INVESTIGATING INFLUENTIAL FACTORS OF TECHNOLOGY ADOPTION IN CONSTRUCTION SAFETY MANAGEMENT

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

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DECLARATION

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

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APPROVAL FOR SUBMISSION

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ABSTRACT

Fatal and near-fatal accidents continue to plague the construction industry. The exacerbation of construction safety is attributed primarily to poor safety awareness and lack of innovativeness. The point is, advancements in safety technologies can ameliorate construction safety, thus it is odd that the construction industry is slow to adopt new technologies. As such, this calls for empirical evidence to acquire a deeper insight into this phenomenon. The present study bridges the gap in knowledge and practice by evaluating the potentials of safety technology, factors influencing its adoption and strategies to raise the adoption level. Following a detailed literature review, a questionnaire survey was developed encompassing 10 potentials, 20 factors and 10 strategies that were identified. A total of 133 responses were gathered from the Malaysian construction practitioners. The survey data was subjected to descriptive statistics and exploratory factor analysis. Findings revealed that the leading potentials of safety technologies are: improve hazard identification, reinforce safety planning, and enhance safety inspection. All the considered factors were perceived to be significant, with the most influential factors being expertise and skill of project team, proven technology effectiveness, top management support, government promotion and initiative, and technology reliability. As for the potential strategies, it is uncovered that reinforcement of training and education is more likely to raise the safety technology adoption, followed by provision of government incentives and establishment of government mandates. Four underlying factors were found from factor analysis, namely organisation's commitment and technology orientation, supporting technological attributes, personal perception and performance expectancy, and government support. A possible limitation of this research is its focus on a small group of construction practitioners, thus limiting the generalisability of the findings. This study provides more profound insights into the factors influencing safety technology adoption and recommends strategies to promote the adoption. These findings could potentially assist the practitioners in making informed decisions on implementing safety technologies, which will ultimately lead to enhanced safety performance. This study also supplements the existing body of knowledge around this under-explored area in the construction management studies.

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LIST OF SYMBOLS / ABBREVIATIONS

α	Cronbach's alpha reliability coefficient
$\bar{x}$	Mean
σ	Standard deviation
H	Value of Kruskal-Wallis test
t	Value of one-sample t-test
r_s	Spearman rank correlation coefficient

3D	Three dimensional
4D	Four dimensional
AFAD	Automated flagger assistance device
AI	Artificial intelligence
AR	Augmented reality
BIM	Building information modelling
CCTV	Closed-circuit television
CIDB	Construction Industry Development Board
CITP	Construction Industry Transformation Programme
CLT	Central Limit Theorem
CTAP	Construction technology adoption process
DOSM	Department of Statistics Malaysia
ECG	Electrocardiography
EEG	Electroencephalography
GDP	Gross domestic product
GIS	Geographic Information Systems
GPS	Global Positioning Systems
ICT	Information and communication technologies
IMU	Inertial measurement unit
IoT	Internet of Things
QR	Quick response code
RFID	Radio frequency identification
RTLS	Real-time location tracking system
SAVES	System for Augmented Reality Environment Safety
SOCSO	Social Security Organisation

SPSS	Statistical Package for the Social Sciences
UAV	Unmanned aerial vehicles
URL	Uniform Resource Locator
UWB	Ultra-wideband
VR	Virtual reality
WIMU	Wearable inertial measurement unit

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

In Chapter 1, a synopsis of this research is presented. This chapter discusses the background of the study, problem statement, research aim, research objectives, research questions, research scope, research justification, research method, chapter outline and conclusion.

1.2 Background

As established by The World Bank (2020), the Gross Domestic Product (GDP) of Malaysia was 364.7 billion USD in 2019. Over the decades, it is undeniable that the construction industry has been a major contributor to the economic development of a country (Department of Statistics Malaysia, 2020b). As reported by the Department of Statistics Malaysia (2020b), the construction industry had contributed 4.7% to the GDP of Malaysia in 2019, which amounted to RM71 billion. Despite it only accounts for less than 5% to the economy, the significance of the construction industry to the growth of other sectors cannot be overlooked due to its extensive linkages with the rest of the economy (Ibrahim, et al., 2010).

The construction industry is highly labour-intensive, thus it plays a crucial role in national employment. Department of Statistics Malaysia (2020) reported that the total employment in 2019 was 15.1 million people. Hirschmann (2020) reported that the construction industry accounted for 9.57% or 1.463 million of the workforce. Being a growth enabler to the nation's economy and employment, the construction industry is constantly being beleaguered as a 3D's industry, which is dirty, dangerous and demanding (Yap and Lee, 2019). Due to its dynamic, complex and unique nature, the construction industry is viewed as an extremely high-risk industry as it involves a large chunk of hazardous tasks (Chong and Low, 2014). Consequently, construction labours are exposed to various safety risks while working in such a dangerous working environment, which potentially lead to injuries, permanent disabilities and fatalities.

Being one of the high-risk industries in the world, the greatest challenge of the construction industry is construction safety (Fang, et al., 2020). In Malaysia, the health and safety issues in the construction industry are regulated by the Occupational Safety and Health Act (1994). In line with the Construction Industry Transformation Programme 2016-2020 (CITP) which is established by the Construction Industry Development Board (CIDB), safety is one of the strategic thrusts to future-proof the construction industry in Malaysia. This scheme aims to dwindle the worksite fatalities and injuries by 10% annually in order to engender a safe and healthy working environment (CIDB, 2019).

Along with the development of Industry 4.0, Construction 4.0 as a counterpart of Industry 4.0 is introduced to digitally transform the construction industry towards the 4^{th} industrial revolution. Such transformation will push the construction industry towards the implementation of automated modelling and manufacturing activities. Ultimately, it aims to reduce cost and enhance construction productivity, quality and safety. Nonetheless, it is worth noting that safety issue is one of the compelling issues inhibiting this transformation (Craveiro, et al., 2019).

As the construction industry experiences resurgence in growth and development, the number of occupational accidents and fatalities increase accordingly. As reported by SOCSO (2018), the industrial accidents in Malaysia reported in 2017 amounted to 36,661 cases. Out of the total 36,661 cases, 21.5% or 7,870 cases were reported to have happened in the construction industry. From this figure, approximately 1.5% or 120 resulted in fatalities. Although the construction industry is not the industry that records the highest accidents as compared to other sectors, yet its figure is increasing gradually from 2013 to 2017. All these figures provide a clear picture that the accidents happening in the construction industry are alarmingly high, it is indeed a substantial challenge to the construction industry, thus concerns should be raised on the safety issues.

Generally, the significant characteristics of construction projects are time, cost, quality and safety. Nonetheless, Hamid, Majid and Singh (2008) revealed that a greater priority has been placed on the first three attributes at the expense of safety. Many employers tend to focus more on maximising their profit instead of implementing safety management practices. They further posited that the possible reason for the employers not emphasising safety is lack of recognition of the actual cost of an accident. In fact, accidents will increase the construction cost by 15%, subsequently affecting the financial success of construction companies (Mohammadi, Tavakolan and Khosravi, 2018). This also explains the significance of construction safety. Maintaining workplace safety will keep the workers injury-free and avoid any critical costs arising from an unsafe workplace such as time and money lost after an accident. For that reason, it must be emphasised that workplace safety is essential as each and every worker desire to work in a safe environment. Also, health and safety are core values in enhancing the wellness of every party involved in the construction industry.

1.3 Problem Statement

As highlighted by the Department of Statistics Malaysia (2020b), the construction industry is regarded as the least productive industry as opposed to other sectors like services, manufacturing, agriculture, mining and quarry. In view of this, Alkaissy, et al. (2020) advocated the view that there are several issues constantly plaguing the construction industry which restrain it from contributing tremendously to the nation and one of the issues is construction safety.

Despite the progressive development of the construction industry in recent decades, safety performance is still unsatisfactory (Ibrahim, et al., 2010). It is one of the industries that holds the poorest safety records among other industries notwithstanding that the construction industry in many countries have put in massive efforts in enforcing construction safety-related laws and regulations as well as safety management systems in construction projects (Fang, et al., 2020).

Additionally, Cai, et al. (2020) opined that growing population and limited usable land area give rise to an upsurge of high rise projects in many countries. Such a high elevation working environment will consequently lead to the rise of fatalities and accidents. Against this background, Chi, et al. (2015) and Chong and Low (2014) pointed out that the most frequent accidents happened in the construction industry are workers falling from an elevation and being hit by falling objects. This essentially implies that effective safety management is significantly prudent to meet the growing demand for high-rise projects.

In an attempt to curtail accidents in construction projects, researchers and construction stakeholders have focused on safety management methods such as safety training programs (Wilkins, 2011), safety behavioural approaches (Fang, et al., 2020) and risk modelling (Alkaissy, et al., 2020). Nonetheless, Nnaji, et al. (2019) pointed out that these safety approaches are in administrative forms and their effectivenesses are limited, thus more innovative safety measures are needed to further ward off injuries and deaths in construction.

In line with the emergence of Industry 4.0, there is a new series of paradigm shifts and construction technology has evolved significantly. For instances, big data, internet of things (IoT), artificial intelligence (AI) and simulation (Badri, Boudreau-Trudel and Souissi, 2018). Numerous concerted efforts have been taken to advocate and encourage these construction technologies and the significances of these technologies have been emphasised in many research studies (Skibniewski and Zavadskas, 2013; Li, et al., 2017). In order to achieve an integrated construction safety 4.0 environment, there are also various safety technologies emerged and developed over the years, such as building information modelling (BIM), unmanned aerial vehicles (UAV), wearable technologies, laser scanning, RFID and many more (Martinez, Gheisari and Alarcón, 2020; Karakhan, et al., 2019; Wu, et al., 2013; Li, et al., 2017).

A plethora of extant studies have emphasised the need for construction technologies to achieve the aims of reducing cost as well as boosting construction productivity and performance. Nonetheless, there has been a lack of attention paid to the safety technologies in enhancing the overall health and safety management in the construction industry. Moreover, despite various construction safety technologies having been tested and proven effective for safety management, still, their utilisations are not much prevailing in actual construction projects (Nnaji, et al., 2019). In order to bridge the research gap and maximise the adoption of safety technologies, this study targets to identify the application of safety technologies in construction projects. It is believed that such maximisation is impossible without perceiving the potentials of safety technologies and influential factors impacting the technologies adoption.

Therefore, research on these safety technologies, predictors and solutions to encourage technology adoption is highly necessary to curb the unwanted work-related injuries and fatalities in the construction industry. This also allows the construction stakeholders to make informed decisions in adopting their preferred safety technologies, consequently resulting in a safer working environment.

1.4 Research Aim

This study aims to raise safety technology adoption to tackle the safety issues currently plaguing the construction industry so as to promote a safety-conscious construction industry.

1.5 Research Objectives

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

1. To explore the potentials of safety technologies in construction projects
2. To investigate the influential factors of safety technologies adoption in construction projects
3. To recommend potential strategies in enhancing the adoption level of safety technologies in construction projects

1.6 Research Questions

The research questions of this study are as follows:

1. What are the potentials of safety technologies in construction projects?
2. What are the influential factors impacting the adoption of safety technologies in construction projects?
3. How to enhance the adoption level of safety technologies in construction projects?

1.7 Research Scope

This study primarily deals with the potentials of safety technologies and influential factors of safety technology adoption in construction projects in Malaysia. It also seeks to explore the potential strategies in enhancing the safety technology adoption in the construction industry. This study was carried out in Klang Valley, Malaysia. A questionnaire pertaining to safety technologies was prepared and distributed to the construction practitioners, particularly developers, consultants and contractors.

1.8 Research Significance and Justification

Safety is immensely essential in transforming the construction industry into a robustly developed industry with high safety and quality standards. The adoption of safety technologies in construction projects can drive the industry towards the path of Construction 4.0 and Industry 4.0. This is because technological advancements have high potentials in enhancing the safety management and performance of construction projects, thereby attenuating the incessantly growing workplace accident rates. Therefore, this research is regarded as a contributor to both the safety management of construction projects as well as the development of the construction industry.

This research delves into the potentials of implementing safety technologies in the construction industry. Therefore, this study can provide valuable information for the construction practitioners to acquire deep insight on the feasibilities of the technologies, thus allowing them to make an informed decision on adopting safety technologies that fit their project requirements or conquer their current safety issues faced. Meanwhile, this study also sheds new light on the influential factors of safety technologies adoption and recommends strategies for its stimulation. In this regard, a clear understanding of which determinants and promotion strategies that could significantly influence technology implementation can be acquired, which is beneficial to the successful adoption of safety technologies in the industry. The awareness of drivers and barriers that are significantly correlated to the technology adoption can aid policy makers and advocates to devise strategies to mitigate the hindrances and hence promote the adoption. It is also worth noting that this study represents the first empirical effort focused on augmenting the understandings of the influential factors impacting the deployment of safety technologies in the Malaysian construction industry.

All in all, this research contributes to promote safety awareness among the practitioners and foster a safety culture in the construction industry, which ultimately leads to a safer workplace where the well-being of everyone involved in the industry is preserved.

1.9 Report Outline

This research comprises of five major chapters, which include introduction, literature review, research methodology, results and discussion as well as conclusion and recommendation. The report is outlined as follows:

1.9.1 Chapter 1: Introduction

Chapter 1 is the introductory part of the entire research which discusses the overall content of the study. This chapter includes the background of the construction industry, construction safety and technologies. This chapter also outlines the problem statement, research aim, research objectives, research questions, research scope, research significance and justification as well as report outline. It also identifies the limitation of the research area on safety technologies.

1.9.2 Chapter 2: Literature Review

This chapter reviews the literature based on the previous related studies conducted by other researchers. At the beginning of this chapter, an introduction is included to briefly discuss the overall content of this chapter. Further, it discusses the fundamental definition of the research area, potentials of safety technologies, influential factors of safety technologies adoption as well as the strategies to raise the adoption of safety technologies.

1.9.3 Chapter 3: Methodology and Work Plan

This chapter shows how research is conducted. The research methods and mechanisms are explained in this chapter. It comprises research types, research design, sampling design, data collection method and data analysis techniques. Lastly, a conclusion is included to summarise the entire chapter.

1.9.4 Chapter 4: Results and Discussion

This chapter discusses and analyses results after conducting data collection through the questionnaires distributed to respondents. Finally, the overall results and findings generated are concluded at the end of this chapter. This chapter also evaluates the generated results with the research aim and objective to achieve the ultimate research purpose.

1.9.5 Chapter 5: Conclusions and Recommendations

This chapter is the last chapter of the research. The main purpose of this chapter is to conclude the overall findings of the research. Besides, the research limitations and suggestion for future research are also unfolded in this chapter to provide insights for other researchers to study on the similar research area in the future.

1.10 Summary

After studying the background of the research area, the research gap is identified successfully. This highlights the demands on conducting a research evaluating the influential factors of safety technology adoption to encourage the implementation of safety technology in the construction industry. Hence, research aim and research objectives are established to bridge the research gap and contribute to the construction industry. This study is carried out mainly to raise the safety awareness of the construction players in the industry so as to mitigate workplace accidents.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, existing theories and previous studies conducted by other researchers are studied and reviewed. This chapter begins with a brief introduction of construction safety, construction safety technology and technology adoption. Through reviewing the previous related studies, the potentials of safety technologies in construction projects are explored and discussed in this chapter. Furthermore, this chapter also entails the influential factors of safety technology adoption in construction projects as well as the potential strategies to raise the safety technology adoption level.

2.2 Construction Safety

Safety is defined as a situation in the absence of danger and risk. In the context of the construction industry, safety is the prevention of the occurrence of workplace accident (Yeo, Yu and Kang, 2020). The construction industry is one of the major stimulants to the growth of the nation's economy, nonetheless, the industry has been constantly challenged by various issues such as low productivity, poor image and poor safety management (Pedro, Le and Park, 2016).

As compared to the other sectors, safety is an aspect that has stagnated in the contemporary construction industry (Nnaji, et al., 2019). Issues of construction safety are explicitly associated with inadequate site management, hazardous working conditions, unskilled labours, low adoption level of advanced safety technology and low emphasis on safety. Ultimately, this results in high workplace accident rate. According to the Heinrich's Domino Theory, the underlying causes of construction accidents comprise of human's unsafe behaviours (Guo, Yu and Skitmore, 2017) and construction hazards (Deng et al., 2019). Gibb, et al. (2014) who proposed an accident causation method found out that significant learning can be acquired by appraising the root causes of accidents to mitigate accidents in the future. The consequences of accidents cannot be neglected as accidents would not only affect the person who suffered injuries, but also adversely impact the work progress, completion time and construction cost of the project.

2.3 Construction Safety Technology and Technology Adoption

Numerous previous studies advocated that construction safety can be enhanced through the emerging technologies (Melo, et al., 2017; Awolusi, Marks and Hallowell, 2018; Skibniewski and Zavadskas, 2013). Generally, safety technologies entail all the advanced technologies being implemented to enhance occupational safety. In other words, it is the application of information technology, digitalisation, visualisation and sensing technologies to advance the safety management in the construction industry. Some of the safety technologies implemented in construction projects are BIM, wearable technologies, sensing devices, localisation technologies, drones, and so forth. In line with the emergence of Construction 4.0 and rapid development of safety technologies, it is prudent to explore potential approaches to enhance the integration of these technologies into the safety management of construction projects (Nnaji, et al., 2019).

According to Sepasgozar and Davis (2018) who proposed the Construction Technology Adoption Process (CTAP) cube, technology adoption is a process where a user decides to accept or reject new technology. When the technology is adopted, the next phase is technology implementation, where the technology is utilised and applied in projects. The CTAP cube also highlighted that it is essential to explore the influential factors affecting the adoption process.

2.4 Types of Safety Technology in Construction Projects

2.4.1 Building Information Modelling (BIM)

Generally, BIM is the simulation of construction and operation of a building via a computer software model (Enshassi, Ayyash and Choudhry, 2016). It is a semantically-based and object-oriented approach to assist a project team to systematise and coordinate project information to enhance the information flow (Fargnoli and Lombardi, 2020). The significance of BIM to the overall safety management of construction projects cannot be overlooked.

BIM has been applied in numerous construction projects mainly for the purpose of designing for safety and safety planning (Nnaji, et al., 2019; Azhar, 2017; Skibniewski, 2014; Okpala, Nnaji and Karakhan, 2020). In this vein, design errors can be diminished. For instance, automatic rule checking can be performed using BIM when safety rules are established in the model (Zhang, et al., 2013). This provides the designers to validate the conformity of both object organisation and construction processes. Furthermore, designers can utilise 4D-BIM to detect overlapping and possible clashing of space and tasks (Guo, Yu and Skitmore, 2017). On the other hand, Hossain, et al. (2018) proposed a risk review system in BIM to perform risk identification early in the design phase. Knowing that not every risk can be identified and alleviated during the design stage, Hossain, et al. (2018) further suggested a risk review system to be integrated into BIM to aid the designers in analysing possible residual risk pertinent to design aspects and components during construction, operation and maintenance phases.

Furthermore, various researchers have also stressed the effectiveness of BIM in conducting safety training (Behzadan and Kamat, 2013; Nnaji, et al., 2019; Guo, Yu and Skitmore, 2017; Azhar, 2017). BIM allows the workers to apprehend the actual working conditions through visualisation. In particular, hands-on safety operations can be visualised by the workers to ease their understandings. In an attempt to further strengthen the capabilities of BIM in the area of safety management, BIM can be integrated with other technologies such as augmented reality and virtual reality (Li, et al., 2018; Karakhan, et al., 2019).

2.4.2 Wearable safety technologies

As the name implies, wearable safety technologies entail attaching small electronic devices to the worker’s body which is capable of delivering a wealth of safety benefits (Nnaji and Karakhan, 2020). Besides user-friendly and affordable, these technologies are also effective in monitoring the safety of the workers working in a hazardous construction site.

In a study conducted by Ahn, et al. (2019), wearable inertial measurement unit (IMU) is one of the most common wearable safety technologies used in fall prevention. IMU can be worn in various body locations such as ankles and lower back to assess and gather psychological data concerning the workers’ dynamic movements along reference axes. Moreover, there are other wearable safety technologies available in the industry, such as electrocardiography (ECG) and electroencephalography (EEG) which are used to monitor workers' cardiac and brain activities respectively. On the other hand, Cai, et al. (2020) also suggested using wristbands and safety helmets to keep track of the workers' health conditions.

In addition, Antwi-Afari, et al. (2020) proposed wearable insole pressure systems which are inserted into the workers' safety boots to continuously monitor dangers without interrupting the construction operations. It is evident that there is a positive relationship between the workers' gait interruption in a certain area and the existence of hazard in that area. In this system, the workers' gait disruption patterns are constantly monitored, thereby enabling early identification of possible hazards in construction sites. Accordingly, it allows the safety officer to establish further actions to mitigate the hazards in the shortest time possible.

2.4.3 Unmanned Aerial Vehicles (UAV)

Unmanned aerial vehicles (UAV) are generally referred to as drones. As the name implies, UAV does not necessitate on-board pilot (Melo, et al., 2017). Therefore, it can alleviate potential exposure risk to the workers as it can be remotely operated from the ground. In the contemporary construction industry, drones are utilised by construction practitioners to execute safety and non-safety related supervisions and inspections (Nnaji, et al., 2019; Karakhan, et al., 2019; Gheisari and Esmaeili, 2019; Okpala, Nnaji and Karakhan, 2020). Drones are often equipped with sensors such as camera as well as motion sensor and are used to reach dangerous or inaccessible locations to collect visual data in a short time (Martinez, Gheisari and Alarcón, 2020).

There are various categories of drones, which comprise single-rotor, fixed-wing, fixed-wing hybrid and multirotor. Among all these drones, the multirotor drone is recognised as a more advanced technology (Li and Liu, 2019). With its multiple rotors and fixed-pitch blades, it is indubitably durable and has high mobility to operate in small and confined space. Hence, this makes it practical to be applied in safety management. In this context, it eliminates the safety issue of arduous and hazardous structural inspections, land surveying and various construction and maintenance activities. Furthermore, the multirotor drone can gather and convey real-time videos of actual site conditions from any viewpoints of the construction site, thus easing and facilitating the safety monitoring and inspection tasks.

2.4.4 Automation and Robotics

In a previous study, Cai, et al. (2020) conducted a survey on the effectiveness of automation and robotics for high rise projects and the result has proven that application of automation and robotics can enhance the workers' safety while performing high-risk and high-difficulty tasks. As suggested by several experts from both the construction industry and academia in the study, robotics can replace humans to perform quality inspection which is highly labour intensive and time-consuming. This is due to its capability in handling numerical data and carrying out inspection task in confined and hazardous areas that may pose potential risks for the workers. Furthermore, the study also advocated that with the aid of sensors such as laser scanners and thermal cameras, robotics is intelligent enough to detect massive defects that may expose the workers to safety risk.

Considering that falling from an elevation is one of the most frequent accidents happening in construction sites, automated fall protection systems are suggested by Cai, et al (2020) to be utilised in construction projects. Additionally, safety risks that arise from the workers' erroneous operations can be mitigated through the automation of conventional construction equipment. Other than that, an automated flagger assistance device (AFAD) is a kind of robotic technology used to enhance workplace safety by replacing human flaggers. It enables the workers to control the device remotely without exposing themselves to busy and dangerous traffic. With AFAD, the entire traffic control flagging process is automated (Karakhan, et al., 2019).

2.4.5 Virtual Reality (VR)

Generally, VR is a visualisation technology that immerses users in an artificial digital environment through 3D and computerised representation of reality. In order to experience VR, one must wear a VR headset. Several researchers have studied the benefits of VR in construction projects and have proven its capabilities in safety planning, safety management and safety training (Sacks, Perlman and Barak, 2013; Azhar, 2017; Pedro, Le and Park, 2016).

During the planning phase, VR allows the engineers and contractors to visually monitor site situations and identify potential safety risk (Zhou, Whyte and Sacks, 2012). Through walkthroughs in VR models, potential collisions or hazards can be detected accurately and easily (Cheng and Teizer, 2013; Hadikusumo and Rowlinson, 2004). Hence, effective protective actions can be taken in the pre-construction phase to mitigate the risk. Besides, it also allows the workers to visually recognise the construction sequence as well as materials and equipment specification in advance of construction commencement. Accordingly, hazard identification can take place and safety plans can be formulated.

Ineffective safety training and workers' literacy levels are contributors to workplace accidents. Hence, there is a growing demand to establish a more effective and interactive form of safety training using virtual reality (VR) (Le, Pedro and Park, 2015). VR can achieve a paradigm shift towards learning through enhancing the workers' experiences during the learning process (Eiris, Gheisari and Esmaeili, 2018). Such interactive training will stimulate the workers' cognitive competencies and safety awareness which directly enhance their understanding of the training provided (Zhao and Lucas, 2015). In specific, VR enables the workers to explore the construction environment and rehearse hazardous tasks to promote hazard visualisation. Accordingly, they are able to prepare for the unpredictable safety hazards that may happen owing to poor on-site safety management (Shafiq and Afzal, 2020). Furthermore, VR is a multi-user friendly approach as it does not require a migrant worker to have any specific language or literacy abilities to participate in VR based safety education. It is, therefore, worth to highlight that enriching the workers' hazard identification abilities through VR training scheme can be valuable (Karakhan, et al., 2019).

2.4.6 Augmented Reality (AR)

Augmented reality (AR) is a visualisation technology that overlays virtual information on the real-world environment. In other words, it generates an environment where computerised data is superimposed onto the user's view of a real-world scenario. In construction, AR can intensify the visualisation of 3D job site environments by superimposing 3D virtual models onto real-time videos (Chi, Kang and Wang, 2013). As distinguished with VR, the real world will not be replaced in AR, instead, the real world is amplified with pertinent information so both real and virtual objects will appear in an AR environment (Behzadan and Kamat, 2013).

In an effort to advance safety training, Albert, et al. (2014) alluded System for Augmented Virtuality Environment Safety (SAVES) to construct a high-fidelity AR training environment. Such a feasible and risk-free learning environment has rewarding potential in raising the workers' hazard identification capabilities. Similarly, a panoramic AR tool was also developed by Eiris, Gheisari and Esmaeili (2018) to enhance the workers' fall hazard identification skills. In another study carried out by Kim, Kim and Kim (2017), AR is also used in construction hazard avoidance system where the hazard information is presented as AR in the workers' wearable devices. This system works as a visualisation tool with loads of significant hazards information, which allows the workers to discover hazardous conditions.

Considering the extensive contribution of AR and VR to the construction industry, a plethora of research studies have been conducted that integrate both VR and AR (Li, et al., 2018). It is found that more accurate hazard identification and better safety training can be expected through these collaborative platforms.

2.4.7 Ultra-wideband (UWB)

Ultra-wideband (UWB) is an active radio frequency technology. It is extensively applied in construction safety management, specifically in objects positioning and tracking at both indoor and outdoor (Zhang, Cao and Zhao, 2017; Kim, Kim and Kim, 2017; Guo, Yu and Skitmore, 2017). Owing to its wide spectrum range, UWB signals can be transmitted speedily with centimetre-level discrepancies (Skibniewski, 2014). As opposed to RFID, UWB tends to consume lower energy and has higher penetration potential, thus reinforcing the locating and tracking process. In the past, Cheng, et al. (2011) studied the application of UWB system in a harsh construction environment and the result has disclosed that UWB is efficacious in determining high proximity of construction resources through the computation of the distance between two resources. As a result, struck-by accidents can be averted. Overall, the wide-ranging benefits of UWB make it optimal for numerous applications in construction projects, either independently or collaboratively (Awolusi, Marks and Hallowell, 2018).

2.4.8 Radio Frequency Identification (RFID)

Precise localisation and tracking are exceptionally vital to safety management. According to Zhang, Cao and Zhao (2017), RFID is a technology that uses radio signals to identify a particular target. It encompasses a few core components, which are tag, reader and back end system. It operates by attaching the tags on the personal protective equipment (PPE) worn by the construction workers. Aside from using computer to monitor the data provided by RFID, a mobile phone can be utilised as well. Due to its capability in locating single or several targets accurately in static or dynamic working conditions, RFID has been applied tremendously in various construction projects, particularly in safety design, hazard identification, accident forewarning system, quality inspection and safety training. In addition to its locating and tracking function, RFID can also detect workers' unsafe behaviour (Karakhan, et al., 2019; Guo, Yu and Skitmore, 2017; Skibniewski, 2014).

Towards enhancing the situational awareness and safety in the operations of construction equipment, Teizer, et al. (2010) proposed an autonomous safety mechanism by incorporating RFID, where this sensing technology is tagged on resources like labours, equipment and material. This approach was proven effective to assemble location-aware data where workers and moving equipment intersect. As a worker enters the detection area, the RFID system will trigger the alarm to provide real-time warning to the workers when they are in too close proximity to hazardous equipment. A similar proximity warning system employing RFID is also studied by Kim, Kim and Kim (2017).

Furthermore, Kim, et al. (2016) examined the capabilities of RFID-based Real-Time Location Tracking System (RTLS) in identifying hazardous locations in construction sites, where the RFID tags are attached on workers' safety helmets. This real-time location tracking is functioned by comparing the workers' real path to their ideal path. Eventually, the result of this study has verified the effectiveness of this system in hazards identification such as areas with insufficient fall protections, perilous piling materials and system flaws. Accordingly, the proposed system can significantly mitigate the possible hazardous areas to impede an accident from occurring.

2.4.9 Quick Response Codes (QR codes)

Quick Response Codes (QR code), also known as two-dimensional barcodes, is a type of matrix barcode used in safety management. The existence of smartphones or tablets has significantly led to a major development of QR codes in recent years (Karakhan, et al., 2019). In a previous study conducted by Lorenzo, et al. (2014), QR-code is placed on the workers' tags or safety helmets. By simply scanning the QR code using QR code reader installed in smartphones or tablets, the construction workers can retrieve information through a designated URL. Accordingly, they will become aware of important safety information and the standard operating procedure relevant to a certain location or equipment on the site. Safety officer can also use QR code to ensure that the workers have already completed the required training prior to conducting tasks at certain locations or handling specific equipment (Lorenzo, et al., 2014).

2.4.10 Network Camera

A network camera, also refers to as IP camera, generally acts as a site surveillance and live monitoring tool in various construction projects (Okpala, Nnaji and Karakhan, 2020). Due to the emergence of visual technologies, there are various visual recording devices available in the industry such as video camera and closed-circuit television (CCTV) (Seo, et al., 2015). These camera devices are installed on sites to capture video and convey the recordings over an IP network.

As accident is unforeseen and may happen in any area of a construction site, implementation of the network camera is a vital supplement to safety management (Nnaji and Karakhan, 2020). In order to stimulate safety monitoring, a complete coverage of construction site via cameras is prudent to give a maximum view field. This camera technology offers a wide range of benefits such as real-time recording, resources tracking, hazard identification and unsafe behaviour detection. Through the recorded video clip generated by the system, safety managers can gather and examine all the images of workers' actions and site conditions that may be a contributor to accidents. In essence, it provides guidance for them to take necessary preventive measure to mitigate the risk (Zhang, et al., 2018).

2.4.11 3D Laser Scanning

As elucidated by Schueremans and Van Genechten (2009), 3D laser scanning is a technology that allows the users to obtain 3D data without contacting the item's surface. Its flexibility feature allows scanning objects that are complicated in shape while maintaining data accuracy and scanning speed. Once the scanning is completed, the data will be used to create digital 2D drawings or 3D models. In order to ensure thorough scanning of the entire structure, numerous scan positions are needed. This technology eliminates the need for humans to work in hazardous areas to perform on-site monitoring and measurement. Given this, it is competent in mitigating the incessantly growing injuries in construction sites (Nnaji, et al., 2019).

2.4.12 Digital Signage

In an effort to cultivate a safe working environment, technology has emerged to replace board signage into digital signage. Digital signage has been seen applying in construction sites for site safety boards (Nnaji and Karakhan, 2020). It acts as an effective approach to ensure that the workers and visitors are aware of the possible occupational hazards. In contrast to the conventional safety board signage, digital signage appears to be more attention-seeking, therein lies its potential in reinforcing the safety message intended to be delivered. Additionally, it also provides reminders of safety precautions and standard operating procedures in conducting certain construction activities as well as handling hazardous materials and equipment to ensure that they work safely (Karakhan, et al., 2019)**.** Through the effective use of digital signage, the safety awareness of construction workers is likely to raise, ultimately making the construction site a safer workplace.

2.5 Summary of types of safety technologies in construction projects

The following Table 2.1 and 2.2 present the summary of the application and capabilities of several types of safety technologies sorted out from the literature review.

Note to Table 2.1

Authors: **1**-Ahn, et al. (2019); **2**-Albert, et al. (2014); **3**-Antwi-Afari, et al. (2020); **4**-Awolusi, Marks and Hallowell (2018); **5**-Azhar (2017); **6**-Behzadan and Kamat (2013); **7**-Cai, et al. (2020); **8**-Cheng, et al. (2011); **9**-Cheng and Teizer (2013); **10**-Chi, Kang and Wang (2013); **11**-Eiris, Gheisari and Esmaeili (2018); **12**-Enshassi, Ayyash and Choudhry (2016); **13**-Fargnoli and Lombardi (2020); **14**-Gheisari and Esmaeili (2019); **15**-Guo, Yu and Skitmore (2017); **16**-Hadikusumo and Rowlinson (2004); **17**-Hossain, et al. (2018); **18**-Karakhan, et al. (2019); **19**-Kim, et al. (2016); **20**-Kim, Kim and Kim (2017)**; 21**-Le, Pedro and Park (2015); **22**-Lorenzo, et al. (2014); **23**-Li, et al. (2018); **24**-Li and Liu (2019); **25**-Martinez, Gheisari and Alarcón (2020); **26**-Melo, et al. (2017); **27**-Nnaji, et al. (2019); **28**-Nnaji and Karakhan (2020); **29**-Okpala, Nnaji and Karakhan (2020); **30**-Pedro, Le and Park (2016); **31**-Sacks, Perlman and Barak (2013); **32**-Schueremans and Genechten (2009); **33**- Seo, et al. (2015); **34**-Shafiq and Afzal (2020); **35**-Skibniewski (2014); **36**-Teizer, et al. (2010); **37**-Zhang, et al. (2018); **38**-Zhang, Cao and Zhao (2017); **39**-Zhao and Lucas (2015); **40**-Zhou, Whyte and Sacks (2012).

Table 2.1: Summary of types of safety technologies in construction projects.

Ref	Safety Technologies	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
1	BIM					✓	✓						✓	✓		✓		✓						6
2	VR					✓				✓		✓					✓		✓			✓		6
3	AR		✓				✓				✓	✓									✓			5
4	UWB				✓				✓							✓					✓			4
5	Wearable safety technology	✓		✓				✓																3
6	RFID															✓				✓	✓			3
7	Automation & Robotics							✓											✓					2
8	QR Code																		✓				✓	2
9	UAV														✓									1
10	Digital Signage																		✓					1
11	Network Camera																							0
12	3D Laser Scanning																							0

Table 2.1 (Cont'd)

Ref	Safety Technologies	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total
1	BIM	✓				✓	✓	✓						✓		✓				6
2	UAV		✓	✓	✓	✓	✓	✓												6
3	VR								✓	✓			✓					✓	✓	5
4	Network Camera						✓	✓				✓				✓				4
5	RFID													✓	✓		✓			3
6	UWB													✓			✓			2
7	3D Laser Scanning					✓					✓									2
8	Wearable safety technology						✓													1
9	AR	✓																		1
10	Digital Signage						✓													1
11	Automation & Robotics																			0
12	QR Code																			0

Table 2.2: Final summary of types of safety technologies in construction projects.

Ref	Safety Technologies	Total Frequency
1	BIM	12
2	VR	11
3	UAV	7
4	AR	6
5	UWB	6
6	RFID	6
7	Wearable safety technology	4
8	Network Camera	4
9	Automation & Robotics	2
10	QR Code	2
11	3D Laser Scanning	2
12	Digital Signage	2

2.6 Potentials of safety technology adoption in construction projects

2.6.1 Design for safety

In general, the notion of design for safety is related to the incorporation of safety considerations in the design of a project. A study conducted by Behm (2005) has demonstrated that there is a significant relationship between construction safety and decisions made upstream from the construction site. Similarly, this finding is also supported by Gambatese, Behm and Rajendran (2008) where it is emphasised that construction safety risks would have been minimised or eradicated if the design for safety concept has been adopted. Therefore, such practice has been urged in numerous past research studies (Zhou, Whyte and Sacks, 2012; Nnaji, et al., 2019; Hossain, et al., 2018; Hadikusumo and Rowlinson, 2004; Bansal, 2011). This, in turn, induces the introduction and development of safety technologies to be integrated into the design and planning phase.

In a past study, Shafiq and Afzal (2020) ascertained that virtual construction technologies such as BIM, VR and AR have great potentials in augmenting safety climate, specifically in safety designing and planning of temporary structures. Additionally, Fargnoli and Lombardi (2020) further advocated that BIM is a great design-for-safety tool to achieve the “zero accident” vision in the construction industry. By adopting these state-of-the-art technologies in construction projects, safety can be addressed efficiently and effectively during the design and preconstruction phases. The implementation of safety technologies in these phases offer opportunities to wipe out safety risks before they appear on the jobsite and to eradicate hazards as the project progresses. As such, safety performance can be substantially enhanced.

2.6.2 Reinforce safety planning

As asserted by Zhang, et al. (2013), a safe construction site requires effective safety planning throughout the project life cycle, from the design stage, through construction execution and extending into the operation and maintenance phase. It has been avowed that planning for safety at the preliminary stage of a project is a crucial step for ensuring safety. According to Li, et al. (2018), safety planning is one of the roles of the safety management team to identify hazards prior to work commencement. Besides, this task also involves making decisions on appropriate safety measures to prevent accidents. In most of the construction projects, safety planning and project planning are viewed as different tasks, thus resulting in two independent teams accountable for the separate planning tasks. Such separation and the resulting poor communication have indirectly engendered difficulties for the safety engineers to determine the appropriate safety measures to mitigate hazards (Perlman, Sacks and Barak, 2014). Furthermore, traditional safety planning is conducted through frequent manual observations, thus it is greatly inefficient and prone to errors. With these in mind, improvements in safety planning and safety performance can be achieved through the adoption of safety technologies (Zhang, et al., 2013).

The mushrooming adoption of safety technologies in the construction industry is altering the way of how effective safety planning can be achieved and these technological advancements have been studied in numerous research papers (Martinez, Gheisari and Alarcón, 2020; Ganah and John, 2015). For instance, Zhang, et al. (2013) developed an automated rule-based checking system in BIM to integrate safety planning in work breakdown structures and project schedules. Such a framework allows the construction activities that are inherently hazardous to be identified at the planning stages and corrected accordingly. Furthermore, Bansal (2011) utilised Geographic Information Systems (GIS) based navigable 3D animation in safety planning to predict areas and activities that are prone to accidents, subsequently allowing the safety managers to establish preventive measures. His approach also involves the integration of safety code provisions and safety database, which makes the safety planning more effective and realistic.

2.6.3 Enhance safety monitoring and supervision

Medium to large construction projects typically involve a large amount of construction workers and equipment which necessitate continual site monitoring. The manual method of safety monitoring and supervision requires the safety managers to walk from one location to another, which is highly ineffective (Zhou, Irizarry and Lu, 2018). Martinez, Gheisari and Alarcón (2020) stated that most of the construction projects have an average of two safety managers on the site, which is found to be inadequate to execute the safety monitoring and supervision tasks especially for medium to large size projects.

Accordingly, this situation may limit their abilities to monitor the construction projects effectively. Furthermore, safety monitoring is difficult to execute owing to difficulties in visiting several locations simultaneously and the fact that certain areas are unsafe or inaccessible to be monitored. These grounds restrict the safety managers to carry out frequent monitoring of the workplace and supervision of the workers, consequently leading to poor safety performance in construction projects.

With the emergence of safety technologies such as UAV, sensors and wearable technologies, the above-mentioned issues can be solved (Gheisari and Esmaeili, 2019; Asadzadeh, et al., 2020). These innovations assist the managers to conduct safety monitoring through providing real-time information. For instance, Teizer, et al. (2010) proposed an autonomous safety alert system that transmits real-time information which can facilitate the entire safety monitoring process. Moreover, UWB is also proven technically feasible for real-time monitoring of equipment and examining the possibilities of collisions (Hwang, 2012). Furthermore, a case study assessing the integration of UAV in safety monitoring has found that videos captured by the UAV carried significant data for safety monitoring. Besides, such technology provides a global view of a construction site which is far more effective than local views from people, therein lies its potential to be applied in high-rise projects. Such a comprehensive view of the site allows the managers or supervisor to be more informed about the site conditions so as to detect any unsafe situations easily (Martinez, Gheisari and Alarcón, 2020).

2.6.4 Enhance safety inspection

According to Woodcock (2014), inspection is one of the core elements of safety management to carry out early detection and correction of safety risk. This task is performed by safety specialists to examine unsafe conditions and provide risk information to the construction workers. Nonetheless, the traditional communication approach that has been practised in most of the construction projects makes the safety inspection process inefficient. As a result, it may engender high safety risks on the site (Li, et al., 2018). In view of this, visual safety technologies can be adopted to facilitate the inspection process (Nnaji, et al., 2019; Karakhan, et al., 2019; Gheisari and Esmaeili, 2019; Okpala, Nnaji and Karakhan, 2020; Siebert and Teizer, 2014; Melo, et al., 2017). In a recent study conducted by Martinez, Gheisari and Alarcón (2020) in Chile, UAV is proven to be a feasible safety inspection tool which offers the safety managers another set of eyes on the site to streamline their inspection tasks. This technology also replaces human to conduct hazardous inspections in areas that are inaccessible and unsafe. The inspection outcomes generated by the technologies can then be used to enhance site safety performance through identifying and understanding the trend of hazardous working situations or behaviour (Lin, et al., 2014).

2.6.5 Improve hazard identification

Hazard identification, which also refers to risk recognition, is the primary step in safety risk management. Li, et al. (2018) stated that conventional hazard identification relies on traditional sources such as drawings and past accident cases. Moreover, heuristic knowledge is applied in traditional hazard identification to formulate prevention strategies against expected hazards by conducting project meetings. Accordingly, such methods fail to reflect the real site situations precisely and devise an effective prevention strategy to mitigate safety risk.

In order to enhance the hazard identification process, Zhou, Irizarry and Li (2013) and Gheisari and Esmaeili (2019) suggested deploying innovative technologies for timely detection of hazards and correction of errors so as to prevent the occurrence of accidents. The findings of Perlman, Sacks and Barak (2014) revealed that VR users were able to assess greater risk level and identify more hazards in a virtual environment than the ones who relied on photographs and records. Furthermore, these technologies are also capable of providing instant feedback to subjects upon hazard identification. On the other hand, sensor-based safety technologies also have great potentials in identifying and eliminating preventable safety hazards rooted in the design phase prior to construction commencement (Asadzadeh, et al., 2020).

2.6.6 Enrich safety education and training

According to Li, et al. (2018), the central objective of safety education and training is to allow the construction workers especially the novices to grasp the safety concerns in relation to job location, type of task and type of risk. Over the years, digital training and education have gained momentum in augmenting the cognitive learning of the construction workers. It has been found that the conventional ways of delivering safety education and training are tedious, costly and potentially risky depending on actual site conditions. In view of this, the evolution of safety technologies offers new opportunities for more efficacious safety education and training.

Various researchers have stressed the effectiveness of BIM in conducting safety training (Behzadan and Kamat, 2013; Nnaji, et al., 2019; Guo, Yu and Skitmore, 2017; Azhar, 2017). This technology allows the workers to apprehend the actual working conditions through visualisation. In particular, hands-on safety operations can be visualised by the workers to ease their understandings. In an attempt to further strengthen the capabilities of BIM in this respect, several studies suggested BIM to be integrated with other technologies like AR (Li, et al., 2018; Karakhan, et al., 2019).

Furthermore, Karakhan, et al. (2019) highlighted that enriching the workers' hazard identification abilities through virtual training schemes can be valuable. From this perspective, VR can be employed to achieve a paradigm shift towards learning through enhancing the workers' experiences during the interactive learning process (Eiris, Gheisari and Esmaeili, 2018). Such interactive training will stimulate the workers' cognitive competencies and safety awareness which directly enhance their understanding of the training provided (Zhao and Lucas, 2015). In specific, it allows the workers to rehearse the construction operations and study the safety hazards in a risk-free virtual environment. Accordingly, the information arouse in the virtual environment could be easily conveyed to and interpreted by the workers (Li, et al., 2018). Furthermore, it is a multi-user friendly approach whereby a migrant worker does not need any specific language or literacy abilities to participate in digital-based safety education.

2.6.7 Raise safety awareness

The construction practitioners' safety awareness has a direct relationship with the safety performance (Yu, et al., 2014). Effectively fostering the safety awareness of the workers is paramount to deliver enhanced safety outcomes in construction projects (Yap and Lee, 2019). Cheng and Teizer (2013) proposed using visualisation technology to conduct real-time safety monitoring with an ultimate aim to improve construction safety and raise the safety awareness of workers and equipment operators. Likewise, another research that was undertaken by Kim, Kim and Kim (2017) also affirmed the effectiveness of AR in intensifying the workers' safety awareness.

Besides, localisation technologies also have great potential to enhance equipment operators' situational awareness. Accordingly, the operators are able to identify hazardous situations more promptly (Hwang, 2012). A similar technology is also promoted by Zhang, Hammad and Rodriguez (2012) to aid in crane's route prediction so as to enhance crane driver's context awareness. Through adopting these technologies, construction personnel on-site are becoming inherently more conscious of the workplace surroundings and its risks. Aside from improvements shown on the workers on site, another study also highlighted the potentials of safety technologies in breeding the designers' awareness of construction safety issues, thereby enabling them to underpin health and safety in their designs (Zhou, Whyte and Sacks, 2012). As the construction participants become more aware of the construction safety issues, a safety culture can therefore be cultivated (Zhao and Lucas, 2015), which is highly significant for achieving a consistently satisfactory safety performance in construction projects (Trinh, Feng and Jin, 2018).

2.6.8 Enhance near-miss reporting and analysis

Near-misses are unplanned incidents that posed possibilities to result in accidents or fatalities but did not. These incidents can offer valuable data about the potential hazards and roots of accidents (Wu, et al., 2010). If such incidents are discovered in time and preventive actions are performed, a zero-injury job site is possible. Therefore, reporting near-misses occurring in a construction project is critical for safety improvements (Golovina, Teizer and Pradhananga, 2016). Nonetheless, gathering near-miss data is onerous due to the fact that the existing data collection methods may be influenced by retrospective and qualitative decision of individual workers who report the incidents (Yang, et al., 2016). In light of this, several authors have studied the methods to further improve near-miss reporting and analysis in the industry. One of the available ways for collecting quantitative near-miss data is the adoption of safety technologies.

As a proactive approach to avert accidents, kinematic and physiological sensors can be integrated into wearable sensing technologies to capture workers' near-miss falls and report to safety managers subsequently (Ahn, et al., 2019). In the US, Shen and Marks (2016) developed a near-miss information visualisation tool in BIM to allow the construction personnel to visualise and analyse the reported near-miss information. On the other hand, Riaz, Edwards and Thorpe (2006) developed a system by merging GPS, smart sensors and wireless networks to enhance near-miss accident reporting so as to allow the managers to learn how to enhance health and safety in the construction site. The reports may be used as a training aid or act as a benchmark to compare the safety performance across a number of projects. Moreover, these near-miss data could also assist the managers in making proactive decision-making, thereby preventing accidents in the future (Okpala, Nnaji and Karakhan, 2020).

2.6.9 Enhance accident investigation

Post-accident investigations are crucial to enable the construction stakeholders and workers to learn from past wrong-doing and minimise the occurrence of similar incidents in the future (Jiang, Fang and Zhang, 2015). When safety incidents happen, the workers' behaviours and safety management system are meticulously scrutinised during accident investigations (Wachter and Yorio, 2014). A case study performed by Azhar (2017) in the US uncovered that 4D BIM simulations and VR immersive environments can be deployed to streamline accident investigation by recreating incident sequence and setting. Another US study conducted by Gheisari and Esmaeili (2019) also revealed that drone has great potential in recordkeeping, thus facilitating the accident analysis and investigation process. The photographs of an accident recorded in the technology system can be utilised to investigate the causes of the accident and potential onsite safety problems. Moreover, the photographs can also be used for subsequent litigation upon the occurrence of an accident.

2.6.10 Facilitate safety communication

It is apparent that traditional communications such as face-to-face meetings, paper-based drawings and documents are practised in most of the construction projects. In recent decades, it is observed that the construction industry has been exerting some efforts in innovating the communication method. This can be seen with the utilisation of telecommunication systems such as facsimile and email in construction projects, which has undoubtedly enhanced the speed of work. Nevertheless, the efficiency and quality of information exchange in the health and safety aspects on site are still unsatisfactory. This is where safety technologies come into play (Ganah and John, 2015). A similar observation is also found in Lin, et al. (2014), where it is mentioned that integrated communication with project participants can be achieved through the adoption of technologies. Such integrated communication can raise the participants' safety awareness and ensure that no safety issues are being neglected.

The potentials of safety technologies in enhancing and facilitating safety communications between the construction participants on site have been explored in numerous studies. For instance, Riaz, Edwards and Thorpe (2006) proposed a system that integrates sensing technologies as well as information and communication technologies (ICT) to lubricate real-time communication on the site through sending alerts and notifications to the safety manager. Besides, a research undertaken by Ganah and John (2015) in the UK has addressed the feasibilities of BIM in streamlining safety communication through enhancing transactional understanding of the work activity to be executed. This technology presents a new way of communication which allows safety information to be fed forward and backward, ultimately fortifying the safety management in construction projects. In China, Zhou, Irizarry and Lu (2018) also ascertained the potentials of UAS as a type of intermedium tool for remote interaction with the construction workers. This technology allows the safety manager to obtain real-time feedback and take necessary preventive measures.

2.7 Summary of potentials of safety technologies in construction projects

The following Table 2.3 and 2.4 present the summary of the potentials of safety technologies sorted out from the literature review.

Note to Table 2.3

Authors: **1**-Ahn, et al. (2019); **2**-Asadzadeh, et al. (2020); **3**-Azhar (2017); **4**-Bansal (2011); **5**-Behm (2005); **6**-Behzadan and Kamat (2013); **7**-Cheng and Teizer (2013); **8**-Eiris, Gheisari and Esmaeili (2018); **9**-Fargnoli and Lombardi (2020); **10**-Gambatese, Behm and Rajendran (2008); **11**-Ganah and John (2015); **12**-Gheisari and Esmaeili (2019); **13**-Golovina, Teizer and Pradhananga (2016); **14**-Guo, Yu and Skitmore (2017); **15**-Hadikusumo and Rowlinson (2004); **16**-Hossain, et al. (2018); **17**-Hwang (2012); **18**-Jiang, Fang and Zhang (2015); **19**-Karakhan, et al. (2019); **20**-Kim, Kim and Kim (2017); **21**-Li, et al. (2018); **22**-Lin, et al. (2014); **23**-Martinez, Gheisari and Alarcón (2020); **24**-Melo, et al. (2017); **25**-Nnaji, et al. (2019); **26**-Okpala, Nnaji and Karakhan (2020); **27**-Perlman, Sacks and Barak (2014); **28**-Riaz, Edwards and Thorpe (2006); **29**-Shafiq and Afzal (2020); **30**-Shen and Marks (2016); **31**-(Siebert and Teizer (2014); **32**-Teizer, et al. (2010); **33**-Trinh, Feng and Jin (2018); **34**-Wachter and Yorio (2014); **35**-Woodcock (2014); **36**-Wu, et al. (2010); **37**-Yang, et al. (2016); **38**-Yap and Lee (2019); **39**-Yu, et al. (2014); **40**-Zhang, et al. (2013); **41**-Zhang, Hammad and Rodriguez (2012); **42**-Zhao and Lucas (2015); **43**-Zhou, Irizarry and Lu (2018); **44**-Zhou, Whyte and Sacks (2012).

Table 2.3: Summary of potentials of safety technologies in construction projects.

Ref	Potentials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Total
1	Enhance safety inspection												✓							✓		✓	✓	✓	✓	✓	✓	8
2	Design for safety				✓	✓				✓	✓					✓	✓									✓		7
3	Enrich safety education and training			✓			✓		✓						✓					✓		✓				✓		7
4	Enhance safety monitoring and supervision		✓										✓					✓						✓				4
5	Reinforce safety planning				✓							✓												✓				3
6	Improve hazard identification		✓										✓									✓						3
7	Raise safety awareness							✓										✓			✓							3
8	Enhance near-miss reporting and analysis	✓												✓													✓	3
9	Enhance accident investigation			✓									✓						✓									3
10	Facilitate safety communication											✓											✓					2

Table 2.3 (Cont’d)

Ref	Potentials	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	Total
1	Raise safety awareness							✓					✓	✓		✓	✓		✓	6
2	Enhance near-miss reporting and analysis		✓		✓						✓	✓								4
3	Design for safety			✓															✓	2
4	Reinforce safety planning	✓													✓					2
5	Enhance safety monitoring and supervision						✓											✓		2
6	Enhance safety inspection					✓				✓										2
7	Improve hazard identification	✓																✓		2
8	Facilitate safety communication		✓															✓		2
9	Enrich safety education and training																✓			1
10	Enhance accident investigation								✓											1

Table 2.4: Final summary of potentials of safety technologies in construction projects.

Ref	Potentials	Total Frequency
1	Enhance safety inspection	10
2	Design for safety	9
3	Raise safety awareness	9
4	Enrich safety education and training	8
5	Enhance near-miss reporting and analysis	7
6	Enhance safety monitoring and supervision	6
7	Reinforce safety planning	5
8	Improve hazard identification	5
9	Enhance accident investigation	4
10	Facilitate safety communication	4

2.8 Influential factors of safety technology adoption in construction projects

Owing to limited studies conducted on the influential factors of technology adoption particularly in the area of safety management, this section also includes reviewing the past studies that focused on the factors of adopting other construction technologies to achieve various construction outcomes such as productivity enhancement, cost reduction, quality and collaboration improvements. In other words, the factors identified in this section were not limited to safety technologies; instead, the factors were for all technologies used for construction management. This, in turn, highlights the research gap where there has been a lack of studies investigating the factors of safety technology adoption. Additionally, identifying the factors outside the purview of safety management also increases the number of potential factors.

2.8.1 Capital cost of technology

In China, Cai, et al. (2020) who studied the contributing factors of application of automation and robotics for high-rise buildings reported that initial investment cost of technology was ranked as the most influential factors of adoption. Similarly, several research studies also emphasised that cost is the most apparent determinant of new technology adoption (Low, Arain and Tang, 2019; Nnaji, et al., 2020; Zhang, et al., 2020; Ahuja, et al., 2018). This is because the nature of construction is high risk and low profit, as a new technology is adopted, a huge amount of capital cost will incur which include the cost of purchasing new machines or software and upgrading existing machines or software (Ayinla and Adamu, 2018; Delgado, et al., 2019; Tsai, Mom and Hsieh, 2014). These costs can have a major impact on the survivability of the companies, especially those small and medium-sized firms. Therefore, cost is the major factor that the construction companies would consider because technology adoption is considered as a costly and high-risk investment.

2.8.2 Level of training required

Generally, trainings are highly vital to equip the project team and workers with necessary knowledge and skills of using the technology in carrying out their works to meet the optimum performance (Nnaji, et al., 2019). Therefore, technology implementation requires the firms to fork out additional money for the training cost, particularly the cost of recruiting educational consultancy and experts in related field (Tsai, Mom and Hsieh, 2014). Against this background, Delgado, et al. (2019) and Ayinla and Adamu (2018) mentioned that the resources required for training are critical concerns for firms who intend to adopt new technology. In this connection, Nnaji and Karakhan (2020) stated that technology that requires extensive training will hinder the adoption of the technology.

2.8.3 Technology brand and reputation in the industry

Brand reputation is based on the perception of customers or stakeholders towards a certain brand. In the US, the brand and prestige of technology are identified as one of the factors of safety technology adoption in construction projects (Nnaji, et al., 2019). Besides, an interview conducted by Sepasgozar and Davis (2018) revealed that construction practitioners tend to go for pre-owned technologies introduced by some well-known and prestigious brand manufacturers in the industry instead of purchasing new technologies from new or disreputable brands. This is because they believe that software or equipment developed by a manufacturer who has a high reputation in the industry is more reliable. In essence, this indicates that technology brand and reputation in the industry are vital concerns for companies in making decisions to adopt a technology (Nnaji, et al., 2020; Zhang, et al., 2020).

2.8.4 Proven technology effectiveness

According to Nnaji, et al. (2019), construction firms tend to adopt technologies that have already been proven competent and complied with a range of strict requirements. Technology is proven effective when its features satisfy the established requirements to achieve decent performance (Cai, et al., 2020). Essentially, unproved effectiveness indicates poor readiness of the technology as the technology is still immature (Delgado, et al., 2019). When a new technology offers more advantages than the current technologies or working methods, an organisation is more driven to adopt the new technology. This is supplemented by an Australlian study conducted by Hong, et al. (2018) which found that the effectiveness of BIM such as cost reduction and data accuracy are drivers triggering the construction firms to adopt this technology in their projects.

2.8.5 Technology reliability

In a recent US study carried out by Nnaji, et al. (2020), technology reliability was ranked as the first effective predictor of safety technology adoption. This essentially indicates that construction practitioners are concerned about the potential of new technology to meet the desired project performance consistently. In other words, a reliable technology offers consistent result by functioning consistently in accordance with its specification. In India, there is also a huge propensity for the firms to gain trust in a technology that has high reliability (Ahuja, et al., 2018).

2.8.6 Technology compatibility

Technology compatibility is the extent to which a technology is discerned as coherent with the demands of construction players and the current conditions of projects (Ahuja, et al., 2018). This aspect is under the consideration of potential adopters as the adoption of new innovative solution may cause hefty changes to the existing work practice. Technology is said to be compatible if it does not cause severe interruption to the existing working practice (Nnaji, et al., 2019).

A decision-maker has to consider the ability of the technology to integrate with construction processes prior to implementing the technology. When a technology fits the construction requirements and processes, there is a likelihood that the technology will be adopted. In such a context, technology compatibility is regarded as an influential factor of safety technology adoption (Nnaji, et al., 2020; Son, Lee and Kim, 2015). Nonetheless, Chen, et al.'s (2019) study revealed that technology compatibility is not a significant factor in influencing BIM adoption in China.

2.8.7 Technology complexity

Technology complexity is the degree of complication of using a technology. It is associated with the amount of effort and expertise necessitated to get familiarised with new technology (Nnaji, et al., 2019). Owing to a more significant learning curve, firms are likely to be discouraged to adopt a technology that is difficult and complicated to use. According to Delgado, et al. (2019), high technology complexity will limit the usability and effectiveness of various technologies. In contrast, if the technology is easy to use, the firms tend to be attracted to adopt it (Chen, et al., 2019). Several prior studies also indicated that there exists a significant relationship between the technology adoption and technology complexity (Nnaji, et al., 2020; Choi, Hwang and Lee, 2017; Okpala, Nnaji and Karakhan, 2020; Enshassi, Ayyash and Choudhry, 2016; Ahuja, et al., 2018).

2.8.8 Size of organisation

The ability of a construction firm to adopt new technologies is influenced by its size. In the case when the technology is complicated to use and requires an intensive amount of resources such as cost and technical support, there is a likelihood that larger companies adopt more new technologies than the smaller firms. This is because the size of the organisation is a determinant of its financing capability. To put it in another way, the greater the size of a construction firm, the greater the resource advantage to exercise innovation and implement new technology (Fernandes, et al., 2006). Nonetheless, this assertion is contrary to that of Kamal, Yusof and Iranmanesh (2016), wherein it is found that a larger company does not absolutely represent greater innovativeness than a smaller company.

2.8.9 Top management support

According to Son, Lee and Kim (2015), top management support is the extent to which the top management comprehends the significance and usefulness of technologies. It has been recognised as an influential factor of successful technology adoption by a number of authors (Fernandes, et al., 2006; Tsai, Mom and Hsieh, 2014; Nikas, Poulymenakou and Kriaris, 2007; Zakaria, et al., 2018; Nnaji, et al., 2020; Ahuja, et al., 2018). In the absence or lack of support and commitment from the top management, the successful adoption of technologies is nearly impossible. This is because the top management plays a key role in influencing the behaviour of firms in adopting new technologies, thus their approach can be considered as a driver or a barrier to the diffusion of new technologies in construction.

Support and commitment from senior management levels of construction firms are essential to allocate required resources such as money, time and training to implement new technology in a project (Ding, et al., 2015). If the top managements perceive that the technologies can provide safety benefits, then they will actively engage in the implementation process in a way that rational approaches will be performed to analyse and understand these new technologies, subsequently, accept and adopt these technologies for their projects (Chen, et al., 2019). Besides, top management can also boost the technology adoption by promoting the application of technologies within their organisations by providing necessary support to the workers. It has been noted that when the top management allocates resources to their workers to fund the technology adoption, there is a motivating effect on the workers to learn and apply new technologies in their activities. Moreover, Fernandes, et al. (2006) further emphasised that with the intensive support from the top management, the companies can easily confront unanticipated challenges during the application of technology in construction projects. In short, the top management has the capacity to initiate and build a more favourable environment to ease the technological adoption (Son, Lee and Kim, 2015).

2.8.10 Expertise and skill of project team

A China study undertaken by Tsai, Mom and Hsieh (2014) revealed that technical competence of a project team will affect the technology adoption. In this vein, Nikas, Poulymenakou and Kriaris (2007) supplemented that a skilled project team can enhance the diffusion of technology in a project. This is because a technologically sound project team has a higher inclination to implement new innovative solutions in their projects (Ahuja, et al., 2018). Besides, they can establish a solid practical foundation for implementing the new technology (Hong, et al., 2018).

Owing to high adoption cost involved, technologies such as VR requires critical evaluation and substantial planning prior to adoption. For that reason, the skills of the project team act as an influential factor of the adoption outcome. In specific, the skills required are often associated with information technology related skills. A project team that is rich in IT experiences and skills has higher capabilities to administer and deal with technical issues related to technology adoption. In addition, such a capable team can also stimulate the workers' involvement and enhance training, which is vital to the successful technology adoption (Fernandes, et al., 2006). On the other hand, Hong, et al. (2018) asserted that a firm may face collaborative challenges due to communication issues resulting from inexperienced staffs. From this perspective, the authors further stressed the significance of expertise and skill of project team in this respect.

2.8.11 Organisation culture

A construction firm may face challenges in adopting a new technology due to aversion of stakeholders or workers in accepting a change in the current workflow (Hong, et al., 2018; Delgado, et al., 2019). They tend to maintain their traditional and old-school working mindset because they are too used to carry out their tasks in a conventional way, thus they may feel reluctant to adopt new technology. Such an attitude is considered as a significant inhibitor of safety technology adoption. In the UK, Ayinla and Adamu (2018) identified that elder professionals tend to perceive more traditionally than younger professionals, and the elder groups are usually at the top management levels, which implies that they are often the decision-makers of technological adoption. Accordingly, their attitudes can result in a knock-on effect on the firm's technological development. Furthermore, a systematic literature review performed by Son, Lee and Kim (2015) uncovered that a conducive organisational culture is essential for technology implementation in construction projects.

2.8.12 Social influence

Social influence is a psychological aspect where construction practitioners may be influenced to accept a technology if they discern the utilisation of the particular technology is prevailing among the other practitioners (Zhang, et al., 2020). According to the study of Choi, Hwang and Lee (2017) in the US, there is a positive relationship between social influence and the intention to adopt safety technology. Early adopters are more conscious about social influence as opposed to late adopters. This is due to their curiosity towards new technology in the market. Besides, Tsai, Mom and Hsieh (2014) also stated that influence from partners who have adopted a particular technology will indirectly act as a driver to technology adoption.

2.8.13 Organisation technology readiness

Organisation technology readiness refers to state of preparedness of an organisation to adopt a technology. This readiness is associated with the firm's availability of resources like capital, knowledge and expertise to adopt a technology. A study conducted in Taiwan revealed that the decision to adopt technologies is strongly influenced by organisation technology readiness (Mom, Tsai and Hsieh, 2014). The higher the level of readiness, the chance of successful adoption will be higher as well (Chen, et al., 2019).

2.8.14 Organisation data security

Data security and encryption are the most pivotal concerns in the development of safety technologies. Construction stakeholders tend to consider if the technology will induce any security or privacy threats to their projects or organisations. In some previous studies, data confidentiality is the most crucial consideration in the implementation of BIM (Hong, et al., 2018), RFID and mobile technology (Osunsanmi, Oke and Aigbavboa, 2019). Similarly, cybersecurity is also the main struggle for construction organisations to adopt IoT in their projects (Badri, Boudreau-Trudel and Souissi, 2018).

2.8.15 Personal privacy

Choi, Hwang and Lee (2017) who studied the use of wearable sensing devices in safety management highlighted that perceived privacy issue is one of the inhibiting factors of adopting the safety technology. This is due to the disinclination of workers towards sharing their personal information that may pose harm to them. Particularly, they might feel uneasy to share their location information to be monitored through the wearable devices during idle period. Moreover, invasion of worker's privacy has also been found as a key factor hindering the adoption of computer vision technologies (Seo, et al., 2015) and drone (Gheisari and Esmaeili, 2019).

2.8.16 Perceived vulnerability

Perceived vulnerability refers to the worker's awareness of the likelihood that they may encounter health risk. According to Zakaria, et al. (2018), there is a link between situational awareness and technology adoption. The project team leader who acts as the decision-maker will allocate resources to adopt a technology based on the levels of awareness. Owing to the dirty, dangerous and difficult nature of the construction industry, construction workers are constantly exposed to various safety risks while working in such hazardous working environments. If they are aware that such environments are threatful to their health and safety, they are more likely to discern that the technology is advantageous to their current situation and tend to accept adopting such technology (Choi, Hwang and Lee, 2017). An earlier study in the US also stated that perceived vulnerability is a prominent factor of adopting artificial intelligence in construction projects (Okpala, Nnaji and Karakhan, 2020).

2.8.17 Perceived usefulness

Perceived usefulness is based on the potential benefits of the technology. It is associated with the beneficial enhancements attainable through technology adoption as perceived by the construction stakeholders (Hong, et al., 2018). According to Zhang, et al., (2020), construction practitioners are likely to adopt technology such as VR if they believe that such technology can achieve desired safety performance and other project outcomes like maximisation of productivity and efficiency. Moreover, other past studies have also reported that perceived usefulness will affect the behavioural intention to adopt safety technology (Choi, Hwang and Lee, 2017; Tsai, Mom and Hsieh, 2014; Nikas, Poulymenakou and Kriaris, 2007; Son, Lee and Kim, 2015). This is particularly related to those technology followers, also known as late technology adopters, who are likely to adopt a new technology based on the perceived usefulness (Fernandes, et al., 2006).

2.8.18 Personal motivation

Personal motivation is the degree to which the practitioners are motivated to utilise the technologies. It entails a range of triggers that entice them to adopt new technology (Hong, et al., 2018). The motivation is influenced by the perceived usefulness and drawbacks of adopting a certain technology. Several studies reported that motivation is a critical aspect for the adoption of certain technologies in construction projects (Okpala, Nnaji and Karakhan, 2020; Tsai, Mom and Hsieh, 2014; Ding, et al., 2015). On the contrary, Choi, Hwang and Lee (2017) have not found any significant relationship between motivation and intention to adopt wristband for safety management.

2.8.19 Government promotion and initiative

The government plays a key role in boosting technology adoption in the construction industry (Low, Arain and Tang, 2019; Tsai, Mom and Hsieh, 2014). This is because the government can take initiative to encourage the development and application of technologies for safety purposes (Chen, et al., 2019). In fact, government promotion will create and provoke awareness, knowledge and interest among the construction practitioners to adopt new technology. This can be done by the government through providing incentives to captivate more investment in new technologies. This incentive is immensely beneficial especially for those small and medium-sized construction firms that have limited resources and have to rely on government funding to ensure successful technology adoption (Zakaria, et al., 2018). On the other hand, Cai, et al. (2020) found that government support on the academic research and utilisation of automation and robotics in construction projects are contributors to the adoption of these technologies.

2.8.20 Government regulations

The construction industry operates in a dynamic environment where government regulations and building standards are necessary to monitor the construction activities and provide a safe workplace for the workers. This essentially indicates that the construction industry is highly regulated and this may influence the decision making process on technology adoption (Zakaria, et al., 2018). In view of this, the significance of government regulations in driving the adoption practice and motivating the construction firms to be innovative cannot be overlooked (Hong, et al., 2018; Nnaji, et al., 2020; Ahuja, et al., 2018). This is in line with the research conducted by Ayinla and Adamu (2018) in the UK, where the construction companies adopted BIM due to pressure from government regulations. Likewise, the contractors in the Nigerian construction industry also perceived that government support through legislation is a driver to adopt new technology (Abubakar, et al., 2014). Nonetheless, Chen, et al. (2019) on the other hand denied the significance of government pressure in technology adoption in the context of Chinese construction industry.

2.9 Summary of influential factors of safety technology adoption in construction projects

The following Table 2.5 and 2.6 present the summary of influential factors of safety technology adoption in construction projects sorted out from the literature review.

Note to Table 2.5

Authors: **1**[a]-Choi, Hwang and Lee (2017); **2**[a]-(Enshassi, Ayyash and Choudhry (2016); **3**[a]-Fernandes, et al. (2006); **4**[a]-Gheisari and Esmaeili (2019); **5**[a]-Nnaji, et al. (2019); **6**[a]-Nnaji, et al. (2020); **7**[a]-Nnaji and Karakhan (2020); **8**[a]-Okpala, Nnaji and Karakhan (2020); **9**[a]-Osunsanmi, Oke and Aigbavboa (2019); **10**[a]-Seo, et al. (2015); **11**[a]-Zhang, et al. (2020); **12**[abce]-Cai, et al. (2020a); **13**[abce]-Delgado, et al. (2019); **14**[b]-Kamal, Yusof and Iranmanesh (2016); **15**[b]-Low, Arain and Tang (2019); **16**[b]-Sepasgozar and Davis (2018); **17**[b]-Zakaria, et al. (2018); **18**[be]-Ahuja, et al. (2018); **19**[bcde] -Mom, Tsai and Hsieh (2014)**;20**[bcde]-Tsai, Mom and Hsieh (2014); **21**[bcdef]-Hong, et al. (2018); **22**[cd]-Ayinla and Adamu (2018); **23**[cd]-Chen, et al. (2019); **24**[d]-Son, Lee and Kim (2015); **25**[f]-Abubakar, et al. (2014); **26**[f]-Ding, et al. (2015); **27**[f]-Nikas, Poulymenakou and Kriaris (2007).

Indicators: [a] Safety management; [b] Productivity enhancement; [c] Cost reduction; [d] Time reduction; [e] Quality enhancement; [f] Collaboration improvement

Table 2.5: Summary of influential factors of safety technology adoption in construction projects.

Ref.	Influential Factors	1[a]	2[a]	3[a]	4[a]	5[a]	6[a]	7[a]	8[a]	9[a]	10[a]	11[a]	12[abce]	13[abce]	Total
1	Technology complexity	✓	✓			✓	✓	✓	✓					✓	7
2	Capital cost of technology						✓					✓	✓	✓	4
3	Level of training required					✓		✓						✓	3
4	Technology brand and reputation in industry					✓	✓					✓			3
5	Proven technology effectiveness					✓							✓	✓	3
6	Personal privacy	✓			✓						✓				3
7	Perceived usefulness	✓		✓								✓			3
8	Top management support			✓			✓								2
9	Social influence	✓										✓			2
10	Perceived vulnerability	✓							✓						2
11	Personal motivation	✓							✓						2
12	Technology reliability						✓								1
13	Technology compatibility					✓									1
14	Size of organisation			✓											1
15	Expertise and skill of project team			✓											1
16	Organisation culture													✓	1
17	Organisation data security									✓					1
18	Government promotion and initiative												✓		1
19	Government regulations						✓								1
20	Organisation technology readiness														0

Table 2.5 (Cont'd)

Ref.	Influential Factors	14[b]	15[b]	16[b]	17[b]	18[be]	19[bcde]	20[bcde]	21[bcdef]	22[cd]	23[cd]	24[d]	25[f]	26[f]	27[f]	Total
1	Top management support				✓	✓		✓			✓	✓		✓	✓	7
2	Government regulations				✓	✓			✓	✓	✓		✓			6
3	Capital cost of technology		✓			✓		✓		✓						4
4	Expertise and skill of project team					✓		✓	✓						✓	4
5	Perceived usefulness							✓	✓			✓			✓	4
6	Government promotion and initiative		✓		✓			✓			✓					4
7	Technology compatibility					✓					✓	✓				3
8	Personal motivation							✓	✓					✓		3
9	Organisation culture								✓	✓		✓				3
10	Level of training required							✓		✓						2
11	Technology complexity					✓					✓					2
12	Organisation technology readiness						✓				✓					2
13	Technology brand and reputation in industry			✓												1
14	Proven technology effectiveness								✓							1
15	Technology reliability					✓										1
16	Size of organisation	✓														1
17	Social influence							✓								1
18	Organisation data security								✓							1
19	Perceived vulnerability				✓											1
20	Personal privacy															0

Table 2.6: Final summary of influential factors of safety technology adoption in construction projects.

Ref	Influential factors	Total Frequency
1	Technology complexity	9
2	Top management support	9
3	Capital cost of technology	8
4	Perceived usefulness	7
5	Government regulations	7
6	Government promotion and initiative	5
7	Level of training required	5
8	Personal motivation	5
9	Expertise and skill of project team	5
10	Proven technology effectiveness	4
11	Organisation culture	4
12	Technology brand and reputation in industry	4
13	Technology compatibility	4
14	Personal privacy	3
15	Perceived vulnerability	3
16	Social influence	3
17	Organisation data security	2
18	Organisation technology readiness	2
19	Technology reliability	2
20	Size of organisation	2

2.10 Potential strategies to enhance safety technology adoption in construction projects

2.10.1 Integrate technological requirements in construction projects

Nnaji and Karakhan (2020) advocated the view that certain technological requirements can be incorporated and mandated in contract documents by the employers. This approach can boost the application of innovative safety solutions to enhance safety management in the construction industry. Moreover, in advance of choosing a contractor to execute a construction project, utilisation of safety technology can be identified as a key basis to evaluate the contractor's past performance pertaining to occupational health and safety (Enshassi, Ayyash and Choudhry, 2016). This, in turns, indirectly motivates the contractors to adopt safety technology in their projects.

2.10.2 Implement safety incentives programme within the construction firm

According to Karakhan and Gambatese (2018), incentive is meant to shape the workers' behaviours and enhance their safety performances. In essence, incentive is regarded as a motivating behavioural approach. In the context of safety management, workers with satisfying safety behaviour and performance will be rewarded. Such incentive programme can incite the safety awareness among the construction workers (Mohammadi, Tavakolan and Khosravi, 2018), thereby triggering their acceptance of using new technology in work process. On the other hand, Nnaji and Karakhan (2020) also asserted that the employers should offer incentives to those contractors who take initiatives to implement safety technologies in their construction projects.

2.10.3 Pilot application of safety technology

Construction firms might perceive that some of the technologies in the industry are still immature and not well-developed yet to be utilised in actual projects. In light of this, pilot test can be inaugurated by the technology manufacturers (Cai, et al., 2020) and the government (Yuan, Yang and Xue, 2019; Suprun and Stewart, 2015). Pilot application can advance the users' understandings on the tested technology. This programme can also ensure the practicality and feasibility of the technology. Besides, any incompatibility of the technology with the existing practices can be detected through the pilot testing. Thereafter, redesign of the software or machines can be performed to tackle the issue. Given that proven effectiveness of a technology is one of the adoption considerations, pilot application can yield motivating effects to adopt the tested technology by offering evidence base to the firms (Ayinla and Adamu, 2018).

2.10.4 Organise technology exhibitions

Considering that technological knowledge is essential for users prior to adopting technology, organising technology exhibition is therefore a potential strategy to grease the wheels of safety technology adoption. According to Sepasgozar, Davis and Loosemore (2018), technology exhibition is an event or market place that allows the potential adopters to explore feasible means to enhance their existing practices or conquer their current issues. It is pinpointed that technology exhibition is far more effective than the other adoption strategies as it is able to aim a huge number of potential adopters at only one place.

This approach is expedient as it offers a conducive environment for the technology vendors to interact with the potential adopters. In other words, the vendors can demonstrate and explain the technologies physically to the potential adopters, thus allowing them to learn and gather information regarding the newly developed technologies available in the industry (Sepasgozar and Davis, 2018). In such a context, verbal communication can streamline their understandings of a particular technology, especially in the circumstances when the technology is complicated. This is particularly beneficial for those potential adopters that have none or little technology knowledge. Besides, this exhibition also allows the customers to compare the technological products offered by different vendors. By provoking awareness towards these products through the exhibition, the construction firms' adoption intentions are likely to be persuaded and steered towards investing and implementing these technologies in their projects. With this in view, technology exhibition is regarded as a notable medium for technology transfer which ultimately aids in elevating the adoption decision process (Sepasgozar and Davis, 2019).

2.10.5 Provide government incentives

As aforementioned, the initial investment cost of technology has been recognised as a prominent factor of safety technology adoption. In view of this, Ayinla and Adamu (2018) advocated the view that government can contribute to give a lift on the technology adoption through granting incentives to various construction firms. Accordingly, such an effort can shave off the implementation cost directly, subsequently expediting the company's participation in new technology (Yuan and Yang, 2020). Indeed, such public financial support is an enticement to captivate more potential adopters to implement technologies in their projects (Suprun and Stewart, 2015). It has also been studied that most of the clients in the Chinese construction industry acknowledged that government policies are immensely valuable for the adoption of technology such as BIM (Yuan, Yang and Xue, 2019). Besides, government incentives are also beneficial in the development of technical expertise (Ahuja, et al., 2018), which is highly critical for facilitating the diffusion of technologies. Apart from this, Yuan, Yang and Xue (2019) further proffered that tax exemption would be able to invigorate the technological application in the industry.

2.10.6 Establish government mandates

In an European study, Delgado, et al. (2019) emphasised that both incentives and mandates are drivers of technology adoption, nonetheless, mandates are far more effective than incentives in terms of expediting the adoption process. In the UK, the government has enacted a mandate for the application of BIM particularly for public projects and have shown satisfying adoption outcome. Similarly in Canada, it has been denoted that setting BIM as a mandatory provision for public projects can galvanise the rate of BIM adoption (Porwal and Hewage, 2013). This is also in line with the research conducted by Ayinla and Adamu (2018) in the UK where it has been argued that the government mandate is an effective approach as some construction firms tend to stick with traditional practices. In this regard, the government can stimulate awareness of firms on enhancing safety through technological application. Darko, et al. (2018) also strengthened the point that government mandates can significantly bolster the adoption of technology as these mandatory regulations will exert regulatory strain on the companies to apply technologies in their projects in order to fend off amercement as a result of non-compliance.

2.10.7 Revamp organisation culture and attitude

According to Ayinla and Adamu (2018), a competent change management approach is a feasible strategy to raise the adoption level of technology in construction projects. Senior management levels of construction firms should exercise top-down motivation strategy to wipe out the traditional mind-set of conducting works. The active involvement of top management will vigorously transform the workers' safe working concepts. In this vein, their positive attitudes, support and commitment are indispensable aspects to initiate advanced and efficacious technological adoption plan. Such a supportive organisation culture can provoke the workers' concern towards safety, ultimately triggering the acceptance of technological application in work processes (Mohammadi, Tavakolan and Khosravi, 2018).

2.10.8 Reinforce training and education

Successful adoption of safety technology can never be achieved if the project team is poor in technology knowledge. In fact, education and training are tremendously essential to equip the project team and workers with necessary safety technology knowledge to carry out their works. Besides, such approach can also stimulate awareness of a particular technology concept. This implies that the technical capabilities of the workers can be augmented, which are crucial to the successful technology diffusion (Manley and Mcfallan, 2006). As such, government along with the decision-makers in the industry should encourage the setting up of training board aiming to train the construction practitioners pertaining to innovative safety management. Construction firms on the other hand should also take regulative measures to reinforce the technical skills of the workers (Enshassi, Ayyash and Choudhry, 2016).

Additionally, construction firms can hire new workers who are technically sound and have the ability to train and guide the existing team. It is also further emphasised that training should not just only be provided to the workers in a construction firm, but the subcontractors and suppliers should also undergo the necessary training to ensure successful adoption of technologies in construction projects (Ahn, Kwak and Suk, 2016).

2.10.9 Recruit new graduates

In a past study, Manley and Mcfallan (2006) advocated hiring new graduates as a human resource approach to raise the innovativeness of construction firms. Owing to the graduates' exposures to university courses based on state-of-the-art technologies in the construction industry, graduates are viewed as valuable in the perspectives of innovative companies. Besides, some innovative companies deduce that elder employees might be uncreative and obstinate in advancement, hence, they tend to favour young and active workforce over the elder ones. Furthermore, Ayinla and Adamu (2018) suggested training fresh graduates to utilise their knowledge and skills for technology application. In light of this, the quality of higher education is a pivotal strategy (Suprun and Stewart, 2015). More technology-related courses should be covered in the universities to immerse the graduates in technical knowledge and expertise which can contribute to the construction industry (Ahuja, et al., 2018).

2.10.10 Collaboration between industry, universities and research institutes

A tenacious research and development base of technology could aid to raise the technology adoption level. University and research institutes can contribute by developing new technology and designing technology that fits for the construction projects. Thereafter, their research ideas can be transferred to application in actual projects. Besides, they can also validate research outcomes and generate new solutions to tackle the identified issues hampering adoption and further development (Suprun and Stewart, 2015). Furthermore, Shafiq and Afzal (2020) also asserted that the construction industry and academia should work together to encourage construction safety. More scholarly attention should be given to the safety technologies in the industry. Given this, the government should grant funding to support R&D efforts such as setting up R&D centres (Darko, et al., 2018) to eliminate the hindrance of high research cost and eventually trigger interest in innovation investment (Suprun and Stewart, 2015).

2.11 Summary of the potential strategies to enhance safety technology adoption in construction projects

The following Table 2.7 presents the summary of potential strategies to enhance safety technology adoption in construction projects sorted out from the literature review.

Note to Table 2.7

Authors: **1**-Ahn, Kwak and Suk (2016); **2**-Ahuja, et al. (2018); **3**-Ayinla and Adamu (2018); **4**-Cai, et al. (2020); **5**-Darko, et al. (2018); **6**-Delgado, et al. (2019); **7**-Enshassi, Ayyash and Choudhry (2016); **8**-Karakhan and Gambatese (2018); **9**-Manley and Mcfallan (2006); **10**-Mohammadi, Tavakolan and Khosravi (2018); **11**-Nnaji and Karakhan (2020); **12**-Porwal and Hewage (2013); **13**-Sepasgozar and Davis (2018); **14**-Sepasgozar and Davis (2019); **15**-Sepasgozar, Davis and Loosemore (2018); **16**-Shafiq and Afzal (2020); **17**-Suprun and Stewart (2015); **18**-Yuan, Yang and Xue (2019); **19**-Yuan and Yang (2020).

Table 2.7: Summary of potential strategies to enhance safety technology adoption in construction projects.

Ref	Potential Strategies	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
1	Provide government incentives		✓	✓														✓	✓	✓	5
2	Establish government mandates			✓		✓	✓						✓								4
3	Pilot application of safety technology			✓	✓													✓	✓		4
4	Recruit new graduates		✓	✓						✓								✓			4
5	Implement safety incentives programme within construction firm								✓		✓	✓									3
6	Organise technology exhibitions													✓	✓	✓					3
7	Reinforce training and education	✓						✓		✓											3
8	Collaboration between industry, universities and research institutes					✓											✓	✓			3
9	Integrate technological requirements in construction projects							✓				✓									2
10	Revamp organisation culture and attitude			✓							✓										2

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

Chapter 3 mainly discussed the research methodology implemented in this study. This chapter focused on quantitative research, research instrument, sampling design, data collection method, questionnaire survey design and pilot study. Additionally, data analysis techniques were also outlined in this chapter.

3.2 Quantitative research

According to Kumar (2011), research methodology is a systematic way to answer research problems. It comprises a planned series of actions to conceptualise and design research (VanKooten, 2019). There are two forms of research, namely qualitative research and quantitative research. These two types of research are often integrated by researchers to conduct their studies and this is known as mixed-method research.

Generally, qualitative research is associated with circumstances embracing quality which aims to explore the human's behaviour (Kothari, 2003). Qualitative data is gathered in the respondent's context and the connotation of the data is construed by the researchers. The scope of inquiry in qualitative research is broad and it can generate abundant and detailed data from the sample through various qualitative techniques like interviews and focus group (VanderStoep and Johnston, 2009). On the contrary, quantitative research is used to generate research outcomes on the basis of measurement of quantity. This method is used to investigate the relationship between quantifiable variables. Quantitative data can be analysed through a wide range of statistic techniques (Creswell and Creswell, 2018). For this study, the quantitative approach was adopted to determine the potentials of safety technologies, influential factors of safety technology adoption and potential strategies to raise the technology adoption in construction projects. Through this approach, a large sample was included in this study that precisely reflected the population.

3.3 Research design

A research design was formulated upon identifying the research problems. The research design is an investigation framework used by researchers to acquire answers to resolve research questions in an objective, precise and valid manner. It is vital to allow the researchers to form a concept regarding the procedures and tasks to be conducted to accomplish the entire study (Kumar, 2011). In other words, it is an advance plan of the data collection and data analysis techniques for this research (Kothari, 2003). Figure 3.1 illustrates the research flow of this study. As a whole, this research design has streamlined the entire research process and enhanced the efficiency of the research.

3.4 Research instrument

A questionnaire survey was employed in this research to evaluate the respondents' perceptions on the potentials of technologies in construction safety management, factors influencing safety technology adoption and strategies to enhance the adoption level. This research instrument comprises a list of questions which allows the respondents to read, interpret and answer the questions prepared. This mechanism is economical and practical for large sample and it furnishes greater anonymity to the respondents (Kumar, 2011). Additionally, it is an effective technique used to realise quantifiability and objectiveness (Darko, et al., 2018). Besides, this approach has also been extensively adopted to rank relevant variables of technology adoption in construction management studies (Mom, Tsai and Hsieh, 2014; Manley and Mcfallan, 2006; Nikas, Poulymenakou and Kriaris, 2007). The questionnaires were formulated using web-based survey administration platform named Google Form. The link to the questionnaire survey generated by the Google Form was sent to the respondents through email or social media such as WhatsApp and LinkedIn.

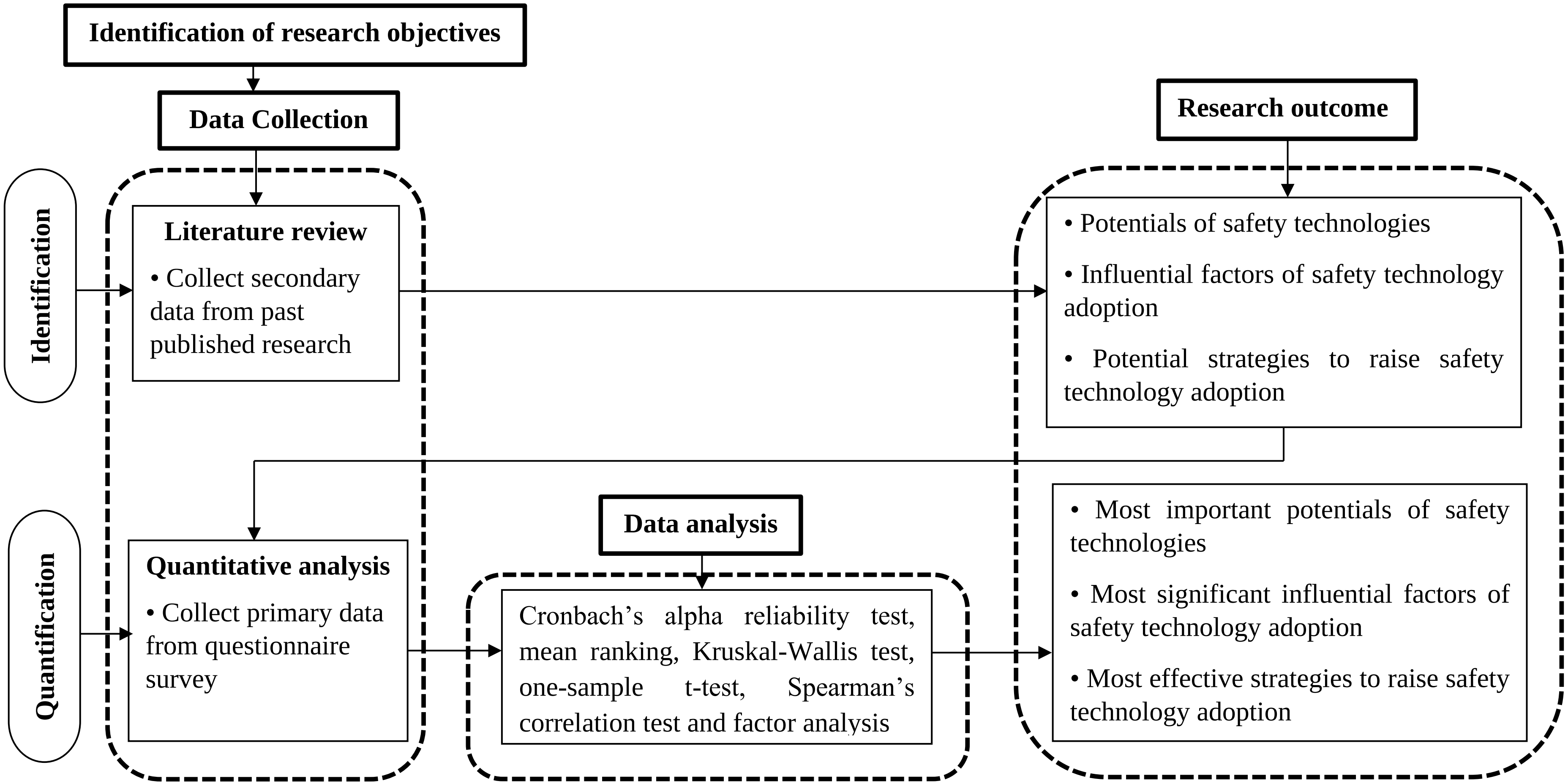

Figure 3.1: Research Flowchart.

3.5 Sampling design

Prior to the commencement of data collection, sampling design was conducted to acquire a sample from a given population. It involves determining the method adopted by researcher to choose a sample (Kothari, 2003). Sampling design is vital as Kumar (2011) emphasised that it can control cost within budget. For this study, since there are budget and time limitations, thus it is unfeasible and impracticable to collect data from the whole populations. This also explains why sampling design is crucially significant in this study. The sampling was designed in a way that the target respondents absolutely represented the study populations. In this study, the sampling design encompassed determining the sampling method, target respondents and sampling size.

3.5.1 Sampling method

Generally, sampling techniques can be categorised into probability sampling and non-probability sampling. The basic notion of probability sampling is random sampling, which covers systematic sampling, stratified sampling and cluster sampling where the probability of each element to be encompassed in the sample can be determined (Kumar, 2011). It ensures every member of the population have the same opportunities to be chosen in the study and it is effective to overcome selection bias (Field, et al., 2006). Conversely, the elements included in a non-probability sampling are not random. This type of sampling entails convenience sampling, judgement sampling and quota sampling (Kothari, 2003), and it can be employed to attain a representative sample (Darko, et al., 2018).

For this study, two non-probability sampling techniques were adopted, namely convenience sampling and snowball sampling, which are commonly used in previous construction management studies (Yap, et al., 2020a; Bagaya and Song, 2016). In the convenience sampling, the respondents are chosen in reliance on their convenience and availability (Shafiq and Afzal, 2020; Kothari, 2003; Creswell and Creswell, 2018; VanderStoep and Johnston, 2009). It was adopted mainly due to the ease with which the respondents can be approached. On the other hand, snowball sampling was employed to achieve a sound overall sample size. This is achieved through the sharing of information by the respondents via referral and social networks (Darko, et al., 2018). The surveyed respondents were asked to share more information pertaining experienced construction practitioners in the industry, particularly those with adequate knowledge of safety technologies. The snowballing process was continued until the required sample size has been attained.

3.5.2 Target respondents

Owing to numerous options of populations, the target population must be identified in this study. Regardless of the respondents' age, educational levels and working experiences, the respondents targeted for this research are the key construction practitioners based in Klang Valley region, comprising developers, consultants and contractors. This region is also known as Greater Kuala Lumpur, which includes major cities in the state of Selangor and is the epicentre of growth in Malaysia (Yap and Chow, 2020). As reported by Department of Statistics Malaysia (2021), most of the construction activities in Malaysia are undertaken in this region. The reason for engaging a variety of professions in the construction industry in this survey is to gain a rich and balanced view of the study. Besides, the diversity of respondents also allows maximising the quality of information in which different perspectives in the industry are represented. They are qualified as respondents for data collection due to their exposure to construction activities, thus they have adequate industrial knowledge and experience regarding the application and adoption of safety technologies in construction projects. Their viewpoints and insights can definitely contribute to this study.

3.5.3 Sampling size

Kothari (2003) stressed the significance of determining the sample size in the sampling process. An adequate sampling size is imperative to prevent sampling bias and the data acquired is more likely to be accurate and precise. In this regard, Yap, Low and Wang (2017) highlighted that the sample size greater than 30 and less than 500 are sufficient for most research. Additionally, the minimum sample size to conduct factor analysis is 100 (Gorsuch, 2015). In this research, the minimum sample size of 120 was targeted with minimum 30 respondents for each sampling group, comprising developers, consultants and contractors.

3.6 Data collection

According to Kumar (2011), there are two ways to collect data, either from primary sources such as interview and questionnaire survey or secondary sources such as government documents and past published research studies. For this study, both methods of data collection were adopted to acquire a broad perspective and understanding about the potentials of safety technology as well as the influential factors and strategies of safety technology adoption in construction. The primary data were obtained through the questionnaire survey distributed to the key construction practitioners comprising developers, consultants and contractors in Klang Valley, Malaysia, whereas the secondary data were obtained by reviewing and extracting the findings of past research. Both of these methods were effective in generating research findings that complied with the research objectives.

3.7 Questionnaire survey design

At the outset of the questionnaire, a brief introduction of the study was presented to enable the respondents to have a basic concept of the research and to acknowledge the three main research objectives of the study prior to answering the survey. Thereafter, a self-completion questionnaire was designed based on prior extensive research studies. It was prepared in a way that presented the notions to the respondents clearly which would bring forth the designated response rate. The questionnaire was broken down into four sections which aimed to gather germane data in relation to the research objectives.

Section A was constructed to obtain information about the respondent's background. Questions in this section were comprised of academic qualification, working experience, current designation and nature of the working company. Section B focused on the potentials of safety technologies in construction projects (10 items). In an attempt to measure how the respondents feel about using advanced technologies particularly for safety management in the future, they were asked to rank 12 types of safety technologies based on their expected effectiveness. In the same section, respondents were requested to rank the potentials of safety technologies according to their degrees of agreement. On the other hand, Section C included rating the factors influencing safety technology adoption in construction projects (20 items). The respondents were then required to rate the potential strategies to raise safety technology adoption (10 items) in Section D. The length of the questionnaire was limited to 15 minutes to prevent the respondents feeling exhausted and to promote a higher quality of response. In this questionnaire, five-point Likert scales were applied in Section B, Section C and Section D. The fundamental grounds of adopting the five-point Likert scale were its capabilities to ease the respondents to express their opinions and engender unambiguous findings (Darko, et al., 2018). The five-point Likert scale used in the questionnaire is presented in Table 3.1.

Table 3.1: Five-point Likert Scale used in the questionnaire.

Weighting	Section B	Section C	Section D
1	Strongly disagree	Strongly disagree	Ineffective
2	Disagree	Disagree	Somewhat effective
3	Neutral	Neutral	Effective
4	Agree	Agree	Very effective
5	Strongly agree	Strongly agree	Extremely effective

3.8 Pilot survey

After preparing the questionnaire, a pilot study was conducted by engaging 30 targeted respondents to uncover any possible problems of the questionnaires before actual data collection. The respondents were asked to advise on the refinement of contents in the questionnaire. This exercise allows various opinions concerning the content and sequence of the questions to be deliberated (Shafiq and Afzal, 2020). Accordingly, the outcome of the pilot study could eradicate contents with tautology (Yuan, Yang and Xue, 2019) and assure all the contents in the questionnaire are explicit and comprehensive (Yap and Lee, 2019). It ultimately ensures the questionnaire contents are in compliance with the research objectives.

3.9 Data analysis

Once the final questionnaire was disseminated to the target respondents and the designated response rate has reached, the collected data were checked to manage missing data and discrepancies of responses (Tsai, Mom and Hsieh, 2014). Besides, the data to be used for analysis was also coded to streamline the entire data analysis process. Thereafter, data analysis was conducted statistically to explore evidential data that would be beneficial for the study and to interpret the data to deduce a conclusion. The responses collected were addressed and analysed via Statistical Practices for the Social Sciences (SPSS). SPSS is a robust data analysis package that is capable of managing complicated statistical procedures (Pallant, 2011).

There were six data analysis techniques used in this study, namely Cronbach's alpha reliability test, one-sample t-test, mean ranking, Kruskal-Wallis test, Spearman's correlation test and factor analysis. These techniques ultimately aimed to investigate the most significant potentials of safety technologies, influential factors and potential strategies of safety technology adoption in construction projects.

3.9.1 Cronbach's Alpha Reliability Test

Cronbach's alpha reliability test is a statistical technique employed to analyse the internal consistency or reliability of data attained from the questionnaire (Hong, et al., 2018). It can be used to evaluate the accuracy of each group rearrangement (Mom, Tsai and Hsieh, 2014). Besides, it is an indicator of average correlations among the samples (Lin, et al., 2008). As aforementioned, the questions in Section B, Section C and Section D of the questionnaire were rated using five-point Likert scales. In this case, Cronbach's alpha reliability test was employed to estimate the level of reliability of the five-point Likert scale measurement. The formula of Cronbach's alpha reliability test is shown in Eq. 3.1 (Jarkas, Al Balushi and Raveendranath, 2015).

$$a = \frac{n}{n-1} - \left(\frac{1 - \sum Vi}{Vtest}\right) \tag{3.1}$$

where,

n = number of items;

Vi = variance of the scores on each item;

V = total variance of the overall scores.

The alpha values vary from 0 to 1 in which a higher alpha value indicates higher reliability, consistency and stability (Ho and Dzeng, 2010). High alpha value is also crucial as it ensures the data is free from random error (Pallant, 2011). Son, Lee and Kim (2015) stated that a sample with an alpha value greater than 0.70 is regarded as reliable, meaning the content of the questionnaire is consistent. Table 3.2 shows the levels of consistency for various ranges of Cronbach's alpha coefficient.

Table 3.2: Cronbach's alpha reliability coefficient ranging scale.

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

3.9.2 One-sample T-tests

With a view to determine the significance of the variables, one-sample t-test was employed to assess whether the mean score of a sample as rated by all the respondents is significantly distinct from a known value (Kazaz and Ulubeyli, 2004; Callistus and Clinton, 2016; Aksorn and Hadikusumo, 2008). Since only sample standard deviation was known in this study, one-sample t-test was used to test and determine the potentials of safety technologies as well as the influential factors and strategies that contribute a great impact to the safety technology adoption. For this study, a test value of 3 which acts as the neutral position was used to determine whether the mean score is significantly dissimilar from 3. The t value was calculated using Eq. 3.2 (Ross and Willson, 2013).

$$t = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}} \tag{3.2}$$

Where,

$\bar{x}$ = sample mean;

μ = proposed constant for the population mean;

s = sample standard deviation;

$\frac{s}{\sqrt{n}}$ = estimated standard error of the mean.

In order to construe the test result, the test significance level was compared in opposition to a 5% level of significance (Low and Quek, 2006). If a specific variable has a significance value greater than 0.05, it indicates that the respondents do not discern this variable as a significant variable (Yap, et al., 2018). On the contrary, significance value smaller than 0.05 represents that the factor is statistically significant to the respondents. There is also another way to define the t-test result, which is to compare the t-value in contrast to the critical t-value established in the t-distribution table (Ross and Willson, 2013; Low and Quek, 2006).

3.9.3 Mean ranking

This study included using mean to assess the ranking of each factor. It was used to determine the level of significance of each factor as perceived by the respondents (Wang and Yuan, 2011). In a case when two or more factors have similar mean value, the factor with a smaller standard deviation carries a greater significance (Yap and Lee, 2019). This study followed the approach of Tsai, Mom and Hsieh (2014) to benchmark the mean score of 4 in the five-point Likert scale as significant, for those factors that fall below this cut-off point yet regarded as being significant were still taken into account for data analysis, for instance, rankings with a neutral value of 3. Once the mean for each variable has been evaluated, the variables were then ranked in accordance with the calculated mean. The mean ($\bar{x}$) and standard deviation (σ) were computed using Eq. 3.3 and Eq. 3.4 respectively (Wan, et al., 2014).

$$\bar{x} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{3.3}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{x})^2}{(n-1)}} \qquad (3.4)$$

where,

x_i = observed values of the sample $(x_1, x_2, x_3 \ldots, x_n)$

n = number of observations in the sample

3.9.4 Kruskal-Wallis Test

Since the data obtained in this study was non-parametric, the Kruskal-Wallis Test was adopted. The Kruskal-Wallis test, also known as H-test, is a non-parametric test which is used to assess the significant ranking difference between the respondent groups (Manley and Mcfallan, 2006). Since it is a non-parametric test, the results were measured on the basis of score rankings. It does not necessitate certain requirements concerning the shape of data distribution (Tsai, Mom and Hsieh, 2014).

Based on the findings of Hecke (2012), the results generated using the Kruskal-Wallis test would have greater power as compared to one-way anova. This is because anova necessitates several assumptions to work effectively such as the normal distribution of data and equivalent population variance. In the circumstance when the data are totally not distributed normally, one-way anova may generate unreliable p-value. For that reason, such finding has significantly strengthened the grounds for employing the Kruskal-Wallis test for this study. Furthermore, instead of adopting the Mann-Whitney test (U-test) in this study, H-test was used because this test allows comparing more than two groups (Pallant, 2011).

According to Shafiq and Afzal (2020), it can be concluded that the respondents have identical opinions concerning the questions in the questionnaire if the significance value is more than 0.05. On the contrary, a value that is equal to or smaller than 0.05 indicates significant differences in perceptions across the respondent groups. The formula of the Kruskal-Wallis test was computed using Eq. 3.5 (Hecke, 2012).

$$H = \left[\frac{12}{n\,(n+1)} \sum_{t=1}^{k} \frac{{R_i}^2}{n_i}\right] - 3\,(n+1) \quad (3.5)$$

where,

n = total sample size (n_1+ n_2 + … + n_k);

k = number of samples;

n_i = sample size in the ith sample;

R_i = sum of the ranks assigned to n_i values of the *i*th sample.

3.9.5 Spearman's Correlation Test

Spearman's correlation test is a non-parametric test and is commonly used by researchers to evaluate the strength of the relationship among various respondents concerning various factors (Gunduz and Ahsan, 2018). Essentially, it was undertaken to assess the extent of consensus between the rankings (Yap and Lee, 2019; Yu, et al., 2014). For this study, it was used to identify the extent of association between the influential factors and potential strategies of safety technology adoption. This test does not necessitate normal distribution and homogeneity of the data (Gunduz and Ahsan, 2018), which is the major ground for adopting this technique in this study. Spearman's correlation coefficient was calculated using Eq. 3.6 (Gunduz and Ahsan, 2018).

$$r_s = 1 - \frac{6\sum d^2}{N(\,N^2-1\,)} \quad (3.6)$$

where,

d = difference between ranks of corresponding variables;

N = number of variables (20 influential factors of safety technology adoption)

Other than showing the strength of the relationship, this test also shows the direction of the relationship, which is either positive or negative. Positive correlation occurs when one variable increases as other variable increases, vice versa (Pallant, 2011). The correlation coefficient ranges from -1 to 1, where -1 represents disagreement while +1 presents agreement. In detail, Table 3.3 discloses the strength of correlations with their respective interpretations.

Table 3.3: Correlation strength between variables.

Correlation Strength	Interpretations
0.90 to 1.00 (-0.90 to -1.00)	Very high positive (negative) correlation
0.70 to 0.90 (-0.70 to -0.90)	High positive (negative) correlation
0.50 to 0.70 (-0.50 to -0.70)	Moderate positive (negative) correlation
0.30 to 0.50 (-0.30 to -0.50)	Low positive (negative) correlation
0.00 to 0.30 (0.00 to -0.30)	Negligible correlation

3.9.6 Factor Analysis

Using ranking as an only method to reduce the factors will lead to poor accuracy and precision. In other words, a ranking analysis may cause some significant factors to be mislaid below the cut-off point, thus this method is insufficient and ineffective to investigate the factors of safety technology adoption in construction projects (Mom, Tsai and Hsieh, 2014). Hence, factor analysis is highly required. Generally, factor analysis is a data reduction statistical technique which aims to determine a category of variables that assesses and evaluates identical latent dimensions (Pallant, 2011). In other words, this technique can determine small groups from numerous correlated variables (Nnaji, et al., 2020) and detect the existence of meaningful patterns between the original variables (Yu, et al., 2014). This study encompassed 20 influential factors and factor analysis could statistically determine potential clusters of predictors of safety technology adoption.

For the purpose of ensuring the sufficiency of the samples, the strength of the relationship between the variables was determined via the Kaiser-Myer-Olkin (KMO) and Bartlett's test of sphericity. These two tests are pre-requisites in advance of carrying out the factor analysis. Essentially, this indicates that the factor analysis can only move forward when both of these tests are passed. These two tests were undertaken to investigate whether the original variable correlates, which ultimately determine its suitability for factor analysis (Wu, et al., 2018). According to Nnaji, et al. (2020), KMO ranges from 0 to 1 and the KMO value must be more than 0.5 to be regarded as adequate for good factor analysis. A greater KMO value represents greater common factors among the variables. Besides, in order to pass the Bartlett's test of sphericity, a p-value must be lower than 0.05. As specified by Yap and Lee (2019), this test is employed to assure that the population correlation matrix is not an identity matrix. This is because the existence of identity matrix will cause the factor analysis to be meaningless (Zhang, et al., 2018).

3.10 Summary

All in all, this chapter defined the research method employed for this study, which is quantitative research. Research flow of this study was also designed and illustrated in this chapter. In order to carry out the quantitative research, a questionnaire survey was employed and distributed to the target respondents. Prior to distribution of the questionnaire, a pilot study of the questionnaire involving 30 respondents was conducted to ensure that the questionnaire is well-designed and adequate to achieve the research objectives. The target respondents for this study were developers, consultants and contractors based in Klang Valley, Malaysia. Non-probability sampling methods such as convenience sampling and snowball sampling were adopted for this study. This chapter also identified six data analysis techniques to be used in the following chapter to generate research findings, which comprised Cronbach's alpha reliability test, one-sample t-test, mean ranking, Kruskal-Wallis test, Spearman's correlation test and factor analysis. In short, this chapter aimed to allow the readers to understand the methods or techniques used in data collection and data analysis in this study.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter reports the results of the questionnaire survey. The data obtained were analysed by using the statistical analysis techniques discussed in the previous chapter. The gathered data was rearranged, processed and tabulated through Statistical Package for the Social Sciences (SPSS) and Microsoft Excel. The analysis and discussion in this chapter were meant to answer the research aims and objectives indicated in Chapter 1.

4.2 Pilot Study

A pilot study was first conducted with the industry professionals to examine the clarity, possible response rate, comprehensibility and appropriateness of the questionnaire survey (Son, Lee and Kim, 2015). The sample size for the pilot test was determined in accordance with the Central Limit Theorem (CLT). Chihara and Hesterberg (2019) asserted that CLT is reasonably accurate when the sample size is equal to or greater than 30. Therefore, a total of 35 questionnaires were disseminated to the construction practitioners and 30 questionnaires were returned, which brings a response rate of approximately 85%. All the pilot respondents had undertaken tertiary education and approximately 60% of them had over five years of working experience in the construction industry. Therefore, they are qualified to offer sound judgements for the pilot study. The questionnaires collected were pilot tested through SPSS.

Table 4.1 summarises the alpha values for each section of the questionnaire. Based on Table 4.1, all sections had achieved an alpha value greater than the threshold value of 0.70 needed to assure the internal consistency of the questionnaire (Yap, et al., 2021). This signifies that the internal consistencies among the data were satisfactory, hence, this study is reliable. Considering that there were no further amendments made to the pilot study questionnaires, all the 30 responses gathered were included in the main study.

Table 4.1: Cronbach's coefficient alpha values for the pilot study.

Category of variables	No. of items	Cronbach's alpha
Expected effectiveness of safety technologies	12	0.870
Potentials of safety technologies	10	0.899
Influential factors impacting the adoption of safety technologies	20	0.921
Potential strategies to raise safety technology adoption	10	0.876

4.3 Response Rate

As the outcome of the pilot study revealed that the instrument was reliable and no further amendment on the questionnaire was needed, the questionnaires were disseminated to the targeted respondents via email and other social media such as LinkedIn and WhatsApp. Table 4.2 presents the response rate for both pilot and main study. In total, 385 questionnaires were distributed between January 2020 and February 2020. In order to raise the response rate, follow-up reminders were issued to non-respondents. Approximately 2% of the non-responses was traced to a significant lack of interest in or understanding of safety technologies and their potential advantages to the industry. Over a period of one month, 103 valid responses were collected in the main study and after combining the pilot responses, a total of 133 valid responses were collected. This has contributed to a satisfactory consolidated response rate of 34.55%. As the response rate is greater than 30%, it is considered adequate for a reliable statistical analysis and above the free parameter ratio needed to yield reliable solutions (Yap, et al., 2020b).

Table 4.2: Response rate.

Distribution method	Questionnaire Distributed	Questionnaire Collected	Response rate
Pilot study (E-survey)	35	30	85.71 %

Main study (E-survey)	350	103	29.43 %
Overall	385	133	34.55%

4.4 Profile of Respondents

Table 4.3 summarises the respondent's backgrounds in terms of their positions in company, working experience and academic qualifications. The responses collected comprised 41 (30.8%) from developers, 44 (33.1%) from consultants and 48 (36.1%) from contractors, which offered a reasonable cross section of industry professionals for a balanced view of responses. Among all the respondents, approximately 40% are in managerial positions. With respect to working experience, nearly half (49.6%) of the respondents have over 10 years of working experience, while only 29.3% have five years or less working experience. Besides, majority of the respondents (99.3%) has had a tertiary education such as diploma, bachelor's degree or higher degree. Therefore, it can be deduced that the respondents are considered sufficiently representative of construction practitioners in Malaysia, thus they are qualified to contribute their opinions concerning construction safety technologies to this study. In short, it is believed that the data source of this survey is reliable in terms of adequacy of working experience and a wider range of perspectives towards the adoption of safety technologies in the Malaysian construction industry.

4.5 Reliability of Results

The internal consistency of data attained from the questionnaire was ascertained with the Cronbach's alpha reliability test. Table 4.4 shows the computed coefficient values for four sets of items. A greater alpha value within a section implies that a respondent who ranks a score for one variable is likely to assign a same score for other variables in that section (Jin, et al., 2017). The Cronbach's coefficient alpha values for expected effectiveness of safety technologies and potential strategies to raise technology adoption are above 0.80, which indicate good reliability. On the other hand, the alpha coefficients for potentials of safety technologies and factors impacting its adoption are above 0.90, which demonstrate excellent reliability. Accordingly, this survey is deemed to be reliable.

Table 4.3: Demographic profile of respondents.

Parameter	Category	Respondents group			Total	Frequency
		Developer	Consultant	Contractor		(%)
Position in company	Executive	21	27	32	80	60.2
	Manager	9	10	9	28	21.1
	Senior Manager	9	3	3	15	11.3
	Director / Top Management	2	4	4	10	7.5
Working experience	<5 years	7	15	17	39	29.3
	5-10 years	7	10	11	28	21.1
	11-15 years	17	12	11	40	30.1
	15-20 years	6	3	3	12	9.0
	>20 years	4	4	6	14	10.5
Academic qualification	Postgraduate Degree (PhD, Master's Degree)	15	10	6	31	23.3
	Bachelor's Degree	24	32	32	88	66.2
	Diploma, Certificate	2	2	9	13	9.8
	High School	0	0	1	1	0.8

Table 4.4: Cronbach's coefficient alpha values for reliability test.

Category of variables	No. of items	Alpha values
Expected effectiveness of safety technologies	12	0.897
Potentials of safety technologies	10	0.901
Influential factors impacting the adoption of safety technologies	20	0.920
Strategies to raise safety technology adoption	10	0.853

4.6 Expected effectiveness of safety technologies in construction projects

4.6.1 One sample T-test

One sample t-test was employed to test whether the safety technologies identified earlier were significant in enhancing construction safety in the expectations of the respondents. The test results are presented in Table 4.5. As shown in the table, 10 out of 12 technologies were proven to be statistically significant to the respondents as their significance values were all lower than 0.05 at the 95% confidence level. Nonetheless, the respondents did not discern UWB and QR codes as significantly effective technologies in enhancing construction safety. This could be due to the limitations of the technologies and the practitioners' poor knowledge on the usefulness and application of the technologies in construction.

The major shortcoming of UWB is precision concerns. Due to the dynamic nature of the construction sites, Umer and Siddiqui (2020) opined that the accuracy of UWB may be affected, thus permanent deployment of this technology is not possible. A similar observation is found in Liu, et al. (2020), where the UWB positioning system may pose lower positioning accuracy and poor positioning reliability due to diversity and irregularity of the people movement as well as the noise of the motion. In support of this, Luo, et al. (2020) also argued that UWB-based approaches require precise configuration of positioning sensors. As for the QR codes, this may be due to their less usage in construction projects. For instance, Guo, Yu and Skitmore (2017) stated that QR code can be used to record safety inspection data, but such activity is still conducted manually by safety officers in practice. This could be related to the respondents' lack of familiarity with the possible applications of QR codes in construction projects (Ramdav and Harinarain, 2018).

Table 4.5: One sample t-test on expected effectiveness of safety technologies.

Mean rank	Safety technologies	Test value = 3	
		t-value	Significance (2-tailed)
1	BIM	12.389	0.000**
8	Virtual Reality (VR)	3.894	0.000**
9	Augmented Reality (AR)	2.603	0.010*
4	Unmanned Aerial Vehicles (UAV)	7.363	0.000**
11	Ultra-wideband (UWB)	1.465	0.145
10	RFID	1.982	0.050*
2	Wearable safety technologies	11.368	0.000**
6	Network Camera	6.438	0.000**
3	Automation and Robotics	9.048	0.000**
12	QR Codes	0.481	0.632
5	3D Laser Scanning	7.467	0.000**
7	Digital Signage	5.982	0.000**

Note: **. The mean is significant at the 0.01 level of significance.

*. The mean is significant at the 0.05 level of significance.

4.6.2 Mean Ranking

Ranked in descending order based on the overall result, Table 4.6 summarises the means and standard deviations of the safety technologies predicated on the effectiveness expectations from the respondents. These findings can measure how the Malaysian construction practitioners feel about using IR 4.0 technologies in the future, particularly on safety management. It appeared that all the safety technologies have a mean score of >3.00, which is regarded as notable in the rating scale. Therefore, it can be deduced that the Malaysian practitioners have positive expectations on the usefulness and benefits of the surveyed technologies in enhancing construction safety. The following discussion deliberates on the three most effective safety technologies.

It is not surprising to observe that BIM is perceived as the most effective safety technology in this study, considering that the capabilities of BIM have been extensively discussed in many past research studies (Deng, et al., 2019; Enshassi, Ayyash and Choudhry, 2016; Chen, et al., 2019) and the application of BIM-related technologies in design and safety management is rising expeditiously (Lu, et al., 2021). Being an object-oriented parametric digital representation, BIM is transforming the project planning, design, construction, operation and maintenance phases. By virtue of its visualisation, coordination and modularisation, BIM plays a propitious role in construction safety (Wen, et al., 2021). According to Tang, et al. (2021), BIM provides opportunities for the practice of design for safety concept due to its powerful data integration and visual modelling capabilities. Specifically, BIM allows linking risk data with design elements in the design phase. Many researchers integrated BIM with relevant databases to improve its function in construction safety. For instance, Zhang, et al. (2015) incorporated safety rules into BIM to identify and prevent fall hazards. Hossain, et al. (2018) integrated a risk review system into BIM to assist the designers to check design elements.

Wearable safety technologies are rated second in the overall ranking. In the realm of construction, the existing trend in technology use exhibits flourishing attentions and active implementations of wearable technologies in worker’s safety management (Nnaji, Jafarnejad and Gambatese, 2020). According to Awolusi, Marks and Hallowell (2018), this technology is often utilised in construction projects for the purposes of physiological monitoring, proximity detection and location tracking. By capturing and transmitting essential information, it can avoid accidents pertaining to falls, caught in, stuck-by hazards and electrocution. With the development of wearable safety technologies, several scholars have demonstrated the use of wearable inertial measurement unit (WIMU) based system to identify hazard (Yang et al., 2017; Kim, Ahn and Yang, 2017; Jebelli, Ahn and Stentz, 2016; Antwi-Afari et al., 2020b). The findings of these studies uncovered that workers’ gait patterns provide significant data for identifying various types of safety risks.

Automation and robotics are in third place. Such advancements can conquer the limitations of traditional construction methods and meet the growing needs of the construction industry (Bock, 2015). Being controlled by computers on-site and dependent on advanced detection and control, automation and robotics have become one of the most promising solutions that can improve up-to-date gathering of safety data and enhance the harsh construction environment with the aim of achieving better safety performance (Cai, et al., 2020b; Akinlolu, et al., 2020). As mentioned by Li (2018), these technologies are highly effective especially when applied in the execution of risky and arduous tasks that are undertaken in hostile environments which may pose critical risks to the workers. This is akin to the observation of Okpala, Nnaji and Karakhan (2020), where automating the construction process using robots can lessen the exposure of workers to hazards while improving safety planning, awareness and communication among the project team. For instance, robots can be used to perform high-risk tasks like welding, bricklaying, excavator control, interior building finishing, infrastructure inspection and so on (Kim, et al., 2020). These advancements can also be applied to perform autonomous installation and gathering of heavy construction materials to build structures such as skyscraper towers (Jung, Chu and Hong, 2013).

4.6.3 Kruskal-Wallis Test

Kruskal-Wallis test was employed to assess the perceptions of different respondent groups on the expected effectiveness of various types of safety technologies. Based on Table 4.6, the test affirms the consistency of the perceptions of three professional groups, except for BIM and RFID.

The test result revealed that BIM was the most effective safety technology in the expectation of the developers and consultants. However, it is found that the contractors had lower expectations on the effectiveness of this technology. By applying the findings of Eadie, et al. (2013) into this study, the difference of opinions between the respondent groups could be due to BIM is mostly used in the design and pre-construction stages with progressively less use in the construction stage. Besides, a past study found that a high percentage of contractors had no BIM knowledge (Enshassi, Ayyash and Choudhry, 2016). Therefore, it is suspected that the contractors' little knowledge and usage of BIM are the underlying reasons that caused them to perceive that BIM is less effective in safety management as opposed to the developers and consultants. Conversely, Enshassi, Ayyash and Choudhry (2016) reported that consultants have the most positive view on BIM in enhancing safety performance among other practitioners. In another study, Jin, et al. (2017) mentioned that developers were considered as the party that received the most advantages from BIM. From the perspective of these two respondent groups, BIM is highly effective in various areas of safety management such as safety planning, design for safety, pre-task planning, hazard identification and safety training. The generally positive and consistent views of the developers and consultants on the expected effectiveness of BIM could suggest that BIM will be increasingly applied in the Malaysian construction industry in the coming years.

As for RFID, the consultants had higher expectations on its effectiveness. From their perspectives, RFID is an effective safety monitoring tool. The workers and equipment can be attached with RFID tags to register their movements in real time (Valero, Adán and Cerrada, 2015). In this respect, there is a wide array of advantages of knowing the approximate location of resources at all time on the construction site. With such wireless sensor technology, location identification can be used to acquire data required for near-real-time decision making and proactive safety monitoring (Montaser and Moselhi, 2014). The real-time data generated by the RFID can also be used to confirm site safety for all workers present at the job site at any time (Costin, Pradhananga and Teizer, 2012). In contrast, the developers and contractors ranked at 11th and 12nd respectively, which demonstrates that RFID is the least effective technology in their perspectives. Their lower expectations on the effectiveness of RFID could be due to its high cost and precision concerns. Wang, Lin and Lin (2007) avowed that cost is a critical factor restricting the widespread adoption of RFID in construction projects. Furthermore, in safety management, accuracy is an essential factor when it comes to position a user at the site, but Valero and Adán (2016) affirmed that the accuracy of pose estimation through RFID is limited. They posited that RFID fails to identify and report the position of the tags accurately when several tags are detected at the same time. Besides, metals and concrete in the construction projects may impact the information exchange process of RFID (Valero, Adán and Cerrada, 2015).

Table 4.6: Mean and ranking of expected effectiveness of safety technologies.

Ref	Safety Technologies	Overall (N = 133)			Developer (N = 41)			Consultant (N = 44)			Contractor (N = 48)			Chi-square	Asymptotic significance
		Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank		
A1	BIM	4.068	0.994	1	4.39	0.945	1	4.318	0.800	1	3.563	1.009	5	23.110	0.000**
A7	Wearable safety technologies	4.015	1.03	2	4.073	0.959	2	3.955	1.099	3	4.021	1.041	1	0.138	0.933
A9	Automation and Robotics	3.932	1.188	3	4.049	1.139	3	4.182	1.018	2	3.604	1.317	4	5.105	0.078
A4	UAV	3.729	1.142	4	3.878	0.98	4	3.864	1.091	5	3.479	1.288	7	2.975	0.226
A11	3D Laser Scanning	3.699	1.08	5	3.683	1.011	5	3.932	1.087	4	3.500	1.111	6	4.151	0.126
A8	Network Camera	3.632	1.131	6	3.390	1.093	7	3.841	1.119	6	3.646	1.158	2	4.006	0.135
A12	Digital Signage	3.579	1.116	7	3.415	1.117	6	3.705	1.069	7	3.604	1.162	3	1.914	0.384
A2	Virtual Reality (VR)	3.398	1.180	8	3.317	1.213	9	3.705	1.153	8	3.188	1.142	8	5.488	0.064
A3	Augmented Reality (AR)	3.256	1.133	9	3.317	1.15	8	3.318	1.177	10	3.146	1.091	9	1.096	0.578
A6	RFID	3.211	1.225	10	3.000	1.265	10	3.614	1.243	9	3.021	1.101	10	8.088	0.018*

Note: **. The mean difference is significant at the 0.01 level of significance.

*. The mean difference is significant at the 0.05 level of significance.

4.7 Potentials of safety technologies in construction projects

4.7.1 One sample T-test

One sample T-test was undertaken to assess the significance of the potentials of safety technologies in construction projects. It can be seen from Table 4.7 that all the potentials have significance levels of less than 0.01. This suggests that all the variables can enhance safety performance at the 99% confidence level.

Table 4.7: One sample t-test on potentials of safety technologies.

Mean rank	Potentials	Test value = 3	
		t-value	Significance (2-tailed)
6	Design for safety	21.187	0.000**
2	Reinforce safety planning	22.313	0.000**
4	Enhance safety monitoring and supervision	19.945	0.000**
3	Enhance safety inspection	20.389	0.000**
1	Improve hazard identification	22.445	0.000**
8	Enrich safety education and training	11.640	0.000**
5	Raise safety awareness	22.112	0.000**
10	Enhance near-miss reporting and analysis	11.754	0.000**
9	Enhance accident investigation	12.583	0.000**
7	Facilitate safety communication	15.216	0.000**

Note: **. The mean is significant at the 0.01 level of significance.

4.7.2 Mean Ranking

Based on Table 4.8, all the potentials have a mean score of >4.00, which is considered notable in the rating scale. The three leading potentials of safety technologies are “improve hazard identification”, “reinforce safety planning” and “enhance safety inspection”.

“Improve hazard identification” is ranked the highest, which is therefore regarded as the most remarkable potential of safety technologies. The construction industry is in high needs of addressing the inefficiencies of the existing hazard identification approach that heavily relies on traditional 2D drawings and paper-based sources, which restrict the ability to identify and analyse hazards effectively (Choe and Leite, 2017; Zhang, et al., 2013). Against this background, the growing implementation of technologies in the industry is changing the way hazard identification can be improved. With this in view, the finding of this study is unsurprising as safety technologies can help the practitioners to identify and resolve hazards easily and effectively. These include BIM (Zhang, et al., 2015), VR (Perlman, Sacks and Barak, 2014), UAS (Gheisari and Esmaeili, 2019) and sensor-based technologies (Asadzadeh, et al., 2020). Besides, an innovative approach using RFID-based real-time tracking system to automatically identify hazardous areas has been proposed by Kim, et al. (2016) and results revealed that RFID has high potentials in hazard identification. Most notably, to curb accidents in the industry, it is necessary that all potential hazards are discovered in early design and planning phases and corrective measures are taken (Kim, Cho and Zhang, 2016).

"Reinforce safety planning" is in second place. Pre-project and pre-task safety planning are essential in achieving a zero accident target (Saurin, Formoso and Guimaraes, 2004). Safety planning encompasses activities such as risk identification, risk assessment and risk control (Zolfagharian, et al., 2014). These activities determine the high risk tasks that require close surveillance and determination of the checklist items for safety inspections (Zhang, et al., 2017). Nonetheless, safety planning is intricate due to the complicated and dynamic nature of the construction projects and its on-site work patterns (Zhang, Boukamp and Teizer, 2015). On top of that, traditional safety planning is highly error-prone and labour intensive (Kim, Cho and Zhang, 2016), as it mostly relies on tacit knowledge, regulations, organisation safety policies and 2D drawings (Choe and Leite, 2017; Zhang, et al., 2015). This, therefore, provokes the emergence of IT-based approaches such as BIM, GIS, VR, AR and sensing technologies that provide new opportunities to enhance safety planning. A case study undertaken by Azhar (2017) revealed that 3D and 4D dynamic tools are more effective in safety planning as opposed to 2D static drawings because they are able to closely simulate the actual site conditions. By utilising BIM models, 4D simulations and VR environment, the construction practitioners can take effective precautionary actions in the project planning phases to mitigate safety hazards. For instance, contractors can utilise these technologies to recognise hazards and communicate mitigation plans to the workers prior to work commencement.

"Enhance safety inspection" is rated third. Site safety inspection is a core component of every safety programme to control the risks through early detection and correction, ultimately preventing the occurrence of jobsite accidents (Cheng, et al., 2004; Woodcock, 2014; Lin, et al., 2014). In spite of the significance of safety inspection, some studies stated that the inspection process in construction projects is challenged by many issues which restrict the efficiency and effectiveness of those evaluations, such as lack of labour, overwork in data collection, data loss, poor communication and difficulty of real-time action to correct problems and take necessary actions (Kim, et al., 2008; Park, et al., 2013). To confront these error-prone inspection issues, some enabling safety technologies such as BIM, UAS and AR have leading potentials in developing a proactive and automatic inspection system to enhance construction safety (Martinez, et al., 2021; Park, et al., 2013). For instance, a case study conducted by Melo, et al. (2017) in Brazil found that UAV allows for good visualisation of working conditions and offers useful data concerning the compliance with safety regulations on-site. Apart from that, Zhang, et al. (2017) also developed an advanced safety inspection approach to integrate mobile computing technologies into the inspection process to raise the efficiency of site safety inspection, facilitate better observation and recording, and enhance the performance of existing site safety management practices through an automatic process.

4.7.3 Kruskal-Wallis Test

Table 4.8 presents the Kruskal-Wallis test results of the potentials of safety technologies. The test found no statistically significant differences in opinions between the respondent groups, except for "design for safety". This implies that other than this variable, there is a strong agreement between the three respondent groups in ranking these potentials.

Based on Table 4.8, it is revealed that the developers ranked this potential as the most significant variable, followed by the consultants and the contractors. This result is not surprising by considering the findings of Toh, Goh and Guo (2017) who had performed a study to evaluate the stakeholders' knowledge, attitude and practice for design for safety in the Singaporean construction industry. It is found that majority of the developers perceived that design for safety is very important and they have been the most active group in safety design reviews. This implies that the developers are proactive towards anticipating potential hazards to prevent bringing them into the workplace. Furthermore, unsafe design may potentially lead to occupational accidents which will result in disruption of the construction process, delay progress, additional cost and impaired reputation of the developer organisations. Therefore, the developers are very concerned about the production of safe designs through adopting innovative approach and thus are more informed of the potentials of technologies in safety design than the other two respondent groups.

In the same study, architects pointed out that safety is not considered a priority in design. In this line of thought, Berwald (2008) highlighted that architects are unwilling to adopt BIM as this technology is too precise which may impede their creativity. Another study reported that majority of C&S engineers were seldom or never asked to address the worker's health and safety in the design phase (Goh and Chua, 2016). From this perspective, it can be presumed that consultants are less aware of safety and the potentials of safety technologies in the design stage, thus explicating the varying rankings on 'design for safety' between the developers and consultants. The test result also revealed that the contractors ranked this potential at the 8th, which is the last three variables. It is suspected that the contractors' design for safety knowledge may be low, with little understanding of how designers can ameliorate construction safety through safety technologies. In this regard, it is essential for the developers to promote the concept of design for safety through adopting safety technologies to the consultants and contractors, as past studies have advocated that the developers are the most influential groups to drive design for safety practice in the construction projects (Lingard, et al., 2009; Votano and Sunindijo, 2014).

Table 4.8: Mean and ranking of potentials of safety technologies.

No.	Potentials	Overall (N = 133)			Developer (N = 41)			Consultant (N = 44)			Contractor (N = 48)			Chi-square	Asymptotic significance
		Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank		
B5	Improve hazard identification	4.489	0.765	1	4.463	0.778	3	4.500	0.731	3	4.500	0.799	2	0.044	0.978
B2	Reinforce safety planning	4.459	0.754	2	4.488	0.952	2	4.568	0.587	1	4.333	0.694	7	5.125	0.077
B4	Enhance safety inspection	4.451	0.821	3	4.390	0.891	5	4.523	0.821	2	4.438	0.769	4	0.757	0.685
B3	Enhance safety monitoring and supervision	4.451	0.839	4	4.439	0.950	4	4.477	0.849	4	4.438	0.741	3	0.581	0.748
B7	Raise safety awareness	4.444	0.753	5	4.293	0.901	6	4.409	0.693	6	4.604	0.644	1	4.022	0.134
B1	Design for safety	4.391	0.757	6	4.537	0.840	1	4.432	0.695	5	4.229	0.722	8	7.277	0.026*
B10	Facilitate safety communication	4.180	0.895	7	4.146	0.853	7	4.045	1.033	7	4.333	0.781	6	1.897	0.387
B6	Enrich safety education and training	4.128	1.117	8	3.951	1.284	10	4.023	1.210	9	4.375	0.815	5	2.241	0.326
B9	Enhance accident investigation	4.113	1.020	9	4.098	1.068	9	4.023	1.171	8	4.208	0.824	9	0.061	0.970
B8	Enhance near-miss reporting and analysis	4.038	1.018	10	4.146	1.038	8	3.955	1.056	10	4.021	0.978	10	1.304	0.521

Note: *. The mean difference is significant at the 0.05 level of significance.

4.8 Influential factors of the adoption of safety technologies

4.8.1 One sample T-test

In an attempt to test and identify the factors having a large influence on safety technologies adoption, one sample t-test was conducted. Based on Table 4.9, the outcomes demonstrate that the respondents perceived that all the 20 factors are significant factors in influencing the technology adoption.

Table 4.9: One sample t-test on influential factors of the adoption of safety technologies.

Mean rank	Influential Factors	Test value = 3	
		t-value	Significance (2-tailed)
6	Capital cost of technology	17.726	0.000**
12	Level of training required	12.720	0.000**
13	Technology brand and reputation in the industry	12.263	0.000**
2	Proven technology effectiveness	21.944	0.000**
5	Technology reliability	19.539	0.000**
10	Technology compatibility	14.580	0.000**
9	Technology complexity	15.820	0.000**
15	Size of organisation	9.123	0.000**
3	Top management support	20.312	0.000**
1	Expertise and skill of project team	20.389	0.000**
14	Organisation culture	10.823	0.000**
18	Social influence	5.946	0.000**
11	Organisation technology readiness	15.895	0.000**
8	Organisation data security	17.641	0.000**
20	Personal privacy	4.892	0.000**
17	Perceived vulnerability	6.115	0.000**
16	Perceived usefulness	6.945	0.000**
19	Personal motivation	4.884	0.000**
4	Government promotion and initiative	17.407	0.000**
7	Government regulations	16.838	0.000**

Note: **. The mean is significant at the 0.01 level of significance.

4.8.2 Mean Ranking

Table 4.10 presents the means and standard deviations for each influential factor and arranged in descending order on the basis of overall and the respondent groups correspondingly. The five highly influential factors based on overall are as follows:

(1) Expertise and skill of project team (Mean = 4.451; δ = 0.821)
(2) Proven technology effectiveness (Mean = 4.406; δ = 0.739)
(3) Top management support (Mean = 4.383; δ = 0.785)
(4) Government promotion and initiative (Mean = 4.338; δ = 0.887)
(5) Technology reliability (Mean = 4.331; δ = 0.785)

The five leading influential factors as perceived by *developers* to be:

(1) Expertise and skill of project team (Mean = 4.366; δ = 1.019)
(2) Proven technology effectiveness (Mean = 4.317; δ = 0.934)
(3) Top management support (Mean = 4.293; δ = 0.844)
(4) Technology reliability (Mean = 4.220; δ = 1.013)
(5) Capital cost of technology (Mean = 4.220; δ = 1.061)

The equivalent for *consultants* are:

(1) Expertise and skill of project team (Mean = 4.568; δ = 0.661)
(2) Technology reliability (Mean = 4.545; δ = 0.589)
(3) Proven technology effectiveness (Mean = 4.523; δ = 0.590)
(4) Technology compatibility (Mean = 4.500; δ = 0.665)
(5) Organisation data security (Mean = 4.432; δ = 0.695)

And for *contractors*:

(1) Government promotion and initiative (Mean = 4.521; δ = 0.772)
(2) Government regulations (Mean = 4.500; δ = 0.715)
(3) Top management support (Mean = 4.479; δ = 0.743)
(4) Expertise and skill of project team (Mean = 4.417; δ = 0.767)
(5) Proven technology effectiveness (Mean = 4.375; δ = 0.672)

"Expertise and skill of project team" is ranked the highest in overall, which is therefore regarded as the most influential factor of technologies adoption in construction safety management. This finding is as expected because human capital is one of the pivotal enablers of technology adoption (Riddell and Song, 2017). In support of this, similar observations are reported in the UK (Eadie, et al., 2013), US (Ku and Taiebat, 2011), Australia (Hong, et al., 2018), Gaza Strip (Enshassi, Ayyash and Choudhry, 2016) and India (Ahuja et al., 2018), all highlighting that the adoption of technologies depends very much on skills and expertise of the project team. Therefore, for successful implementation of safety technologies, construction practitioners with adequate skills and expertise would have to be nurtured. Certainly, technological advancements in the industry have heightened skill requirements in the construction workforce and lead to de-skilling in the workforce (Riddell and Song, 2017). Considering that the features of new technology could be significantly varied from existing practices or old technologies, companies embracing new technology have to acquire new skills and upgrade the skill level of their existing workforce (Boothby, Dufour and Tang, 2010). In this vein, Ayinla and Adamu (2018) affirmed that getting the right skills required is a pre-requisite for closing the gap in technology adoption. Notably, different technologies may have varied skill requirements, thus this suggests that training should be technology-specific.

"Proven technology effectiveness" is ranked second. This finding parallels with a recent study in the US, where it is revealed that proven technology effectiveness was perceived as the second topmost influential predictor of safety technologies adoption (Nnaji, et al., 2019). Construction firms are usually not willing to adopt a new technology if they are unsure about its effectiveness. That is to say, uncertainty about the usefulness of new technologies is a critical impediment for adopting them. In view of this, it is imperative that there is documented evidence proving that the technical attributes of the technology fulfil the desired performance requirements, thereby affirming that the technology is effective (Nnaji, et al., 2020). It should be pointed out that a technology with unproven effectiveness simply signifies that the technology is immature (Delgado, et al., 2019). For technologies to be accepted by the construction practitioners, their effectiveness, applicability to the work process, and value-adding impact must be unceasingly evaluated and established.

"Top management support" is rated third in the overall ranking. Technology adoption is closely linked to positive support from top management (Cao, Li and Wang, 2014; Nikas, Poulymenakou and Kriaris, 2007; Cheng and Teizer, 2013). This is echoed by several past studies that revealed that the most significant factor impacting adoption decision is the commitment and support from the top management (Son, Lee and Kim, 2015; Tsai, Mom and Hsieh, 2014; Chen, et al., 2019). Essentially, this implies that the top management plays a key role in this aspect (Zheng, et al., 2017). This could be due to the fact that they always decide to what extent it is financially wise to invest in innovations (Bossink, 2004). The support from the top management may range from organisational strategy to day-to-day activities (Xu, Feng and Li, 2014). Their endorsement is vital to secure relevant resources such as capital to facilitate the diffusion process (Jensen and Jóhannesson, 2013; Fernandes, et al., 2006; Aksorn and Hadikusumo, 2008). Besides, a proactive management will provide trainings to the workers to upgrade their skills and expertise (Wong and Fan, 2013). Therefore, this study indicates the necessity of great levels of attention, support, engagement and commitment from senior management and key project stakeholders.

"Government promotion and initiative" is ranked fourth. This finding is consistent with Suprun and Stewart (2015) but contravenes with a Turkish study where government-led initiatives were not considered as the main contributor to successful technology adoption (Ozorhon and Karahan, 2017). Zakaria, et al.'s (2018) literature review noted that government promotion is a vital aspect of government-related contextual factors as it engenders attention, awareness, insights and adoption in the industry. In response to the slow technological uptake, the governments of several developed countries like the US, UK and Australia have established various initiatives, including government subsidies to induce more investment in technologies for the aim of accelerating the rate of technology adoption. A study conducted by Low, Arain and Tang (2019) in Singapore also accentuated the role of government in this matter, where it is pinpointed that government-initiated funding programs can aid small local contractors who are interested to adopt technologies. The government can also set up government-monitored technology online portal for firms to acquire useful latest technology updates. They should also provoke urge for technology adoption by engaging contractors in public pilot projects. Essentially, this finding suggests that the government plays a vital role in technology diffusion, by assembling an enabling environment that is conducive for firms to adopt safety technologies through a wide array of government measures.

"Technology reliability" is ranked fifth. To be of interest to the construction industry, the safety technologies must have high reliability to meet the required safety performance consistently (Nnaji, et al., 2020). For instance, a tracking technology is reliable if it is capable of recording and monitoring the activities accurately and precisely (Cheng, et al., 2011). This finding is aligned with Nnaji, et al.'s (2019) study where technology reliability was ranked as the most influential predictor, implying that the US construction firms are highly concerned about this factor before deciding to adopt a safety technology. In another study, AlHogail (2018) found that technology reliability has positive effects on trust towards its adoption. In this connection, Seo, et al. (2015) also highlighted that such technical issue is hindering the application of technologies in real practice. They posited that the essential requirement for successful safety and health control is the reliability and accuracy of data collected by the technology, which is challenging due to the unique nature of construction. That is being said, as construction is characterised by its dynamics such as job sites involving different workers, various types of equipment as well as building materials, and continuously changing working environments. These dynamic attributes at the sites may result in technical issues for safety technology application, such as poor technology reliability. Therefore, this study sheds some light on the importance of this technical feature for technology developers in the industry.

4.8.3 Kruskal-Wallis Test

The results of the Kruskal-Wallis test on the influential factors of safety technology adoption are presented in Table 4.10. It is revealed that the developers, consultants and contractors have similar perceptions on 17 of the 20 factors and differ on the remaining three factors, which are "technology compatibility", "personal privacy" and "personal motivation".

"Technology compatibility" was ranked higher by the consultants. This implies that the consultants are more aware of the compatibility of the safety technology with the current work practice and future systems as compared to the developers and contractors. This may be due to their concerns on the interoperability issues within the software and technologies used by their organisations. This finding coincides with some extant studies that investigated the architect's perceptions in adopting a new technology. According to an empirical research conducted by Son, Lee and Kim (2015), one of the major factors of technology adoption in design organisations is technology compatibility. It is further asserted that compatibility plays a facilitating role in influencing the designer's perception on the technology as being useful and easy to use. Another study in China also found a similar linkage (Ding, et al., 2015). Besides, Berwald (2008) highlighted the concerns of architects that BIM is too precise which may impede their creativity. In this respect, if the adopters are required to alter their existing practice or the technology is opposed to their attitudes, the more unlikely they are to adopt it. This assertion is therefore akin to the findings of this study where the consultants are more reactive to the compatibility of the safety technology prior to adoption. As such, this finding evidently suggests that technology developers should enhance the compatibility and integration between safety technologies and other available software in the industry to promote the technology adoption.

The test results also show that "personal privacy" has been given relatively higher rankings by the contractors while the developers and consultants ranked this the lowest. Some of the safety technologies such as UAV and wearable safety devices would require continuous monitoring at the construction sites to gather context-aware data about what, when and where the workers do. These devices might debase the workers' morale as they might perceive that the organisation is spying on them. They tend to be sensitive towards sharing their personal information such as their locations during idle period and physiological status, especially if exposing these personal information to the management will pose potential threat to them in social sense (Choi, Hwang and Lee, 2017; Okpala, Nnaji and Karakhan, 2020). As such, this critical privacy concern will lead to the workers' reluctance to adopt safety technology at the workplace (Seo, et al., 2015). A study conducted by Gheisari and Esmaeili (2019) in the US which investigated the general contractors' perceptions on the usage of drones as a safety tool has revealed that the contractors are aware of the violation of workers' privacy while using such technology. In this sense, this past research finding ascertained the test result of this study, emphasising the contractors' concerns on the privacy issues of their workers. It is suspected that a lower ranking given by the developers and consultants is probably due to their less usage of these devices, thus they may not be as sensitive as the contractors towards this factor. This study also calls for a better technical solution which incorporates privacy preserving techniques to mitigate privacy concerns among workers, ultimately stimulating safety technology adoption.

Lastly, it is revealed that the contractors perceived "personal motivation" to be more significant than the developers and consultants. Adriaanse, Voordijk and Dewulf (2010) asserted that personal motivation is influenced by perceived benefits and disadvantages of the technologies. Sexton, Barrett and Aouad (2006) on the other hand, highlighted that the motivation to implement new technology is very much shaped by the project environment. Due to the inherently dangerous nature of the construction industry, the industry is reported globally as having the highest accidents rate (Alzahrani and Emsley, 2013; Wu, et al., 2016). While health and safety are the responsibilities of every party involved in the construction project, contractors have to be extra aware that they are accountable for health and safety on construction sites (Othman, 2012; Malekitabar, et al., 2016). This is due to their central responsibility for managing the entire construction process. They are responsible to supervise their employees and implement effective safety practices to raise safety awareness among workers and ensure their safety. Hence, as opposed to the developers and consultants, the contractors and their employees are largely exposed to safety risks. From this perspective, if the contractors perceive that the safety technology is beneficial in mitigating these safety risks and enhancing the safety performance of the construction projects, they may be motivated to adopt the technology. In short, the contractors' roles, their working environment and their perceptions on the safety technologies could expound their higher ranking on "personal motivation" as compared to the other two respondent groups.

Table 4.10: Mean and ranking of influential factors of the adoption of safety technologies in construction projects.

No.	Influential Factors	Overall (N = 133)			Developer (N = 41)			Consultant (N = 44)			Contractor (N = 48)			Chi-square	Asymptotic significance
		Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank		
C10	Expertise and skill of project team	4.451	0.821	1	4.366	1.019	1	4.568	0.661	1	4.417	0.767	4	1.201	0.549
C4	Proven technology effectiveness	4.406	0.739	2	4.317	0.934	2	4.523	0.590	3	4.375	0.672	5	1.092	0.579
C9	Top management support	4.383	0.785	3	4.293	0.844	3	4.364	0.780	8	4.479	0.743	3	1.574	0.455
C19	Government promotion and initiative	4.338	0.887	4	4.195	1.100	6	4.273	0.758	10	4.521	0.772	1	3.486	0.175
C5	Technology reliability	4.331	0.785	5	4.220	1.013	4	4.545	0.589	2	4.229	0.692	8	4.612	0.100
C1	Capital cost of technology	4.316	0.856	6	4.220	1.061	5	4.409	0.787	7	4.313	0.719	6	0.646	0.724
C20	Government regulations	4.293	0.886	7	4.049	1.094	9	4.295	0.795	9	4.500	0.715	2	4.315	0.116
C14	Organisation data security	4.233	0.806	8	4.098	0.970	8	4.432	0.695	5	4.167	0.724	11	4.015	0.134
C7	Technology complexity	4.203	0.877	9	4.122	1.053	7	4.409	0.726	6	4.083	0.821	13	4.010	0.135
C6	Technology compatibility	4.203	0.952	10	3.902	1.261	12	4.500	0.665	4	4.188	0.790	10	6.420	0.040*

Note: *. The mean difference is significant at the 0.05 level of significance.

Table 4.10 (Cont'd)

No.	Influential Factors	Overall (N = 133)			Developer (N = 41)			Consultant (N = 44)			Contractor (N = 48)			Chi-square	Asymptotic significance
		Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank		
C13	Organisation technology readiness	4.135	0.824	11	4.000	0.949	10	4.250	0.781	11	4.146	0.743	12	1.603	0.449
C2	Level of training required	4.038	0.941	12	3.927	0.959	11	3.864	1.133	14	4.292	0.651	7	3.522	0.172
C3	Technology brand and reputation in the industry	3.992	0.933	13	3.805	1.030	13	4.091	1.030	12	4.063	0.727	14	2.807	0.246
C11	Organisation culture	3.962	1.025	14	3.683	1.059	14	3.977	1.131	13	4.188	0.842	9	5.995	0.050
C8	Size of organisation	3.820	1.036	15	3.561	1.305	15	3.818	0.947	15	4.042	0.798	15	2.453	0.293
C17	Perceived usefulness	3.699	1.161	16	3.390	1.243	16	3.773	1.198	16	3.896	1.016	17	3.966	0.138
C16	Perceived vulnerability	3.602	1.134	17	3.317	1.192	17	3.659	1.200	18	3.792	0.988	19	3.594	0.166
C12	Social influence	3.579	1.123	18	3.317	1.171	18	3.659	1.293	17	3.729	0.869	20	3.387	0.184
C18	Personal motivation	3.496	1.172	19	2.878	1.249	20	3.636	1.163	20	3.896	0.881	16	15.866	0.000**
C15	Personal privacy	3.489	1.152	20	2.902	1.136	19	3.636	1.123	19	3.854	1.010	18	16.288	0.000**

Note: **. The mean difference is significant at the 0.01 level of significance.

4.9 Potential strategies to raise safety technology adoption in construction projects

4.9.1 One sample T-test

One sample t-test was also conducted on the potential strategies to enhance the adoption level and the test results are presented in Table 4.11. The results reveal that all strategies are significant at the 0.01 significance level. In other words, this suggests that all the variables have large influences on the success of safety technology adoption at the 99% confidence level.

Table 4.11: One sample t-test on potential strategies to raise safety technology adoption.

Mean rank	Potential strategies	Test value = 3	
		t-value	Significance (2-tailed)
5	Integrate technological requirements in construction projects	10.661	0.000**
4	Implement safety incentives programme	14.195	0.000**
8	Pilot application of safety technology	8.372	0.000**
9	Organise technology exhibitions	5.245	0.000**
2	Provide government incentives	13.375	0.000**
3	Establish government mandates	13.370	0.000**
6	Revamp organisation culture and attitude	11.091	0.000**
1	Reinforce training and education	15.184	0.000**
10	Recruit new graduates	4.349	0.000**
7	Collaboration between industry, universities and research institutes	8.787	0.000**

Note: **. The mean is significant at the 0.01 level of significance.

4.9.2 Mean Ranking

Table 4.12 presents the means and standard deviations for each strategy as arranged in descending orders. All the potential strategies have a mean value above 3.000, which is regarded as notable in the rating scale. The following discussion deliberates on the three most effective strategies to raise safety technology adoption.

"Reinforce training and education" is ranked the highest, which is therefore regarded as the most effective strategy in promoting the safety technology adoption. Sepasgozar, Loosemore and Davis (2016) reported that poor training and skills development are one of the underlying reasons that discourage innovation diffusion in construction. In this line of thought, Nnaji, et al. (2020) opined that management should provide training to the employees to engender a positive safety culture that supports technology implementation. Chan, Darko and Ameyaw (2017) shared a similar view and further stressed that educational programs can enhance the practitioners' knowledge and awareness which are highly crucial for driving the technology application. In support of this, Nnaji and Karakhan (2020) avowed that a qualified and trained workforce is paramount to successful safety technology adoption. They posited that training should start with educating the employees about the benefits of the technologies. The education programme should encompass sufficient information and real-life examples that demonstrate the effectiveness of the technologies on the workers' safety and the organisation. The workers' knowledge on technology application should also be evaluated through written assessments. Such strategies can encourage continuous learning and improvement, ultimately stimulating the diffusion of safety technologies into their work processes.

"Provide government incentives" is in second place. The finding of this study echoes previous research accentuating the critical role of the government incentives in stimulating technology adoption (Howard, Restrepo and Chang, 2017; Eadie, et al., 2013; Suprun and Stewart, 2015; Ayinla and Adamu, 2018; Low, Arain and Tang, 2019; Ahuja, et al., 2018). Yuan and Yang (2020) opined that government subsidies can offset firms' investment costs, thus bringing forward the joining time of the organisations. With the government's financial support, firms that are initially discouraged towards adopting a technology could become driven to implement it in their projects. Moreover, Yuan, Yang and Xue (2019) proposed that government incentives in the form of tax exemption could engender a facilitating environment for promoting technology diffusion activities. In a Malaysian survey, it is reported that 60% of the respondents failed to allocate any financial incentives or support to invest in a new technology (CIDB, 2017). In view of this, the Malaysian government should therefore actively support the construction practitioners in innovating and implementing technologies in their projects through providing financial aid.

"Establish government mandates" is rated the third most potential strategy. Government mandates have been exercised in several developed and developing countries to promote technology diffusion. The US and UK are successful examples in this respect, where satisfactory results arising from the mandates have been reported over the years (Mehran, 2016). Likewise, Malaysia has also mandated BIM to public projects budgeted at RM100 million and above, aiming to achieve at least 40% of the implementation rate by 2020 (Othman, et al., 2020). A survey conducted by CIDB (2017) in Malaysia reported that a high percentage of the respondents agreed on the government's initiative to mandate the use of BIM in the construction industry. Such an initiative shows that the Malaysian government is committed to implement BIM in the industry within a few years. From this perspective, this study suggests that the government of Malaysia should establish a similar mandate approach as well for the safety technologies to be applied in both public and private projects. Such regulatory pressure imposed on the organisations could be an effective driver of safety technologies adoption, ultimately enhancing the construction safety (Enshassi, Ayyash and Choudhry, 2016).

4.9.3 Kruskal-Wallis Test

Based on Table 4.12, the Kruskal-Wallis test revealed that all groups have similar perceptions on the potential strategies to raise safety technology adoption, except for "collaboration between industry, universities and research institutes" that differed significantly. This variable was given much higher ratings by the consultants than the developers and contractors. The finding is not surprising due to the indispensable roles played by the consultants in the industry.

In the construction industry, there is a big pool of specialist talents in the consultants' field, which involve architects, engineers, quantity surveyors, construction manager, project manager, site inspector, health and safety consultant, contract administrator and many more professionals. Their tasks encompass project management, contract administration, work inspection and advice provision. Most importantly, their core duty is to ensure the project to be delivered according to the client's needs (Wen, Qiang and An, 2017). With this in mind, they are accountable to anticipate issues that may affect project success before they arise. In the context of this research, consultants especially the health and safety consultant, project manager, architect and engineer have to ensure that the safety risks in the workplace are well controlled and that the projects are meeting safety standards.

In the UK, Cheng, Proverbs and Oduoza (2006) conducted a survey to assess the satisfaction level of construction clients based on the performance of the consultants and found that the clients perceived that technical accuracy and innovation in working methods are significant key performance attributes for the consultants. In view of this, the consultants must be at the forefront of their niches and industries. They have to constantly engage themselves with the educational and research institutes to acquire in-depth market knowledge. Suprun and Stewart (2015) highlighted that such collaboration is an effective enabler of the adoption process. These institutes are knowledge providers, offering the consultants the latest solutions in the industry and market. With this sophisticated knowledge, they are able to provide advice to the clients on what technologies to use for the best safety results, thereby effectively achieving a safe workplace. Therefore, this could be the reason why the consultants opined that collaboration of the industry with the universities and research institutes are more essential as opposed to the developers and contractors.

Table 4.12: Mean and ranking of potential strategies to raise safety technology adoption in construction projects.

No.	Strategies	Overall (N = 133)			Developer (N = 41)			Consultant (N = 44)			Contractor (N = 48)			Chi-square	Asymptotic significance
		Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank		
D8	Reinforce training and education	4.233	0.937	1	4.244	0.860	1	4.250	0.991	3	4.208	0.967	1	0.206	0.902
D5	Provide government incentives	4.173	1.011	2	4.195	1.054	3	4.409	0.871	1	3.938	1.060	4	5.471	0.065
D6	Establish government mandates	4.143	0.986	3	4.220	0.881	2	4.205	1.069	5	4.021	1.000	2	1.616	0.446
D2	Implement safety incentives programme	4.128	0.916	4	4.098	0.944	4	4.295	0.823	2	4.000	0.968	3	2.207	0.332
D1	Integrate technological requirements in construction projects	3.947	1.025	5	3.951	1.094	5	4.159	0.939	6	3.750	1.021	7	4.256	0.119
D7	Revamp organisation culture and attitude	3.917	0.954	6	3.829	0.972	6	4.068	0.900	7	3.854	0.989	5	1.891	0.389
D10	Collaboration between industry, universities and research institutes	3.835	1.095	7	3.463	1.227	8	4.227	0.961	4	3.792	0.988	6	10.669	0.005**
D3	Pilot application of safety technology	3.789	1.087	8	3.659	1.039	7	4.045	1.140	8	3.667	1.059	8	5.222	0.073
D4	Organise technology exhibitions	3.541	1.190	9	3.341	1.196	9	3.727	1.227	9	3.542	1.148	9	2.774	0.250
D9	Recruit new graduates	3.451	1.196	10	3.293	1.209	10	3.636	1.241	10	3.417	1.145	10	2.015	0.365

Note: **. The mean difference is significant at the 0.01 level of significance.

4.10 Spearman's Correlation Test

Table 4.13 presents the results of Spearman's correlation test employed to examine the association between the influential factors of safety technologies adoption and the potential strategies to raise the adoption level. There is a total of 92 correlations and each of the 10 strategies has at least three significantly correlated influential factors. A closer examination of Table 4.13 reveals that the most effective strategies are "provide government incentives" (D5) and "reinforce training and education" (D8), both with 12 significant correlations. The next handy strategies are "implement safety incentives programme" (D2), "recruit new graduates" (D9) and "collaboration between industry, universities and research institutes" (D10), each with 11 correlations.

Besides, it is also revealed that "proven technology effectiveness" (C4) and "provide government incentives" (D5) have the most significant correlation. According to Nnaji, et al. (2019), construction firms tend to adopt technologies that have already been proven effective and complied with a range of strict requirements. In view of this, it is imperative that there is documented evidence proving that the technical attributes of the technology fulfil the desired performance requirements, thereby affirming that the technology is effective (Nnaji, et al., 2020). Therefore, this calls for relentless efforts in evaluating and establishing the technology's effectiveness, applicability to the work process, and potential value-adding impacts. These efforts may involve R&D and demonstration projects, which are vital for stimulating the pace of technology adoption as they can validate the effectiveness of the technologies in construction safety management to the stakeholders. Nonetheless, it must be pointed out that such approaches would induce high costs. In this regard, the government should grant incentives to support all these research efforts to alleviate the high research cost and eventually trigger interest in innovation investment (Suprun and Stewart, 2015; Darko et al., 2018).

Table 4.13: Correlation between influential factors of safety technology adoption and potential strategies to raise adoption level.

Factors \ Strategies	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	Total correlations
C1	-	0.191*	-	-	0.375**	0.229**	-	-	-	-	3
C2	0.240**	-	-	-	-	-	-	0.289**	-	-	2
C3	0.172*	0.221*	-	-	0.235**	0.215*	-	0.233**	0.258**	0.247**	7
C4	-	-	-	-	0.407**	0.270**	-	-	-	-	2
C5	0.231**	-	-	-	0.239**	-	-	0.175*	0.217*	0.239**	5
C6	0.291**	-	-	-	-	-	-	0.187*	0.290**	0.247**	4
C7	0.368**	0.259**	0.219*	0.189*	0.243**	0.265**	-	0.253**	0.227**	0.307**	9
C8	-	-	-	-	0.252**	0.191*	0.270**	-	-	-	3
C9	-	0.318**	-	-	0.184*	-	0.329**	0.240**	-	-	4
C10	-	0.286**	-	0.210*	-	-	0.254**	0.241**	0.178*	-	5
C11	-	0.218*	-	-	0.208*	-	0.261**	-	-	0.207*	4
C12	-	0.197*	-	0.214*	-	-	0.217*	0.248**	0.297**	0.272**	6
C13	0.228**	0.261**	0.187*	-	0.224**	-	0.278**	0.204*	0.266**	0.289**	8
C14	0.320**	0.302**	-	0.190*	0.197*	-	0.291**	0.266**	0.336**	0.345**	8
C15	-	-	-	0.263**	-	-	-	-	0.223**	-	2
C16	-	-	-	-	-	-	0.188*	-	0.182*	-	2
C17	-	-	-	-	-	-	-	-	-	-	0
C18	-	-	-	0.189*	-	-	-	-	-	0.176*	2
C19	0.190*	0.277**	-	-	0.285**	0.290**	0.274**	0.377**	0.235**	0.173*	8
C20	0.214*	0.245**	0.190*	-	0.215*	0.207*	0.297**	0.290**	-	0.230**	8
Total correlations	9	11	3	6	12	7	10	12	11	11	

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

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

4.11 Factor Analysis

Factor analysis was conducted to determine the principal groupings of the 20 influential factors of technology adoption in construction safety management. Prior to conducting the factor analysis, the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity were first carried out to assess the suitability of the variables for this analysis (Wu, et al., 2018). Based on Table 4.15, it is revealed that both of the tests verified the use of factor analysis for this research. In detail, the KMO for the 20 variables is 0.858, which is greater than 0.50 thus indicating sufficient intercorrelations (Yap, et al., 2018). On the other hand, the value of Bartlett's test of sphericity is 1692.649 and this implies that the population correlation matrix is not an identity matrix (Wang and Yuan, 2011). Moreover, the associated significance level is 0.000 which indicates that all variables had a significant correlation at the 5% significance level. Hence, this denotes that removal of factors was not required (Aksorn and Hadikusumo, 2008).

Table 4.14: Results of KMO and Bartlett's Tests.

Parameter Value	Value
Kaiser-Meyer-Olkin measure of sampling adequacy	0.858
Bartlett's test of sphericity	
Approximate chi-square	1692.649
Degree of freedom	190
Significance	0.000

In the factor analysis, both the scree plot and eigenvalues were used to determine the number of meaningful factors (Yap and Lee, 2019). The principal component analysis yielded four principal factors with eigenvalues greater than 1. The scree plot in Figure 4.1 shows that the 20 influential factors were analysed, and four significant factors were extracted. Table 4.16 presents the total variance explained, from which it can be seen that the four principal factors account for 66.97% of the variance. As the total variance explained exceeds the threshold of 60%, this justifies that the factors verified the adequacy of construct validity in this research (Hair, et al., 2010).

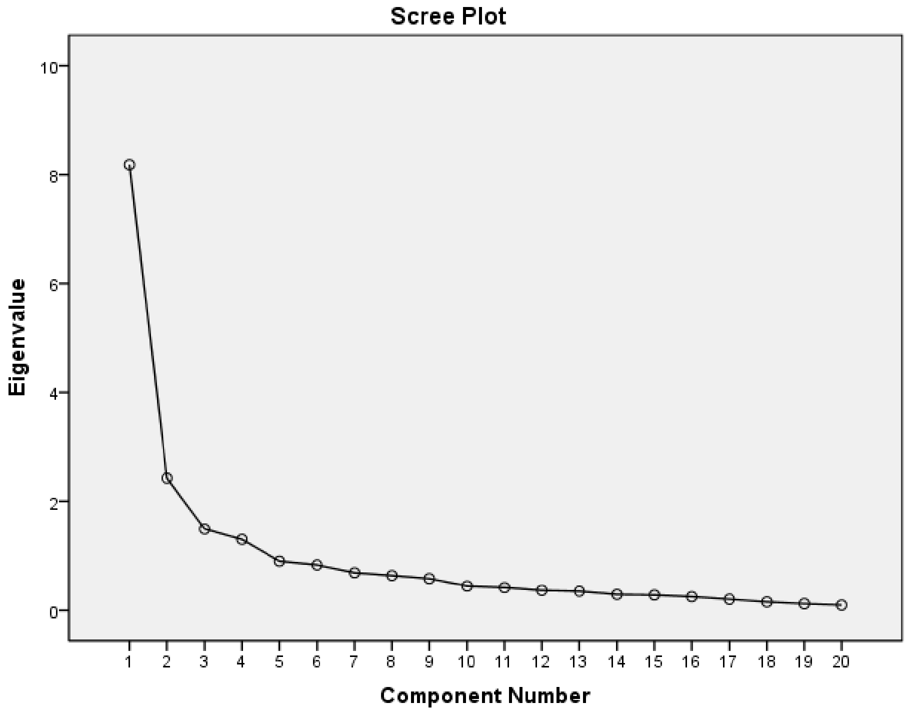

Figure 4.1: Scree plot for 20 variables.

Table 4.15: Total variance explained.

Component	Initial eigenvalues		
	Total	Percentage of variance (%)	Cumulative percentage (%)
F1	8.180	40.901	40.901
F2	2.422	12.110	53.012
F3	1.492	7.460	60.472
F4	1.299	6.497	66.969

In order to ensure a higher explanatory power (Yap, et al., 2021) and better interpretation of these orthogonal factors (Yap and Lee, 2019; Nnaji, et al., 2020), varimax rotation was adopted for the factor analysis in this study. The component matrix after rotation is presented in Table 4.17. Each factor belongs only to one of the four groupings generated by the factor analysis, with the loading on each factor exceeding 0.40. The four components are named based on the variables with higher factor loadings or based on the whole set of variables (Hair, et al., 2010).

Table 4.16: Factor loading and variance explained.

Influential factors of safety technology adoption	Factor loading	Variance explained (%)
Factor 1: Organisation's commitment and technology orientation	-	19.468
Organisation culture	0.795	-
Top management support	0.741	-
Organisation technology readiness	0.662	-
Social influence	0.659	-
Size of organisation	0.615	-
Capital cost of technology	0.567	-
Level of training required	0.527	-
Organisation data security	0.470	-
Expertise and skill of project team	0.420	-
Factor 2: Supporting technological attributes		19.279
Proven technology effectiveness	0.832	-
Technology complexity	0.828	-
Technology reliability	0.821	-
Technology compatibility	0.697	-
Technology brand and reputation in the industry	0.665	-
Factor 3: Personal perception and performance expectancy		17.010
Perceived vulnerability	0.875	-
Personal privacy	0.854	-
Perceived usefulness	0.822	-
Personal motivation	0.764	-
Factor 4: Government support		11.213
Government promotion and initiative	0.868	-
Government regulations	0.793	-
Cumulative variance explained		66.969

4.11.1 Discussion of factor analysis results

4.11.1.1 Factor 1: Organisation's commitment and technology orientation

The first factor has the largest total variance of 19.47%. The variables with the highest loadings are organisation culture, top management support and organisation technology readiness. This implies that organisations' commitment and technology orientation have a significant influence on technology adoption.

Despite the variety of safety benefits that technologies offer, their applications on construction projects have not yet been fully realised. A critical ground for this can be positioned on the difficulties of adoption at the organisational level. A past study has highlighted that organisation culture instigates at the top and employees tend to emulate the manner of top management in decision making (Yap, Lee and Skitmore, 2020). This statement is agreeable, especially considering the assertion of Aksorn and Hadikusumo (2008) where it is emphasised that management must actively support safety efforts at all levels as the employees usually follow the actions of the management. That being said, organisations should strengthen the organisation safety culture and commit to the implementation of new innovative technology to enhance safety.

In order to raise the adoption rate, it is imperative for the organisations to have a pro-active inclination toward the application of new technology. Several extant literatures reported that organisations that have high levels of technology orientation are likely to benefit their business performance (Al-Ansari, Altalib and Sardoh, 2013; Halac, 2015). Yousaf, et al.'s (2020) research found that technology orientation is made up of several dimensions which entail management capability, technological capability, commitment to learning and commitment to change. This is in line with Abbasnejad, et al.'s (2020) opinion which emphasised the significance of management's technological knowledge, leadership skills and commitment to change in technology diffusion.

Essentially, successful implementation of technology necessitates considerable attention and commitment from senior management (Zakaria, et al., 2018). In the context of this research, organisation's commitment refers to the degree to which the top management values the prominence of safety technologies and involves in the adoption and implementation process. In this process, the top management may perform facilitating roles to empower and encourage employees in embracing new technologies (Abbasnejad, et al., 2020). A technology-oriented organisation tends to devote their resources to acquire technologies (Al-Ansari, Altalib and Sardoh, 2013). The resources could be committed to employee trainings or investment in areas that could promote adoption. For effective implementation of technologies, construction professionals with technological competence should be cultivated. This stresses the need for organisation to provide the necessary resources in new skills development and skills level upgrade of the existing workforce (Low, Arain and Tang, 2019; Nikas, Poulymenakou and Kriaris, 2007). Against this backdrop, Son, Lee and Kim (2015) highlighted that any construction organisations that create an enabling environment for their employees are likely to adopt a new technology. Nonetheless, this study contradicts a China study that denied the impact of management support on technology adoption (Ding, et al., 2015).

This finding underscores the criticality of commitments from organisations to ensure the successful implementation of safety technologies in construction projects. The organisation should also place focus on the "technology push" concept within the organisation and ultimately adopt the new technology in safety management.

4.11.1.2 Factor 2: Supporting technological attributes

This factor accounts for the second-largest variation of 19.28% and contains five factors that explain the criticality of supporting technological attributes in influencing technology adoption. This factor is a technology-based factor, which constitutes proven technology effectiveness, technology complexity, technology reliability, technology compatibility as well as technology brand and reputation in the industry, with factor loadings ranging from 0.665 to 0.832.

Technological attributes include complexity, durability, effectiveness, reliability, versatility, maturity, technical support and other relevant technical features (Nnaji, et al., 2019). Sepasgozar and Davis (2019) asserted that technology attributes play a prominent role in impacting user's decisions in adopting a construction technology. This assertion coincides with a study conducted in the US, which revealed that technology-related factors such as technology reliability, effectiveness and durability are the most influential factors of safety technology adoption (Nnaji, et al., 2019). In a recent study, Nnaji, et al. (2020) adopted a similar approach as in this study, which is factor analysis, and found that technological factor accounts for the largest total variance. Likewise, Peansupap and Walker (2005) also found a similar result that the technology characteristics such as compatibility, relative advantage and complexity have above moderate impacts on information and communication technology diffusion and adoption within the Australian construction organisations. In another Australian study, a strong correlation between maturity as well as brand of technology and decision of technology adoption is discovered (Sepasgozar and Bernold, 2012).

All these findings attained from the extant literatures suggest that supporting technological attributes will determine safety technology adoption, which further prop up the finding of this research. It is vital that the technology has strong technological attributes and essential feature to perform the specified task so as to meet safety performance requirements. It is worth noting that when a new technology offers more advantages than the current technologies or working practice, an organisation is more driven to adopt the new technology.

4.11.1.3 Factor 3: Personal perception and performance expectancy

Perceived vulnerability, personal privacy, perceived usefulness and personal motivation created the third factor. This is a people-concerned factor, which accounts for 17.01% of the total variance explained.

Aside from organisational factor, research has found that individual level factors will influence decisions to implement new technology (Davies and Harty, 2013). Howard, Restrepo and Chang (2017) pointed out that acceptance of a technology is an individual act based on personal perceptions, thus it is asserted that user’s perceptions and expectations towards the technology plays a crucial role in its adoption rate. For instance, some construction workers may feel reluctant to adopt a new technology in their work process due to the perceptions and concerns that the technology may endanger their personal privacy (Gheisari and Esmaeili, 2019; Choi, Hwang and Lee, 2017; Son, Lee and Kim, 2015). On another note, adoption level may be positively exalted when they perceive that the working environment and activities are hazardous and may pose critical health threats to them, thus provoking their motivations to accept the implementation of safety technologies in their work processes (Okpala, Nnaji and Karakhan, 2020; Choi, Hwang and Lee, 2017).

Moreover, the worker's belief and evaluation of the usefulness of the technology is also essential. This factor has received a great deal of attention from several studies that revealed that performance expectancy will significantly impact an individual's behavioural intention to accept and use a technology (Catherine, et al., 2017; Choi, Hwang and Lee, 2017; Son, Lee and Kim, 2015; Venkatesh, et al., 2003). Generally, performance expectancy relates to the extent to which an individual believes that they can acquire benefits in work performance by using a system (Venkatesh, et al., 2003). In the context of this research, performance expectancy relates to perceived enhancement of safety performance acquired through adopting safety technologies. It suffices to say that the construction practitioners will only adopt a technology due to the conviction that the technology can provide answers to their queries. With this in mind, if they perceive that the safety technology may enhance the safety performance on-site, they may accept the use of the technology. Hence, personal perception and performance expectancy represent a crucial factor in accelerating or hampering the adoption of safety technologies among construction practitioners.

4.11.1.4 Factor 4: Government support

Factor 4 accounts for 11.21% of the total variance explained, emphasising the two most significant factors with regard to the government's support. Government promotion and initiative attained the highest loading, followed by government regulations, all with a factor loading exceeding 0.700. Although the total variance explained of this factor was ranked lower as compared with other critical factors as afore-discussed, it still plays a significant role in influencing the safety technology adoption in construction projects.

Safety can be ameliorated at different hierarchical levels of a construction project, which is from the government to individual level. The government level being stationed at the top of the hierarchy constitutes occupational, health and safety departments that formulate rules and regulations as well as manage implementation of them. The existing trend in stimulating adoption is a top-down approach, thus stressing the crucial role of government in diffusing adoption (Hong, et al., 2018). According to Delgado, et al. (2019), the government is the biggest construction client and the amount of public spending on infrastructure has a massive impact on technology adoption. This essentially signifies that the government is the key driver to enforce technologies in health and safety practice (Ganah and John, 2015). This statement is further verified by taking the governments of other countries as examples. In Asia, the Singaporean government has been the leader in the BIM adoption process and has enforced BIM in many public projects (Enshassi, Ayyash and Choudhry, 2016). Furthermore, the Korean government has also been the prime mover for the rapid adoption of BIM through establishing legislative actions (Son, Lee and Kim, 2015).

Intrinsically, the government has many tools to support the adoption of new technologies in the construction industry such as promoting collaboration with universities and research institutes, financial incentives, supplementary requirements in contracts and mandates. All these tools have different extents of effectiveness. A number of past studies have accentuated the role of government in fueling the adoption exercise. For instance, Ding, et al.'s (2015) China study suggested that the government may launch some demonstration projects to manifest the economic benefits and effectiveness attained from safety technology adoption. In Nigeria, Abubakar, et al. (2014) mentioned that government agencies should conduct awareness enhancing programs to snuff out the firm’s resistance to change and encourage construction stakeholders to uphold safety technologies in practice.

Furthermore, the government may provide financial support such as government incentives and subsidies programs to motivate stakeholders as such economic support will directly offset the cost of technology adoption. This has been discussed in a Malaysian study, wherein Kamal, Yusof and Iranmanesh (2016) stated that the government should provide financial and tax support to the construction firms so as to enhance their innovation. Through the provision of tax incentives, the Malaysian government can stimulate firms to involve in

R&D activities and bolster their collaborations with knowledge providers like universities and research institutes so as to breed more innovations that will contribute a significant impact to the construction safety.

Other than financial support, the provision of knowledge support by the government is also essential in diffusing adoption. Hong, et al. (2018) highlighted that knowledge supporting activities such as training and consultation provided to small to medium organisations can offer a solid practical foundation for technology implementation. Such knowledge support can equip the employees with competent professional skills.

There is no doubt that government support could have major impacts on the success of technology adoption and may either hamper or stimulate technological changes. Overall, this factor evidently suggests the need for government to actively support the adoption of safety technologies to engender a safety-conscious construction industry.

4.12 Summary

The findings were generated based on the data collected from 133 construction practitioners in the Malaysian construction industry within the Klang Valley area. The overall response rate was 35%. The tests conducted for this study were Cronbach's alpha reliability test, one sample t-test, mean ranking, Kruskal-Wallis test, Spearman's correlation test as well as factor analysis. The reliability test demonstrated that all the data collected in this research were reliable. One sample t-test revealed that UWB and QR codes were not discerned as statistically significant in the expectations of the respondents. Based on the mean ranking analysis, the three most effective safety technologies were BIM, wearable safety technologies as well as automation and robotics. Besides, the top three potentials of safety technologies are "improve hazard identification", "reinforce safety planning" and "enhance safety inspection". Meanwhile, the five most influential factors of safety technology adoption were "expertise and skill of project team", "proven technology effectiveness", "top management support", "government promotion and initiative" and "technology reliability". Additionally, "reinforce training and education", "provide government incentives" and "establish government mandates" were identified as the leading potential strategies to raise technology adoption in construction safety management. On the other hand, the Kruskal-Wallis test revealed that there were significant differences in perceptions between the respondent groups on the expected effectiveness and potentials of safety technologies, influential factors of technology adoption and potential strategies to raise technology adoption level. Besides, Spearman's correlation test uncovered two strategies with the most significant correlations, which are "provide government incentives" and "reinforce training and education". Lastly, the factor analysis has successfully identified four underlying factors from 20 influential factors, namely "organisation's commitment and technology orientation", "supporting technological attributes", "personal perception and performance expectancy" and "government support".

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter, the findings of the study are concluded in accordance with the research aim and objectives as indicated earlier in the research. The research implications and limitations are also discussed in this chapter. At the end of the chapter, several recommendations are proposed for further improvements of future studies on similar research.

5.2 Conclusion

Being stigmatised as a dirty, dangerous and difficult (3D) industry, the Malaysian construction industry is critically plagued with incessantly growing occupational accidents and fatalities (CIDB, 2018). Current statistics indicate that the construction industry is considerably lagged behind other major industries in technology adoption and implementation (Bosch-sijtsema, et al., 2021). Previous studies suggested that incorporating advanced technology into safety management practices could offer valuable opportunities for enhancing construction safety (Liu, et al., 2020; Nnaji, Jafarnejad and Gambatese, 2020; Martinez, Gheisari and Alarcón, 2020; Asadzadeh, et al., 2020).

Unfortunately, in spite of a plethora of safety technology related studies, implementation of safety technologies are not much prevailing in actual construction projects (Nnaji, et al., 2019). Besides, little is known about the dimensions influencing safety technology adoption in developing countries like Malaysia. In addition, prior studies have allocated a great amount of attention on examining the factors affecting the diffusion of innovations particularly aimed to improve construction productivity, quality and project management. Nonetheless, there has been a paucity of attention paid to the factors influencing the construction practitioners' decisions to adopt safety technologies to improve construction safety. In response to this, this study addresses the knowledge gap and rectifies the exacerbating safety situation by examining the potentials of safety technologies, influential factors of technologies adoption and potential strategies to raise the adoption level.

A comprehensive literature review as conducted has successfully identified 10 potentials of safety technologies, 20 influential factors and 10 potential strategies. Following the detailed literature review, a questionnaire was formulated as a tool for data collection in the field survey targeted at the Malaysian construction practitioners from different discipline groups comprising developers, consultants and contractors based in the Klang Valley region in Malaysia. A total of 133 sets of responses were obtained and analysed using the appropriate statistical techniques. All the variables were ranked and prioritised in accordance with their mean scores. The research objectives were achieved by the end of the study and summarised as follows:

Objective 1:

The first objective and research question were to appraise the potentials of safety technologies in construction safety management. All the 10 potentials are found to be significant and the three potentials with the highest means are: improve hazard identification, reinforce safety planning and enhance safety inspection. Apart from that, there is a strong agreement between the three respondent groups in ranking these potentials, except for “design for safety” which was ranked relatively higher by the developers, as they are proactive towards safety designs and have been the most active group in safety design reviews. To further measure how the practitioners feel about using IR 4.0 technologies particularly on safety management in the future, the respondents were asked the evaluate the effectiveness of several types of safety technologies based on their expectations. It is found that the practitioners in Malaysia have high expectations on the feasibilities of BIM, wearable safety technologies, and automation and robotics in improving safety performance on site.

Objective 2:

Further, the second objective was aimed to uncover the factors affecting safety technologies adoption in construction projects. Through the empirical survey, all 20 factors are found to be relevant and significant. It is revealed that the expertise and skill of project team are the most influential factor, while the other leading factors include proven technology effectiveness, top management support, government promotion and initiative, and technology reliability. By adopting the factor analysis technique, the underlying factors impacting safety technology diffusion were identified. The four principal factors comprised organisation’s commitment and technology orientation, supporting technological attributes, personal perception and performance expectancy, and government supports. Intrinsically, these underlying dimensions highlight the significance of considerable outputs from the top managements, individuals, technology developers and policymakers to drive changes. The results also provide the global construction community with deeper insights into devising effective strategies in facilitating the adoption process, which will ultimately lead to improved safety performance in construction. It is worth noting that the respondents had heterogeneous views on several influential factors, namely technology compatibility, personal privacy and personal motivation. It is found that the developers ranked these three factors relatively lower than the consultants and contractors.

Objective 3:

The present study also identified ten potential strategies to raise safety technology adoption, thereby achieving and answering the third research objective and question of this study. All the potential strategies are found to be significant. In the overall context, the three most effective strategies are reinforcement of training and education, provision of government incentives and establishment of government mandates, indicating the vital roles played by the management and government. Nonetheless, the analysis revealed that there were significant differences in the perceptions of the respondent groups on “collaboration between industry, universities and research institutes”. Such differences were due to distinct roles played by different disciplines in the industry. Based on the correlation test between the influential factors of technology adoption and strategies to raise the adoption level, it is revealed that “provide government incentives” and “reinforce training and education” have significant correlations with the factors. Meanwhile, “proven technology effectiveness" and "provide government incentives" have the most significant relationship.

Overall, the current study represents the first empirical effort focused on augmenting the understandings of the influential factors impacting the adoption of safety technologies in the Malaysian construction industry. By conducting a research on safety technology adoption, the implementation of emerging technologies at different phases in the construction life cycle is expected to escalate. Accordingly, the construction safety performance can be enhanced, thereby bridging the lacuna between the construction sector and other industries in terms of safety.

5.3 Research implications

Due to the rising number of fatalities and injuries in the construction industry, there is a pressing need to ameliorate worker's safety. To abate this scourge, safety technologies should be adopted in construction projects. This study offers a big picture on the technology adoption for construction safety in Malaysia and contributes to practice and research in the following ways. As of today, there is not much literature on safety technology adoption. The theoretical implication of the study is that this research is one of the few studies that has focused on the factors influencing safety technology adoption, rather than other technologies such as ICT and productivity-related technologies that have received a great amount of attention in numerous past studies. Researchers can utilise the findings of this research to further extend to a narrower scope of study in a similar research area.

The practical implication of this study is to promote safety technology adoption in Malaysia. The findings are expected to be of great value and utility for construction firms and government who are interested in adopting safety technologies with important insights stemming from the research, particularly on various types of safety technologies, their benefits, influential factors and potential strategies to enhance the adoption rate. It is believed that understanding of these influential factors is an essential mechanism to stimulate the construction firms to prepare for safety technology adoption. The rankings of the factors have practical implication as it provides a basis for refining the most significant influential factors that the construction stakeholders should place focus on for successful adoption. Additionally, using the findings from the present study, construction stakeholders who are involved in evaluating the viability of implementing a safety technology can first place emphasis on the 20 influential factors discovered in this study, which could guide sound and informed decision-making. This is essential as concentrating on these factors would offer beneficial insight on adoption prior to devoting a huge amount of money into the adoption.

This study revealed that organisation factors are significant factors in making a decision of whether to adopt a safety technology, followed by technological and government factors. Against this backdrop, top management can offer stronger support and lead their organisations to adopt safety technologies to mitigate safety risks. This study also calls for additional investment in safety training and education to encourage adoption. Government, on the other hand, needs to take a proactive role by developing appropriate strategies and plans to facilitate the diffusion of these technologies. Furthermore, the findings are also valuable to present and future technology developers and manufacturers as this study allows them to better understand the areas that require improvement and ameliorate the approach to be taken to meet the demands of the construction industry.

By taking cognisance of the critical influential factors, the adoption level of safety technology could be raised. Accordingly, enhanced technology adoption would benefit the construction industry through improving workplace safety, mitigating accidents and raising safety awareness among the construction players.

5.4 Research limitations

In spite of the research contributions to the construction safety management, this study is not without its limitations. Firstly, the major limitation of this study is the utilisation of structured questionnaire survey as a data collection tool. This is due to its inability to probe responses for their rich and extensive experiences on the potentials of safety technologies, influential factors of safety technology adoption and strategies to raise the adoption level, as this is only possible with in-depth interviews.

Besides, it should be cautioned that the scope of this study was limited to the construction practitioners in the Malaysian construction industry, thus restricting the generalisability of the findings. Moreover, while the sample size is adequate, it does not include construction technology developer, manufacturer and vendor. In fact, their perceptions on this research could be also meaningful due to their weighty involvement in the R&D as well as sales and marketing process.

5.5 Recommendations for future work

Several recommendations are provided to improve future research. It is suggested that an interpretative approach using in-depth interview could be further conducted to gather the opinions from the target respondents. Such an approach also allows validation of statistical results. Moreover, future work can be expanded to other developing countries so as to enhance the generalisability of the findings. The inclusion of technology developers, manufacturers and vendors as the target respondents of the study should also be considered in future work.

As this study generated findings of technology adoption predictors at the aggregate level which covers organisational, individual, technological and political level, it is suggested that a narrower scope of research could be conducted in the future. Future researchers could delve deeper into the determinants of technology adoption only at a specific level, for instance, organisational level. This allows a more detailed exploration of the management's perceptions and actions towards safety technology adoption at the organisational level.

Considering the uniqueness of the construction industry, there may be aspects of the safety technology adoption process that are different from other industries. This calls for comprehensive research into devising a technology adoption model, particularly for construction safety technologies. Moreover, the findings from the statistical analysis revealed that most of the influential factors have significant influences on the adoption of safety technologies. Utilising these factors, researchers can develop safety technology readiness tools or adoption index that can be applied in practice. This allows the practitioners to make a more informed decision concerning the implementation of safety technologies in construction projects.

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APPENDICES

APPENDIX A: Questionnaire

INVESTIGATING INFLUENTIAL FACTORS OF TECHNOLOGY ADOPTION IN CONSTRUCTION SAFETY MANAGEMENT

Dear Sir/Madam,

Sincere greetings and best regards to you. My name is Karen Lee Pei Han and I am a final year undergraduate student pursuing Bachelor of Science (Honours) Quantity Surveying in Universiti Tunku Abdul Rahman (UTAR). Currently, I am conducting a research for my Final Year Project which titled "Investigating Factors Influencing Technology Adoption in Construction Safety Management".

There are three main research objectives to be achieved:

1. To explore the potentials of safety technologies in construction projects
2. To investigate the influential factors impacting the adoption of safety technologies in construction projects
3. To recommend strategies in enhancing the adoption level of safety technologies in construction projects

This questionnaire consists of four sections and is designed to be completed within 15 minutes. I would be obliged if you could spend time to participate in this survey which allows me to gather valuable information that is imperative to the research. Your response to this questionnaire survey is highly valuable to contribute to the development of the Malaysian construction industry. Please be assured that all the data collected through this survey will be solely used for academic purposes and will be strictly kept confidential.

Should you require any clarification, please do not hesitate to contact me at karenlee1819@gmail.com or 016-5188903. Your valuable time and effort in participating in the survey are greatly appreciated. Thank you.

Yours faithfully,
Karen Lee Pei Han

Section A: Respondent's Background Information

1. Which of the following best classifies your organisation?
    - ☐ Developer
    - ☐ Consultant
    - ☐ Contractor

2. What is your position in your organisation?
    - ☐ Executive
    - ☐ Manager
    - ☐ Senior Manager
    - ☐ Director / Top Management

3. How many years of working experience do you have in the construction industry?
    - ☐ < 5 years
    - ☐ 5 -10 years
    - ☐ 11-15 years
    - ☐ 15 - 20 years
    - ☐ 20 years

4. What is your highest academic qualification?
    - ☐ Postgraduate Degree (PhD, Master’s Degree)
    - ☐ Bachelor’s Degree
    - ☐ Diploma, Certificate
    - ☐ High School

Section B: Potentials of construction safety technologies

5. Are you satisfied with the current safety practices in your construction projects?

Not at all satisfied	1	2	3	4	5	Extremely satisfied

6. In your opinion, how important is the adoption of safety technologies in improving construction safety?

Not at all important	1	2	3	4	5	Extremely important

7. To your best knowledge, please indicate your level of expected effectiveness of the listed safety technologies to improve health and safety in construction projects.

	Ineffective	Somewhat effective	Effective	Very effective	Extremely effective
Building Information Modelling (BIM)	1	2	3	4	5
Virtual Reality (VR)	1	2	3	4	5
Augmented Reality (AR)	1	2	3	4	5
Unmanned Aerial Vehicles (UAV)	1	2	3	4	5
Ultra-wideband (UWB)	1	2	3	4	5
RFID	1	2	3	4	5

Wearable safety technologies	1	2	3	4	5
Network Camera	1	2	3	4	5
Automation and Robotics	1	2	3	4	5
QR Codes	1	2	3	4	5
3D Laser Scanning	1	2	3	4	5
Digital Signage	1	2	3	4	5

8. In your perception, to what extent do you agree with the potentials of safety technologies in construction projects?

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Design for safety	1	2	3	4	5
Reinforce safety planning	1	2	3	4	5
Enhance safety monitoring and supervision	1	2	3	4	5
Enhance safety inspection	1	2	3	4	5
Improve hazard identification	1	2	3	4	5
Enrich safety education and training	1	2	3	4	5
Raise safety awareness	1	2	3	4	5

Enhance near-miss reporting and analysis	1	2	3	4	5
Enhance accident investigation	1	2	3	4	5
Facilitate safety communication	1	2	3	4	5

Section C: Influential factors impacting the adoption of safety technologies in construction projects

9. In your opinion, what is your level of agreement on the following factors influencing the safety technology adoption in construction projects?

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Capital cost of technology	1	2	3	4	5
Level of training required	1	2	3	4	5
Technology brand and reputation in the industry	1	2	3	4	5
Proven technology effectiveness	1	2	3	4	5
Technology reliability	1	2	3	4	5
Technology compatibility	1	2	3	4	5
Technology complexity	1	2	3	4	5
Size of organisation	1	2	3	4	5

Top management support	1	2	3	4	5
Expertise and skill of project team	1	2	3	4	5
Organisation culture	1	2	3	4	5
Social influence	1	2	3	4	5
Organisation technology readiness	1	2	3	4	5
Organisation data security	1	2	3	4	5
Personal privacy	1	2	3	4	5
Perceived vulnerability	1	2	3	4	5
Perceived usefulness	1	2	3	4	5
Personal motivation	1	2	3	4	5
Government promotion and initiative	1	2	3	4	5
Government regulations	1	2	3	4	5

Section D: Strategies to raise safety technology adoption in construction projects

10. In your opinion, how effective are the following strategies in enhancing the adoption of safety technologies in construction projects?

	Ineffective	Somewhat effective	Effective	Very effective	Extremely effective
Integrate technological requirements in construction projects	1	2	3	4	5
Implement safety incentives programme	1	2	3	4	5
Pilot application of safety technology	1	2	3	4	5
Organise technology exhibitions	1	2	3	4	5
Provide government incentives	1	2	3	4	5
Establish government mandates	1	2	3	4	5
Revamp organisation culture and attitude	1	2	3	4	5

Reinforce training and education	1	2	3	4	5
Recruit new graduates	1	2	3	4	5
Collaboration between industry, universities and research institutes	1	2	3	4	5

End of Questionnaire Survey.

Thank you very much for participating in this survey.