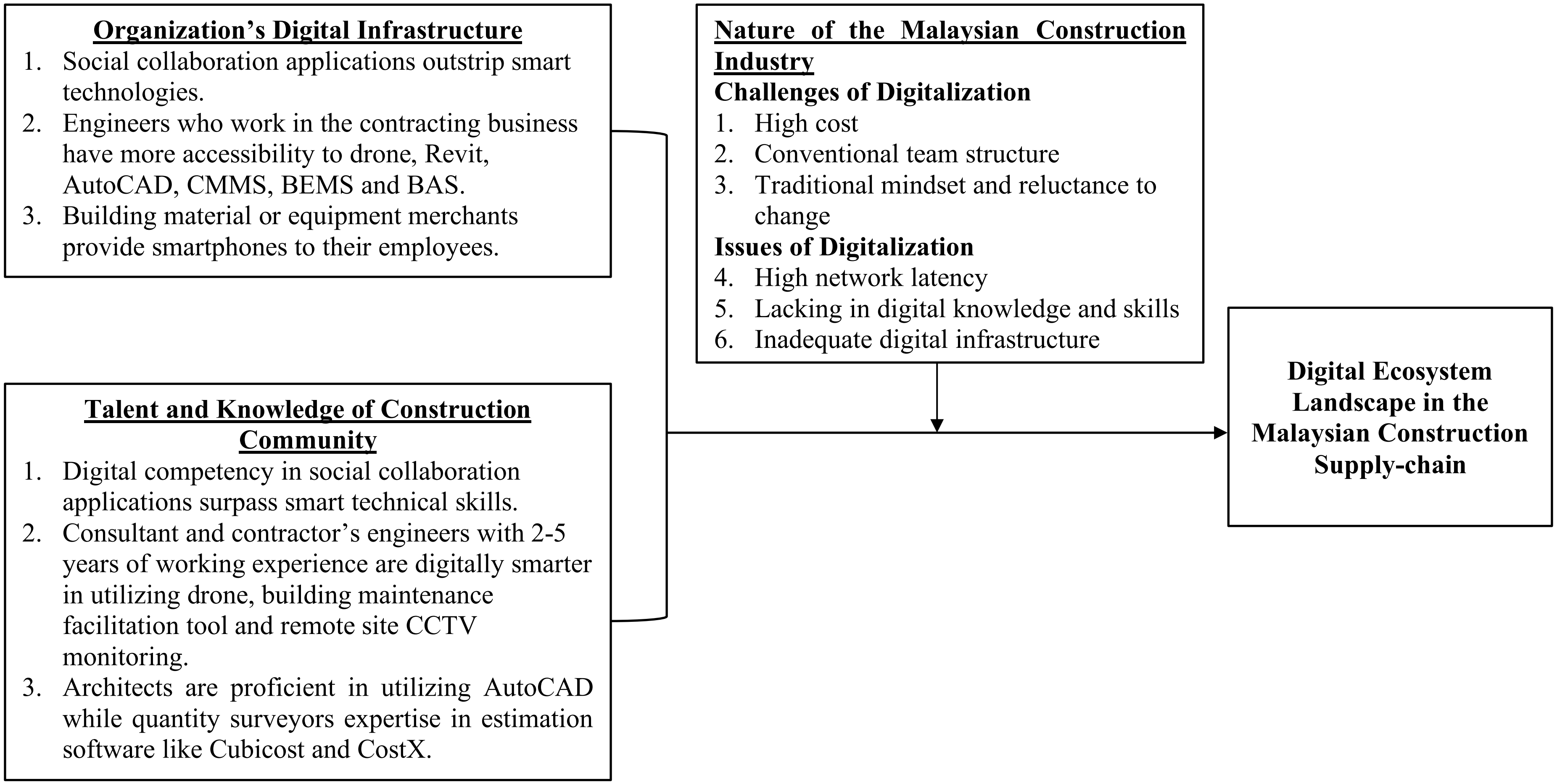

Figure 5.1: Digital Ecosystem Landscape in the Malaysian Construction Supply-chain

5.3 Research Implication

This research findings serve as a good reference and inputs to the regulators to develop further policies that will ensure the success of National Construction Policy 2030. The results enable the regulators to visualise the issues that lagged most of the organization behind from achieving the 50% digitization target of the policy and formulate strategies to alleviate them. For instance, financial assistance and incentives are needed to facilitate the construction supply-chain

Furthermore, the findings act as a wake up call to prompt the construction organization in addressing the digitalization issues that hampered the digitization pathway. For instance, conducting workshops and training programme as well as upgrading the digital infrastructure are crucial for streamlining construction supply-chain. Also, the engineer's digital competency surpass other professions. Perhaps it would push other professions such as architects, quantity surveyors and builders to upskill themselves with their respective specialized softwares too.

Apart from that, the findings provide an overview on the current digital ecosystem in the construction supply-chain. It infers that the construction supply-chain is currently facing a lack of digital talent in the smart digital technologies. The skill gap need to be filled to gear up digitalization in the construction supply chain. It can inspire researchers to develop further research on similar topic, particularly to close the talent gap.

Besides, the findings of the digital knowledge and talent of construction community can be used by the educational institutions as an input for improvement of their course curriculum. The curriculum should emphasize on the development of savvy technical skills in the application of smart wearables and sensor technology. It aids in supplying and expanding the future digital talent pool to alleviate the construction industry's talent deficit.

5.4 Research Limitations

The key unit of analysis in this research is the organization but the individual filling out the survey might not be an effective representative of the whole company. Although all the results reported in this research satisfied the requirement of the Central Limit Theorem, some of the group are having fewer than 30 respondents, such as "builder" in profession, and working experience beyond ten years of experience. They are insufficient to represent their respective group for pairwise comparisons and consequently they are excluded from the analysis. Lastly, the study’s outcome were based on the input of construction practitioners in Malaysia, and it’s noteworthy that their perspectives may vary from practitioners in other countries due to cultural and societal influences. Therefore, the applicability of these findings to other contexts or regions should be interpreted with care.

5.5 Research Recommendations

To enhance the depth and validity of future research, it is imperative to establish a clearly defined unit of analysis which may be either organization or individual. In addition, future research could overcome the sample size limitations by reconfiguring the demographic data and increasing the number of respondents in the underrepresented groups. This would allow for more robust statistical analysis and meaningful comparisons between groups. Besides, future research could explore the applicability of the findings beyond Malaysia, broadening the scope of the study to facilitate wider generalization of the results.

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APPENDICES

APPENDIX A: Questionnaire

EXAMINE DIGITAL ECOSYSTEM IN THE MALAYSIAN CONSTRUCTION SUPPLY -CHAIN

Dear Sir/Madam,

I am a final year undergraduate student currently pursuing Bachelor of Science (Honours) Quantity Surveying in Universiti Tunku Abdul Rahman (UTAR), Lee Kong Chian Faculty of Engineering and Science (LKC FES). You are cordially invited to participate in this research entitled “Examine Digital Ecosystem in the Malaysian Construction Supply-chain”. The questionnaire consists of 4 sections which may take you 10 -15 minutes to complete. Your contribution to this research is much appreciated. Thank you very much for your time to fill up this questionnaire as every single contribution would greatly mean a lot to this study. All the information that provided will be strictly keep private and confidential, without reveal to any third parties without consent. The information which includes personal information will be only used for this research study. Participant is voluntary participate in this research study, and you are allowed to withdraw your participation from this research study anytime. If you have any queries regarding the research questions, please do not hesitate to contact me at Mingchi0509@1utar.my.

Thank you for your participation.

Yours faithfully,
Low Ming Chi
Bachelor of Science (Honours) Quantity Surveying
Universiti Tunku Abdul Rahman

<u>Section A: Infrastructure to Support the Digital Ecosystem</u>

To what extend do you agree or disagree with the existence of the following digital tools in your current working environment?

Please find the indicator of each scale as follow:

1 - Strongly Disagree

2 - Disagree

3 - Neutral

4 - Agree

5 - Strongly Agree

Ref. code	Statement	1	2	3	4	5
A1	My organization provides tablet to employees.	1	2	3	4	5
A2	My organization provides laptop to employees.	1	2	3	4	5
A3	My organization provides PC to employees.	1	2	3	4	5
A4	My organization provides smartphone to employees	1	2	3	4	5
A5	My organization provides mobile phone allowance to employees.	1	2	3	4	5
A6	We use drone for site inspections.	1	2	3	4	5
A7	The project sites are installed with CCTV.	1	2	3	4	5
A8	We remotely control the heavy equipment implanted with multiple sensors on site.	1	2	3	4	5
A9	We send building materials with barcodes or QR codes on their packaging.	1	2	3	4	5

A10	We set up face recognition camera device at site access point.	1	2	3	4	5
A11	We use wireless sensor for building inspections.	1	2	3	4	5
A12	We provide smart wearables (Eg: smart helmet or AR/VR smart glasses) to our workers.	1	2	3	4	5
A13	We have a reliable and stable Wi-Fi connection.	1	2	3	4	5
A14	We have access to 5G network.	1	2	3	4	5
A15	We have access to 4G network.	1	2	3	4	5
A16	We have access to LAN using Ethernet cable.	1	2	3	4	5
A17	We pair our devices via Bluetooth connection.	1	2	3	4	5
A18	We are able to access to company's intranet remotely.	1	2	3	4	5
A19	We use Microsoft Project or Primavera in project management and scheduling.	1	2	3	4	5
A20	We use BIM360 as construction management tool.	1	2	3	4	5
A21	We use Revit to model building information in 3D.	1	2	3	4	5
A22	We utilize AutoCAD to create 2D and 3D project drawings	1	2	3	4	5
A23	We utilize Navisworks to simulate project timeline and schedule construction sequence.	1	2	3	4	5
A24	We use Google drive, OneDrive, or etc. to share and store project information.	1	2	3	4	5
A25	We conduct virtual meetings via Microsoft Team, Google Hangouts, Zoom, Skype, or etc.	1	2	3	4	5

A26	We communicate through WhatsApp, WeChat or any other communication software.	1	2	3	4	5
A27	We communicate through email.	1	2	3	4	5
A28	We utilize facilitation tools for building maintenance works (Eg: CMMS, BEMS or BAS)	1	2	3	4	5
A29	My organization subscribe to relevant software required for e-tendering.	1	2	3	4	5
A30	We provide real-time feedback through audio or video call.	1	2	3	4	5
A31	We label work done in the photos captured digitally.	1	2	3	4	5
A32	We categorize the photos captured according to their location, date and timestamp.	1	2	3	4	5
A33	We categorize the videos captured according to their location, date and timestamp.	1	2	3	4	5
A34	We analyse the photos to study productivity.	1	2	3	4	5
A35	We analyse the photos to monitor site safety.	1	2	3	4	5
A36	We analyse the photos to monitor work progress.	1	2	3	4	5
A37	We analyse the photos to monitor the quality of workdone.	1	2	3	4	5
A38	We analyse the videos to study productivity.	1	2	3	4	5
A39	We analyse the videos to monitor site safety.	1	2	3	4	5
A40	We analyse the videos to monitor work progress.	1	2	3	4	5

A41	We analyse the videos to monitor the quality of workdone.	1	2	3	4	5

<u>Section B: Digital Knowledge and Talent of Construction Practitioners</u>

How would you rate your competencies and knowledges in applying the following digital tools?

Please find the indicator of each scale as follow:

1 - Fundamental Awareness (basic knowledge)

2 - Novice (limited experience)

3 - Intermediate (practical application)

4 - Advanced (applied theory)

5 - Expert (recognized authority)

Ref. code	Statement	1	2	3	4	5
B1	I use tablet to execute my work.	1	2	3	4	5
B2	I use laptop to execute my work.	1	2	3	4	5
B3	I use PC to execute my work.	1	2	3	4	5
B4	I use smartphones in project-related works.	1	2	3	4	5
B5	I can remotely control the drone to capture images for site inspections and topographical survey	1	2	3	4	5
B6	I can conduct remote site CCTV monitoring.	1	2	3	4	5
B7	I can remotely control the heavy equipment implanted with multiple sensors on site.	1	2	3	4	5
B8	I can scan the barcodes and QR codes on supplied building materials to track their main delivery and storage point.	1	2	3	4	5
B9	I can analyze the workforce data captured by the facial recognition camera device.	1	2	3	4	5

B10	I use wireless sensor for building inspections.	1	2	3	4	5
B11	I wear smart wearables (eg: smart helmet or AR/VR smart glasses) while working on-site.	1	2	3	4	5
B12	I can assess to a reliable and stable Wi-Fi connection.	1	2	3	4	5
B13	I can connect my devices to 5G network	1	2	3	4	5
B14	I can connect my devices to 4G network.	1	2	3	4	5
B15	I can connect my devices to LAN using Ethernet cable.	1	2	3	4	5
B16	I can pair my devices via Bluetooth connection.	1	2	3	4	5
B17	I can access to my company's intranet remotely via VPN.	1	2	3	4	5
B18	I can use Microsoft Project or Primavera in project management and scheduling.	1	2	3	4	5
B19	I can use BIM360 as construction management tool.	1	2	3	4	5
B20	I can use Revit to model building information in 3D.	1	2	3	4	5
B21	I can utilize AutoCAD to create 2D and 3D project drawings.	1	2	3	4	5
B22	I can utilize Navisworks to simulate project timeline and schedule construction sequence.	1	2	3	4	5
B23	I can use Google drive, OneDrive, or etc. to share and store project information.	1	2	3	4	5

B24	I can conduct virtual meetings with my team via Microsoft Team, Google Hangouts, Zoom, Skype, or etc.	1	2	3	4	5
B25	I can communicate with my team through WhatsApp, WeChat, or any other communication software.	1	2	3	4	5
B26	I can communicate with my team through email.	1	2	3	4	5
B27	I can utilize the facilitation tool for building maintenance works. (Eg: CMMS, BEMS or BAS).	1	2	3	4	5
B28	I can export the estimation done in different software (Eg: Cubicost or CostX, etc.) to pdf for e-tendering usage.	1	2	3	4	5
B29	I can provide real-time feedback to my team via audio call or video call while working offsite.	1	2	3	4	5
B30	I can label work done in the photos captured digitally.	1	2	3	4	5
B31	I can categorize the photos captured according to their location, date and timestamp.	1	2	3	4	5
B32	I can categorize the videos captured according to their date and timestamp.	1	2	3	4	5
B33	I can analyze the photos captured to study the productivity.	1	2	3	4	5
B34	I can analyze the photos captured to monitor the site safety.	1	2	3	4	5
B35	I can analyze the photos captured to monitor work progress.	1	2	3	4	5
B36	I can analyze the photos captured to monitor the quality of workdone.	1	2	3	4	5

B37	I can analyze the videos captured to study the productivity.	1	2	3	4	5
B38	I can analyze the videos captured to monitor site safety.	1	2	3	4	5
B39	I can analyze the videos captured to monitor work progress	1	2	3	4	5
B40	I can analyze the videos captured to monitor the quality of workdone.	1	2	3	4	5

Section C: Issues Encountered

Open-ended Questions

Digital ecosystem is a complex network of interlinked companies, digital devices, application,and people cooperating on a secured platform with the presence of trust in attaining the same goal.

Please share your ideas / experience in the following questions.

C1) What do you think the challenges of the digitalization in the construction industry are?

C2) Have you experienced any issues in digitalization? Please share your experiences / examples.

C3) What would you suggest to improve the digital ecosystem in the construction industry?

<u>Section D: Demographic Information</u>

In this section, your personal information will be collected.

Please choose only one answer that most suit you from each question in this section.

D1) 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

D2) Which of the following best described your profession?

- Architect
- Civil & Structural Engineer
- M&E Engineer
- Quantity Surveyor
- Builder
- Others

D3) How many years have you been working in the construction industry?

- Less than 2 years
- 2 – 5 years
- 6 – 10 years
- 11 – 20 years
- More than 20 years

<u>Consent of Participation</u>

By clicking submit of the online questionnaire, you are indicating that:

1) You understand that if you have any additional questions, you can contact Mingchi0509@1utar.my

2) You understand that Privacy Notice of UTAR is available at https://www2.utar.edu.my/PrivacyNotice_English.jsp

3) You understand that you can contact the Research Ethics Officers at +603 9086 0288 or aswini@utar.edu.my

4) You agree to participate in this survey voluntarily

APPENDIX B: Friedman Test of Digital Infrastructure Available in the Construction Organization

Ref Code	Statements	Mean Rank	Chi-Square	Asymp. Sig.
	Device		1590.72	0.000
A1	My organization provides tablet to employees.	10.54		
A2	My organization provides laptop to employees.	22.35		
A3	My organization provides PC to employees.	26.05		
A4	My organization provides smartphone to employees.	12.12		
A5	My organization provides mobile phone allowance to employees.	18.69		
A6	We use drone for site inspections.	17.51		
A7	The project sites are installed with CCTV.	21.84		
A8	We remotely control the heavy equipment implanted with multiple sensors on site.	14.50		
A9	We send building materials with barcodes or QR codes on their packaging.	16.09		
A10	We set up face recognition camera device at site access point.	15.34		
A11	We use wireless sensor for building inspections.	15.26		
A12	We provide smart wearables (Eg: smart helmet or AR/VR smart glasses) to our workers.	12.23		
	Network			

A13	We have a reliable and stable Wi-Fi connection.	24.38
A14	We have access to 5G network.	16.73
A15	We have access to 4G network.	26.12
A16	We have access to LAN using Ethernet cable.	24.28
A17	We pair our devices via Bluetooth connection.	18.58
A18	We are able to access to company's intranet remotely.	20.79
	Application	
A19	We use Microsoft Project or Primavera in project management and scheduling.	21.35
A20	We use BIM360 as construction management tool.	18.22
A21	We use Revit to model building information in 3D.	20.40
A22	We utilize AutoCAD to create 2D and 3D project drawings	25.94
A23	We utilize Navisworks to simulate project timeline and schedule construction sequence.	16.74
A24	We use Google drive, OneDrive, or etc. to share and store project information.	26.65
A25	We conduct virtual meetings via Microsoft Team, Google Hangouts, Zoom, Skype, or etc.	28.76
A26	We communicate through WhatsApp, WeChat or any other communication software.	29.42
A27	We communicate through email.	29.81

A28	We utilize facilitation tools for building maintenance works (Eg: CMMS, BEMS or BAS)	17.45
A29	My organization subscribe to relevant software required for e-tendering.	19.59
	Content	
A30	We provide real-time feedback through audio or video call.	21.77
A31	We label work done in the photos captured digitally.	22.62
A32	We categorize the photos captured according to their location, date and timestamp.	23.30
A33	We categorize the videos captured according to their location, date and timestamp.	22.63
A34	We analyse the photos to study productivity.	22.75
A35	We analyse the photos to monitor site safety.	23.35
A36	We analyse the photos to monitor work progress.	24.77
A37	We analyse the photos to monitor the quality of workdone.	23.93
A38	We analyse the videos to study productivity.	21.99
A39	We analyse the videos to monitor site safety.	21.55
A40	We analyse the videos to monitor work progress.	22.43
A41	We analyse the videos to monitor the quality of workdone.	22.24

APPENDIX C: Friedman Test of Digital Knowledge and Talent Among the Construction Community

Ref Code	Statements	Mean Rank	Chi-Square	Asymp. Sig.
	Device		2346.80	0.000
B1	I use tablet to execute my work.	15.86		
B2	I use laptop to execute my work.	27.65		
B3	I use PC to execute my work.	26.28		
B4	I use smartphones in project-related works.	27.14		
B5	I can remotely control the drone to capture images for site inspections and topographical survey	12.68		
B6	I can conduct remote site CCTV monitoring.	13.10		
B7	I can remotely control the heavy equipment implanted with multiple sensors on site.	10.27		
B8	I can scan the barcodes and QR codes on supplied building materials to track their main delivery and storage point.	14.14		
B9	I can analyze the workforce data captured by the facial recognition camera device.	13.42		
B10	I use wireless sensor for building inspections.	11.86		
B11	I wear smart wearables (eg: smart helmet or AR/VR smart glasses) while working on-site.	10.28		
	Network			
B12	I can assess to a reliable and stable Wi-Fi connection.	24.96		

B13	I can connect my devices to 5G network	18.68
B14	I can connect my devices to 4G network.	27.36
B15	I can connect my devices to LAN using Ethernet cable.	24.48
B16	I can pair my devices via Bluetooth connection.	24.46
B17	I can access to my company's intranet remotely via VPN.	20.62
	Application	
B18	I can use Microsoft Project or Primavera in project management and scheduling.	18.32
B19	I can use BIM360 as construction management tool.	15.03
B20	I can use Revit to model building information in 3D.	16.82
B21	I can utilize AutoCAD to create 2D and 3D project drawings.	24.00
B22	I can utilize Navisworks to simulate project timeline and schedule construction sequence.	14.97
B23	I can use Google drive, OneDrive, or etc. to share and store project information.	27.38
B24	I can conduct virtual meetings with my team via Microsoft Team, Google Hangouts, Zoom, Skype, or etc.	28.53
B25	I can communicate with my team through WhatsApp, WeChat, or any other communication software.	29.16

B26	I can communicate with my team through email.	28.92
B27	I can utilize the facilitation tool for building maintenance works. (Eg: CMMS, BEMS or BAS).	14.37
B28	I can export the estimation done in different software (Eg: Cubicost or CostX, etc.) to pdf for e-tendering usage.	14.56
	Content	
B29	I can provide real-time feedback to my team via audio call or video call while working offsite.	21.44
B30	I can label work done in the photos captured digitally.	22.44
B31	I can categorize the photos captured according to their location, date and timestamp.	22.19
B32	I can categorize the videos captured according to their date and timestamp.	21.69
B33	I can analyze the photos captured to study the productivity.	22.03
B34	I can analyze the photos captured to monitor the site safety.	21.46
B35	I can analyze the photos captured to monitor work progress.	22.76
B36	I can analyze the photos captured to monitor the quality of workdone.	22.37
B37	I can analyze the videos captured to study the productivity.	21.73
B38	I can analyze the videos captured to monitor site safety.	21.66

B39	I can analyze the videos captured to monitor work progress	22.57
B40	I can analyze the videos captured to monitor the quality of workdone.	22.41