EXPLORING THE ADOPTION OF INTERNET OF THINGS IN MALAYSIAN CONSTRUCTION INDUSTRY

ANG TZE QING

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

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

April 2019

DECLARATION

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

Signature : ______________________

Name : ANG TZE QING

ID No. : 14UEB05152

Date : 8th April 2019

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"EXPLORING THE ADOPTION OF INTERNET OF THINGS IN MALAYSIAN CONSTRUCTION INDUSTRY"** was prepared by **ANG TZE QING** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Science (Hons.) Quantity Surveying at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ____________________________

Supervisor : DR. CHIA FAH CHOY

Date : 8th April 2019

ACKNOWLEDGEMENTS

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

In addition, I would also like to express my gratitude to my loving parents and friends who had helped and given me encouragement throughout the development of the research.

ABSTRACT

This is a new era where all things can be connected including businesses, processes, people and devices. The rises of the concept of Internet of Things (IoT) create new opportunities and develop new applications which stimulate most of the industry to move into a momentous revolution period. How the construction industry faces such drastic change? Are Malaysian construction players ready to unleash the power of IoT? This paper intends to examine the readiness of adoption of IoT in Malaysian construction industry and its issues and challenges. The objectives are to explore the general application of IoT and its adoption in construction industry; to investigate the awareness of the industrial players toward the application of IoT and to uncover the issues and barriers of IoT adoption in Malaysian construction industry. Quantitative research approach was adopted in this research. Literature related to the practices and lessons learnt in IoT application has been consulted in order to develop a theoretical framework for this research. A questionnaire survey was conducted to assess the awareness of construction industry community in IoT application, the current practices on IoT and the issues in adopting IoT system. 204 respondents represent the different professionals in the construction industry has participated the questionnaire survey. The findings revealed than younger generation, especially the age group between 25 to 30 years old has better visualisation towards the adoption of IoT in local construction industry. Overall, local construction community has low awareness towards the development of IoT in construction activities. The Malaysian construction industry has not fully prepared for the IoT adoption. This research is expected to boost the awareness of IoT applications in the construction community in order to equip themselves towards the new era of digitalization of everything.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

IoT	Internet of Things
RFID	Radio-Frequency Identification
BIM	Building Information Modelling
GPS	Global Positioning System
LiDAR	Light Detection and Ranging
KPIs	Key Performance Indicator
3D	Three Dimensions
RFI	Request for Information
IP	Internet Protocol
ICT	Information and Communications Technology

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

This is the introductory chapter for this research. The background information and status quo of IoT in construction industry are uncovered in Section 1.2. The previous research in this area of study is revealed in Section 1.3 follows by research aim and research objectives for this study in Section 1.4 and Section 1.5. The research method adopted is discussed in Section 1.6 and the research scope is defined in Section 1.7. A brief chapter outline is provided in Section 1.8.

1.2 Background

Do you ever think about what makes humans being extraordinary among all living beings? The answer is curiosity. Humans curious on things happen around and challenge on the status quo of existing products and rules. This curiosity leads to innovation and effort in improving the living standard through the aids of electronic devices and machines. Humans are smart enough to design machine with the idea of inter-connected devices which enables information sharing among each other (Kashyap, 2016). These smart devices or connected devices are designed using the concept of Internet of Things. They are able to capture and utilise every data we use or share in our daily life and interact with humans to accomplish the tasks given.

The concept, "Internet of Things" (IoT) was first invented by Kelvin Ashton back in 1999 (Ashton, 2009). This concept aims in connecting everything with everyone anytime everywhere. It is widely uses in many sectors to connect the virtual and physical world (Sfar et al., 2018). Some examples of objects use are Radio-Frequency IDentification (RFID) tag, sensor, reader and actuator. The number of connected devices growth rapidly and the total amount of connected devices exceeded the world population in 2011 (Gubbia, et al., 2013). Statista (2018) predicted that the total numbers of interconnected devices will growth gradually to 30 billion in 2020 and reach 75 billion in 2025.

In 2018, 1600 projects around the world are adopting IoT (Scully, 2018). Smart City projects contributed to 367 projects (23 %) and followed by 265 (17 %) connected industry projects and 193 (12 %) connected building projects. Almost half of the Smart City projects are located in Europe and followed by American and Asia with 34 % and 18 % respectively. Asia countries are still a big step behind Western countries in adopting IoT. Malaysia is on the path to realise the vision of smart cities (Bernama, 2018) after the integration of smart city initiatives in 11th Malaysia Plan (2016-2020) (Prime Minister’s Department, 2015). Various initiatives are stimulated by government to adopt IoT in the development of smart cities (Bernama, 2018). Malaysia endorsed Smart City in 2014 and recognized Iskandar region as pilot for Smart City project in Malaysia (Iskandar Regional Development Authority, 2016).

1.3 Problem Statement

Several studies related to IoT in building and construction industry have been carried out. For example, Albishi, et al., (2017) studied the challenges and solution toward the technologies and applications of IoT in smart city, smart energy, smart building and smart health. Besides, Conti, et al. (2018) studied on the security challenges in the IoT environment. There is also study done by Chen, et al. (2014) discussing the application, challenges and opportunities of IoT in China. These studies are not conducted in the different context with respective to Malaysian construction industry. Malaysian construction industry is yet to know the challenges and implications of IoT applications in the local industry Thus, how the local construction industry makes use of IoT in their practice? What are the challenges and issues face by the local construction industry in adopting the IoT application? These are the research questions this study intends to answer.

1.4 Research Aim

The research aim for this study is to explore how Internet of Things (IoT) are being adopted in Malaysian construction industry and the issues and challenges faced by local industry.

1.5 Research Objectives

The following research objectives are established in order to achieve the research aim mentioned above:

(i) To explore the general application of IoT and its adoption in construction industry.

(ii) To investigate the awareness of industrial players towards the applications of IoT.

(iii) To uncover the issues and barriers of IoT adoption in Malaysian construction industry.

1.6 Research Method

Exploratory approach is adopted to establish the adoption of IoT in Malaysian construction industry. The data is collected using questionnaire as it is a quantitative research. The data collected is analysed using both descriptive and inferential analysis to recognise the relationship among the variables. The research approaches conducted to achieve the research objectives is summarised in Figure 1.1.

Phase 1 *Literature Review*	**Phase 2** *Questionnaire Survey and Data Analysis*	
Objective 1 To explore the general application of IoT and its adoption in construction industry	**Objective 2** To investigate the awareness of the industrial players toward the application of IoT	**Objective 3** To uncover the issues and barriers of IoT adoption in Malaysia construction industry.

Figure 1.1: Summary of Research Approaches

1.7 Research Scope and Limitation of the Study

The two main limitations on this research are spatial limitation and temporal limitation. The questionnaires are distributed to developer firms, consultant firms and contractor firms in West Malaysia, particularly in the Klang Valley area. Construction parties from different organisations are invited as different roles have different perspective towards the IoT adoption.

Besides, IoT is a fast changing technology which still in the development stage. This research is undertaken for a year period from June 2018 to May 2019. The rapid development in the IoT applications make this research limited in the temporal dimension.

1.8 Structure of Report

This research is structured into five chapters and each chapter is outlined as below. Chapter 1 is the introductory chapter for the whole research. It provides the background information on IoT in construction industry and reviews the previous research. The necessities to conduct the research in Malaysia context and the restraints of this research are revealed in this chapter. The structure of this research is briefed at the las section of this chapter.

Next, Chapter 2 provides a brief account on IoT. The applications of IoT discusses includes drone, construction site robot, wearable technology, monitoring sensor, 3D printer and information sharing platform. This chapter covers the issues and challenges faced by current construction industry when implementing IoT system. A theoretical framework is proposed to reveal the relationship among the variables discussed in this research.

Chapter 3 reviews the research methodology adopted. The type of research and research design adopted are introduced and justified. The questionnaire design is discussed according to the proposed theoretical framework. Target respondents and sampling size is computed under this chapter. The data analysis methods adopted are uncovered in the last section of the chapter.

Chapter 4 reports the data collected from questionnaire and discuss on the findings. The data collected is presented in a systematic manner according to the objectives. Statistically significant tests are adopted to analyse the data collected and to generalise the findings. Descriptive and inferential statistic utilised is discussed under this chapter. The findings of the research are discussed and compared with the literature reviewed.

Lastly, Chapter 5 concludes the finding of this research. Conclusion is drawn for the research findings and the current status of the industry in IoT adoption. The implications of the research findings are identified. The limitations of this research are revealed follows by recommendations in future research to improve the quality of similar researches in the near future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a brief account of IoT. The current scenario of IoT development is reviewed in Section 2.2 follows by the development of IoT in Section 2.3. The applications of IoT in construction industry and the challenges encountered in IoT adoption are discussed in Section 2.4 and Section 2.5. This chapter is wrapped up by a proposed theoretical framework for IoT adoption in Section 2.6.

2.2 Internet of Things

IoT can be illustrated as the communication of a huge group of objects such as actuators, sensors, Radio-Frequency IDentification (RFID) tags and mobile phone (Atzori, Iera and Morabito, 2010) over the Internet or network (Sadeeq, et al., 2018). The object consists of sensors and electronics and controls by software to generate and collect data from surrounding. The data collected will be transferred to central database or other objects through network.

In the era with ubiquitous networking, IoT undoubtedly becomes the leading path in forming a smart world (Chaouchi, 2010). Services provided through the Internet developed from time to time by identifying the needs of current society. It has evolved from interactions between persons by the helps of machines, such as phone or email services to interactions between machines without human involvement. New computer system starts to provide all-pervading computing with task automation to form a smart world. All the devices are expected to communicate among themselves including the process of initiating, interacting, responding, negotiating, and measuring without the present of manpower (Husain, 2017). It is believe in year 2020, there will be up to 15 billion of connected devices excluding tablets, computers and cell phones (Zayas et al, 2018).

According to Ismail (2017), it is predicted that 964 billion dollars will be spent in IoT investment and around 81 % of organisation planned to kick start the IoT journey in a year time. Half of the organisations are behind in harnessing the capabilities of IoT that might lead to negative impact towards customer. Thus, organisations need to monitor the rapid acceleration in IoT technology and amend the regulation accordingly in approaches towards their partners, customer and workforces (Panetta, 2017).

The development of IoT applications can be explained with the help of Gartner's Hype Cycle. Gartner's Hype Cycle demonstrates the general pattern of the life cycle of a technology from the innovation triggering stage (Gartner, 2018). By referring to the Gartner Hype Cycle in Figure 2.1, the IoT platform still have two to five years to reach the plateau of the expectation. Thus, the organisations should prioritise their achievement in IoT field in order to fulfil the future market expectation and get a step in advance of others competing organisation.

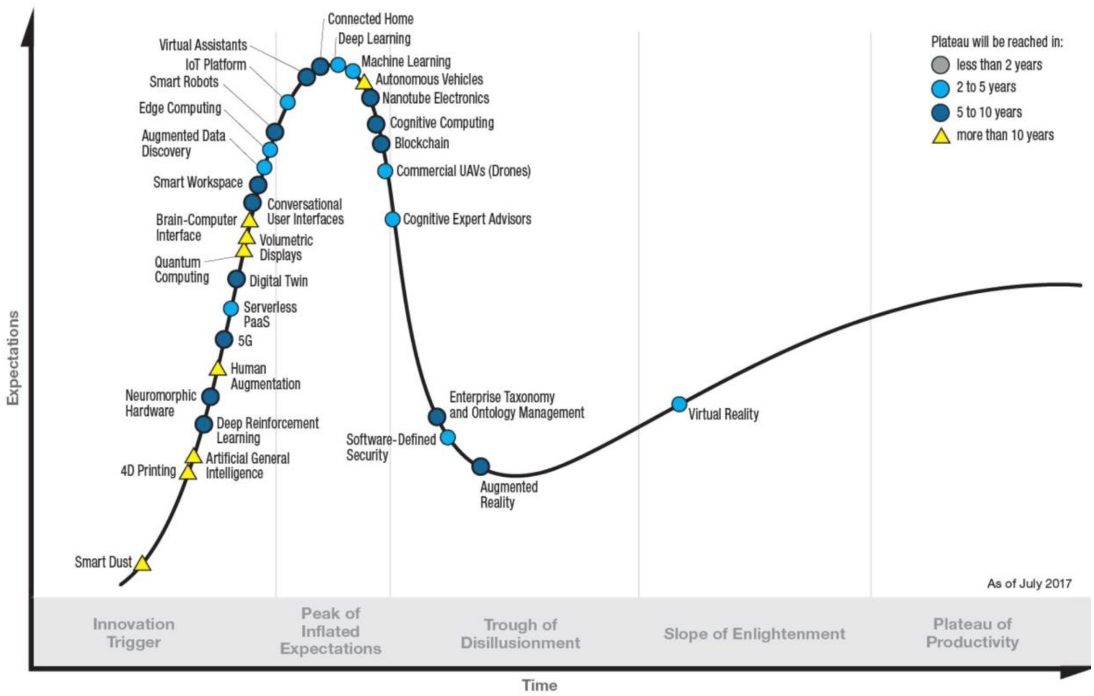

Figure 2.1: Gartner Hype Cycle for Emerging Technologies

(Source: Gartner, 2017)

2.3 Development of Internet of Things

According to Husain (2017), IoT development can be illustrated in three waves. The first wave relates with measuring and tracking of IoT devices which are currently in use. IoT development focus on the sensors and devices as well as the data delivered (McKendrick, 2019). IoT devices are used in measuring the body condition of carrier such as the heart rate and pulse. IoT devices are implanted in various types of equipment to evaluate the performance of systems or collect data for analysis purposes by workers.

The second wave of IoT covers for modelling and predicting purpose (Husain, 2017). This second wave is emerging in the industry now and focused on helping human through the aids of IoT devices (McKendrick, 2019). IoT devices aim in performing in a more sophisticated way instead of just collecting the data from surrounding. The data collected by the IoT devices in the previous stage will be interpreted to model the environment and forecast the future. In order to achieve this stage, the devices are required to equip with higher level of intelligence.

Lastly, the third wave is the development of completely autonomous devices to reveal the full potential of IoT (Husain, 2017). The high intelligent level enables the utilisation of data in projecting a granular, coherent and complex picture of reality. All mobile and autonomous systems are able to perform independently and avoid any conflict in the messy real life environment.

2.4 Application of Internet of Things in Construction Industry

IoT is a smart network connecting the machines and systems to the network to control, detect or program the object automatically (Mahmud, Assan and Islam, 2018). The applications of IoT in the current construction industry worldwide includes drone, construction site robot, wearable technology, monitoring sensor, three dimension printing and information sharing platform. The literature studied for these technologies are presented in Table 2.1 below.

Table 2.1: Literature Map for IoT Applications in Construction Industry

Previous Research	Drone	Construction Site Robot	Wearable Technology	Monitoring Sensor	3D Printer	Information Sharing Platform
Levy, 2017				√		
Higgins, 2017			√	√		√
Gerrard, 2018	√					
Stocking, 2017		√				
Ayemba, 2018	√					
Jones, 2018		√				
Autodesk BIM 360, 2018	√					
BIM +, 2019	√					
Forsberg, Graft and Wernersson, 1995		√				
Murison, 2016			√			

Table 2.1 (Continued)

Dormehl, 2017	√			
Waters and McAlpine, 2016		√		
Maw, 2019		√		
Giatec Scientific, 2018			√	
Kirkpatrick, 2018				√
Hager, Golonka and Putanowicz, 2016				√
Goidea, 2017				√
Buchanan and Gardner, 2019				√
Thryft, 2014				√
Ambrose, 2018				√

2.4.1 Drone

Gerrard (2018) expected that 4,816 drones will be on use in UK skies by 2030 for construction and manufacturing sector. Drone is utilised for two main purposes in construction industry especially during the construction stage (Ayemba, 2018), i.e. monitoring purpose and surveying purpose. For monitoring purpose, drone is used in construction site inspection especially for hazardous areas. Drone is equipped with web cam to collect aerial footage and transfer the data collected back for project stakeholder review. Site inspection can be carried out frequently and efficiently with the help of drone and thus allow construction parties to monitor the construction progress closely.

The data collected by drone is incorporated into Building Information Modelling (BIM) data collection system of the site (Autodesk BIM 360, 2018). Construction parties able to have a better view on the real time construction progress and plan ahead for the resources required includes labours, equipment and materials. The photogrammetry and 360 photography function of drone enables actual site progress to be captured during site scanning (BIM+, 2019). These features of drone ease the process of preparing site progress report as photos can be taken easily by drone in the view that best demonstrating the current site condition and insert into the progress report as the regular weekly updates (Autodesk BIM 360, 2018).

For surveying purposes during preconstruction stage, the details information regarding site condition and environment can be captured accurately using drone that equipped with infrared sensors, geolocation sensors and camera (Autodesk BIM 360, 2018). It helps the construction parties especially client to have a better visualization on the site constrains and prevent any losses due to insufficient inspection on the site condition in the later stage.

Moreover, drone is useful in building surveys during post construction stage especially in investigation of areas which are tricky or difficult to be access by individual such as roof (Ayemba, 2018). Small drone can be utilised in assisting the roof condition to detect defects within a short period of time. Besides, drone can also be used to inspect for maintenance especially for high up structure. Drone not only helps in reducing the time and cost for inspection, it also reduce the safety risk as inspection personal can inspect the structure on ground instead of climbing up to the structure.

2.4.2 Construction Site Robot

Various site robots are begun to be used at the job site, for example, SAM 100 bricklaying robot developed by Construction Robotics (Dormehl, 2017). This bricklaying robot is designed to handle a wide variety of bricks (Stocking, 2017). It works along with human mason by helping the mason in brick installation. This robot able to reduce human masons and improve the productivity as the physical strain on the workers such as heavy lifting work is reduced.

Another example is Built Robotics' autonomous track loader (Stocking, 2017). The track loader is completed with global positioning system GPS and it is guided by digital files to work around the job site to carry out cutting and filling work for small area of site cleaning. It is specified designed with light detection and ranging (LiDAR) to compute the volume of excavation by detecting the surrounding vibration (Jones, 2018).

Rebar tying introduced by Advanced Construction Robotics, TyBot helps to reduce the amount of labour required on site (Jones, 2018). The rebar tying robot has been put into practice in the bridge construction in Beaver County, U.S. in 2017. This robot is placed on the existing bridge structure and the robot will moves around at the gantry to tie rebar at each intersection. This application helps in improving the site productivity as the robot can work alone after setting up.

Another construction site robots being utilised is plastering robot (Forsberg, Graft, and Wernersson, 1995). It is used to spray plaster onto ceilings and concrete walls for large construction project. The robot is equipped with special arm to enable the same mechanical unit to spray on both ceilings and wall. The walls will be divided into segments for the robot to spray plaster onto it until the predetermined thickness. The plastering strategies available are vertical plastering and horizontal plastering.

2.4.3 Wearable Technology

Safety is always the main concerns where the young considered when entering construction industry (Waters and McAlpine, 2016). The introduction of wearable technology helps to improve the safety of the worker in construction site (Higgins, 2017). Construction site workers can equips with wearable technology such as smart helmet that enables management team to track the location of workers in work site. This wearable technology aims to warn site workers on potential hazards around from time to time. It also able to detect worker's condition such as slipped, fallen or tripped and ensure the worker received help at the first hand.

Besides, Laing O'Rourke and MOQDigital in Australia developed a smart helmet equipped with sensor to monitor the heart rate and body temperature of worker and at the same time detect the surrounding humidity and temperature (Murison, 2016). The data collected is analysed to warn the worker who is at the risk on heatstroke. The system will automatically inform the site manager on the potential workers detected to be at the risk of heatstroke. Organisation's safety policies can be enforced in a better way with the aids of wearable technology and most importantly reduce the worker incidents onsite (Maw, 2019).

2.4.4 Monitoring Sensor

Sensors can be implemented throughout the construction process. The adoption of monitoring sensor can be taken into consideration during design phase for sustainable building. One of the green features that usually adopted in green building is to provide sensor to shut down the system that is idle automatically. Furthermore, optimum natural light level can be achieved by using sensor to control the louvers to close or open at different time of a day.

Besides, monitoring sensor can be embedded into construction equipment to monitor the potential causes of failure and schedule for maintenance works. The earlier detection of unusual signal provides sufficient time for the worker to take precaution steps and prevent critical failure that might lead to critical delay on the construction progress. The data collected can be schedule for predictive maintenance to minimise critical failure of equipment.

On the other hand, sensor can be incorporated into the fabrication of the building components. The application of IoT such as RFID sensors in intelligent prefabrication building component helps to resolve the coordination problem usually faced by large and complex project (Levy, 2017). One of the case studies for RFID sensors applications in construction is Leadenhall Building in London (Levy, 2017). Sensors are used to track the individual prefabricated components all the way from supply chain until installation on site. The data collected by the sensors helps to minimize the chances of delays in delivering which have direct effect to the on-site construction activities. Moreover, the data can be merged into the BIM after the installation to allow for real time rendering of the building throughout the process and helps in project controls and computation of Key Performance Indicator (KPIs).

Besides, there is also mobile technology that enables user to fully involve in the prefabrication process. The prefabrication process is completely visible in the system from design phase to construction phase (Higgins, 2017). The users able to track on the real time prefabrication progress such as the manufacturing components, the processing location and the time of deliver.

A waterproof wireless sensor, SmartRock is developed to embed into concrete work during construction process to identify the accurate strength of the concrete casted. It is important for the worker to determine the most appropriate timing to tension the slab in post tension concrete slab construction (Giatec Scientific, 2018). This sensor is installed on rebar before concrete casting to monitor the real-time temperature of the concrete and the concrete strength gained. The actual temperature and strength of the concrete can be collected and observed from time to time using the SmartRock app after the concrete casted. The data collected is shared among the working team to identify the best timing in tensioning the slab.

2.4.5 Three Dimensions Printing

Three dimensions (3D) printing is expected to improve the efficiency of construction activities by shortening the construction period without compromising the sustainability of the end product (Kirkpatrick, 2018). The utilisation of 3D printer in construction industry increases the constructability of building design. 3D printer offered the construction of various building components from decorative pieces to structural element. Different materials such as concrete and foam are used to print the building components into specific shapes. The integration of onsite 3D printer helps to enhance the productivity and ensure the accuracy of construction program.

3D printer is adopted by WinSun, a Chinese organisation in constructing a house in 2014 (Hager, Golonka and Putanowicz, 2016). The building is constructed by extruding the mortar layer by layer through a nozzle. Next, in year 2017, BatiPrint3D is introduced and a demonstration house is constructed within few days by utilising 3D printer (Kirkpatrick, 2018). This 3D printer offered a higher accuracy level than conventional method which is approximately 1mm (Goidea, 2017). The building consists of three layers; one layer of concrete is casted between two layers of polyurethane foam. However, this technology is still in the demonstration stage and not available for mass commercialization.

Besides, 3D printer can be adopted in casting 3D bridge. Castilla-La Mancha is the first 3D bridge casted in two month time in year 2016 (Buchanan and Gardner, 2019). Another example of 3D printing bridge is the concrete bicycle bridge in Gemert, Netherlands. The bridge was printed in sections and installed onsite. Moreover, 3D printing technology is developed to print metal structure for construction projects in an efficiency way by reducing the cost and waste produced (Thryft, 2014). An achievement for 3D metal printing is the stainless steel 3D printed bridge by MX3D, a robotic metal 3D print technology developer (Ambrose, 2018).

2.4.6 Information Sharing Platform

Information sharing platform helps in improving the job site connectivity. Communication delay is a common problem faced by most of the construction project (Higgins, 2017). The adoption of information sharing platform enhances the catching up among the construction parties.

A connected job site allowed parties to access to the latest documents and drawings through smart phone or laptops anytime anywhere. All the construction parties are updated with latest information and thus reducing the mistakes due to delay in communication. Contractors are able to file Request for Information (RFI) when there is discrepancy in drawings and the design teams are able to give prompt respond within few hours instead of taking days and weeks. All the parties including the contractor and design team are updated with the real time activities at the construction site and thus eliminate the possible mistake caused by miscommunication.

2.5 Challenges on IoT Application

As IoT continue to develop and benefit the society, numerous challenges and barriers towards IoT adoption slowly come to light. There are various challenges need to overcome before the thrift of IoT in the construction industry. The challenges studied are summarised in Table 2.2 below.

Table 2.2: Literature Map for Challenges on IoT Adoption in Construction Industry

Previous Research	Communication Requirement	Network Security	Physical Protection	Authentication and Access Control	Data Accuracy	Energy Efficiency	Society Impact	Implementation Cost	Professional Skill
Farhan, et al., 2018	√	√	√			√			
Zayas, et al., 2018	√		√		√				
Kamble, et al., 2019	√							√	
Marwedel and Engel, 2016		√				√			
IoT Security Foundation, 2019			√						
Liu, Xiao, and Chen, 2012				√					
Conti, et al., 2018				√					
Reyna, et al., 2018					√				
Force Technology, 2016					√				
Kamble, et. al. 2019						√			√
MPDigest, 2018							√		
Luthra, et al., 2017								√	
Granjal, Monteiro and Silva, 2015								√	
Kathy, 2019									√

2.5.1 Communication Requirement

A unique, reliable, persistent and scalable address is required for the IoT devices to connect among each other (Farhan, et al., 2018) as IoT is expected to perform many-to-one communication (Zayas, et al., 2018). A private Internet Protocol (IP) address needs to be assigned to every device for the system to identify their belonging devices through the network and transfer the data collected to the ultimate server.

Excellent internet connectivity is required to ensure the real-time flow of data collected by the IoT devices (Kamble, et al., 2019). It is when the construction site is located in suburban area with poor internet penetration as it may delay the data deliver. Network is a necessity to monitor the IoT devices. The real time location, usage and communication among IoT applications can only be monitor through the data transmitted back by each device.

2.5.2 Network Security

Network security appeared to be the biggest challenge for every sector including construction sector (Farhan, et al., 2018). The data collected by IoT devices will be transmitted through various devices and link before it is collected by the ultimate receiver of internet. Warning is given by cybersecurity experts that IoT might be the target for cybercrime and data theft. It is clear that cyber terrorism is a real threat to the construction industry adopting IoT appliances as any compromises and losses of data during the construction process might lead to project delay and bring the project to a grinding halt (Marwedel and Engel, 2016).

2.5.3 Physical Protection

The unattended IoT devices onsite are the attractive targets for destruction, tempering and theft (Zayas, et al., 2018). The adoption of IoT in a construction project created tons of vulnerable point as most of the IoT devices remain immobile for the entire lifetime after installation and every IoT devices contributes to a potential risk (Farhan, et al., 2018). Thus, huge amount of effort is required to protect the installed devices from those malicious attacks as the compromise on the physical protection towards the IoT devices might create potential risk for the attacker to get access towards the data collected by the devices (IoT Security Foundation, 2019).

2.5.4 Authentication and Access Control

Authentication and access control is the key element in resolving privacy and security issues for IoT development (Liu, Xiao, and Chen, 2012). Access control is important to avoid unauthorised parties to access the IoT system through unauthorised manners and allow the access of authorised parties through authorised manner. Besides, authentication is required for the devices to recognise the data's sources as well as the data transferred (Conti, et al., 2018). An effective key management and key deployment is essential for the IoT devices to carry out the authentication exercises.

2.5.5 Data Accuracy

The ability of the IoT devices to address information accurately is another challenge in IoT development (Zayas, et. al 2018). The accurateness of the data collected by IoT devices is highly depends on the performance of the devices (Reyna, et al., 2018). There might be actuators or sensors failure from the beginning or damaged due to programme obsolescence, sudden disconnection or short circuit. All these failure can only be uncovered when test is conducted for the devices. The reliability of the data collected is a doubt when the internet connection is poor as there might be failed attempt during data transmission (Force Technology, 2016).

2.5.6 Energy Efficiency

Most of the IoT devices are mobile system and usually operates in space where the supply of electricity is limited (Marwedel and Engel, 2016). Power supply is a critical concern for IoT devices especially in logistic field (Kamble, et. al. 2019). It is important for IoT devices to carry out energy harvesting as it is impractical to change the battery for millions of devices in IoT system (Farhan, et al., 2018). Energy efficiency devices shall be adopted to prolong the lifetime of the battery. The transmission of unnecessary data and protocol shall be avoided to prevent energy wastage in the transmission process.

2.5.7 Society Impact

The adoption of IoT in the construction industry is a potential threat towards the overall job market (MPDigest, 2018). The development of IoT is expected to slowly take over numerous tedious and repetitive tasks performing by human today. This will result in the job losing for the society that currently performing these drudge works. However, it is hard to predict the overall influence of IoT adoption towards the society as the social sciences is barely kept up with the speed of changes. Organisation should always ensure IoT adoption brings greater benefits to the environment and the society that the negative impacts.

2.5.8 Implementation Cost

Luthra, et al. (2017) stated that high investment cost a barrier stopping organisation to adopt IoT. Large number of devices and sensors required when employing IoT application. Everything that is good comes with a price. A high accuracy, speed and reliability IoT devices required a high initial cost. Organisation required strong financial background to cover the high initial cost of IoT appliances and the payback period is long. Organisations might not able to take this technology risk as this is an irreversible investment that might result in financial loss (Kamble, et al., 2019).

Besides, the restriction in the capital available is directly proportional to the resources available for the IoT devices such as the computation power and the memory to store the data collected (Granjal, Monteiro and Silva, 2015). The operation and maintenance cost of IoT devices contributes to a huge expenses as all the devices consuming batteries to perform.

2.5.9 Professional Skill

Highly trained expertise is required in the operation and development of IoT appliances (Kamble, et al., 2019). IoT network required functional skills and high end technical to install, interface and manage. In order to convert the data collected into valuable information, technician in machine learning and profession from the field of algorithms are required. Thus, a user friendly IoT system should be developed to enhance the adaptability of the application.

Kathy (2019) reported that the construction community in Malaysia consists of a mix pool of players. It consists of millennials who just entered the industry and baby boomers who about to finish their journey in construction industry. Extra effort is required to train the professional skills of this mix variety of construction players as they different learning curve and approach towards the development of IoT. Appropriate continuous training and education should be provided to enhance the professional skills of the construction community.

2.6 Proposed Theoretical Framework for Internet of Things

In a nutshell, the literature reviewed can be summarised into the theoretical framework as shown in Figure 2.2. It is assumed that IoT application in construction industry needs to have awareness from construction practitioners in IoT development. The two moderating variables, “organisational processes, policies and practices” and “challenges on IoT applications” have contingent effect to the IoT application in the construction industry.

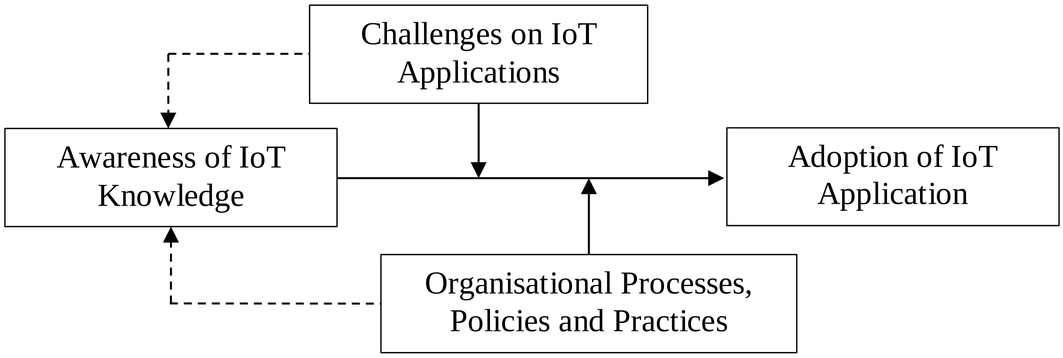

Figure 2.2: Theoretical Framework for Internet of Things

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter revealed the research methodology implemented. Exploratory nature of this research and its justification is explained in Section 3.2. The research instrument adopted in this research is outlined in Section 3.3 follows by the sampling size estimation in Section 3.4. Lastly, a brief account of data analysis methods is provided in Section 3.5.

3.2 Exploratory Study

This research is an exploratory study. It aims to explore the possible uses on IoT applications in Malaysian construction industry and the potential challenges in the adoption of IoT. Exploratory study is used when researcher plan to explore or clarify a problem, issue or phenomenon (Saunders, Lewis and Adrian, 2016). It is conducted when the research topic is not well known by public and there is limited information available (Creswell, 2009).

3.3 Research Instrument

This is a quantitative research as questionnaire is adopted to collect responses effectively from a huge sampling group by requesting all the respondents to answer the same set of questions through Internet via Google form or delivered by hand (Saunders, Lewis and Adrian, 2016). The questionnaire collects sample and information relates to the attitudes, trends and opinions of the respondents (Creswell, 2009).

3.3.1 Questionnaire Design

The questionnaire of this research is structured into four sections. The questionnaire design shown in Figure 3.1 is developed from the theoretical framework proposed in Chapter 2 (Figure 2.2).

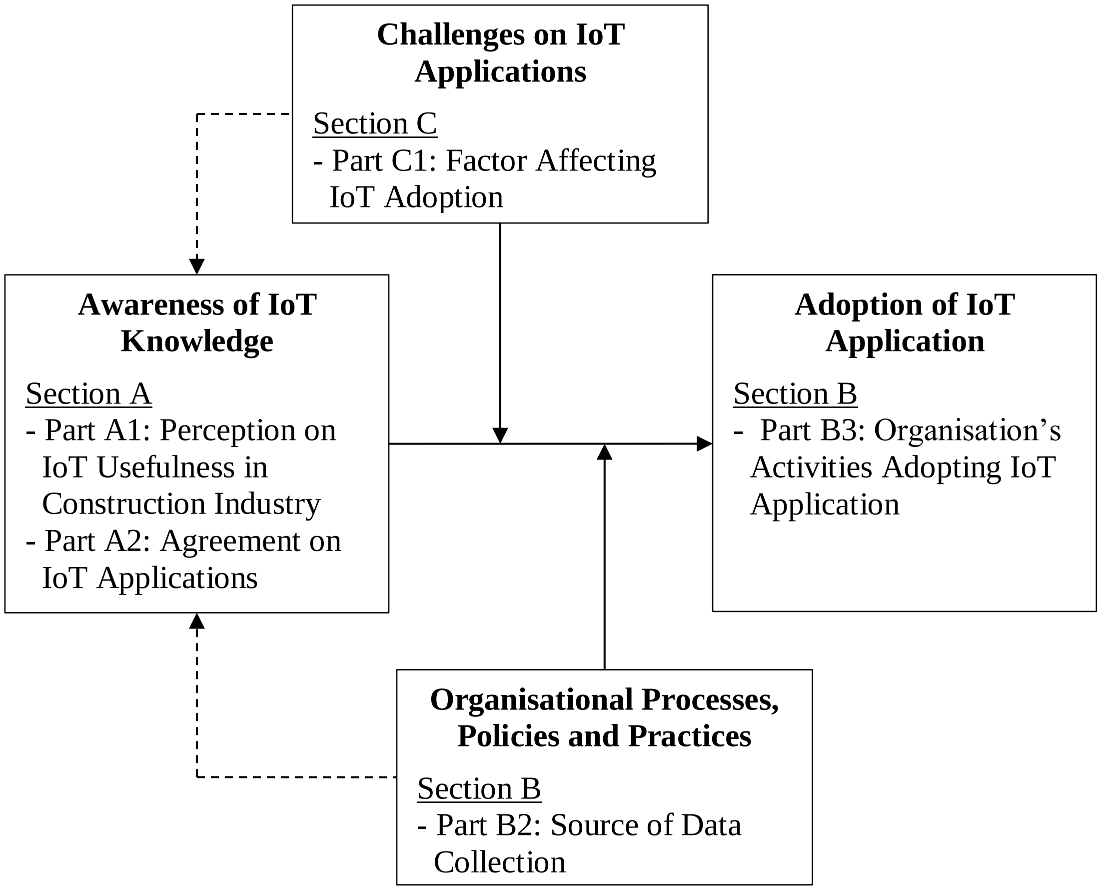

Figure 3.1: Theoretical Framework for Questionnaire Design

Section A consists of two parts to evaluate the respondents' knowledge level in IoT field. Both part A1 and A2 are designed as matrix question. Part A1 focuses on respondents' perception towards the usefulness of IoT applications in construction industry. Six IoT devices reviewed in the literature are listed down in this part. Part A2 consists of 25 statements regarding the functions of IoT. Both Part A1 and A2 required respondents to rate their agreement from strongly disagree to strongly agree. Table 3.1 showed the summary of statements cover by each device.

Table 3.1: Statements Coverage for Each IoT Application in Part A2

IoT Application	Function of IoT Application
Drone	Statement 1 – 4
Construction Site Robot	Statement 5 – 9
Wearable Technology	Statement 10 – 13
Monitoring Sensor	Statement 14 – 18
3D Printing	Statement 19 – 22
Information Sharing Platform	Statement 23 – 25

Section B consists of three parts. Part B1 is a list question to evaluate the respondents' perception on possibility of IoT devices to transform their organisation. Part B2 and B3 are matrix question. Part B2 consists of six conventional data collection methods and four IoT data collection methods as shown in Table 3.2. The data collection methods of organisations are appraised in this part. Part B3 provides 11 construction activities to evaluate the current adoption of IoT devices in construction industry. Both Part B2 and B3 require respondents to reveal the current organisations' practices.

Table 3.2: Sources of Data Collection in Part B2

Data Collection Method	Sources
Conventional	Statement 1, 2, 3, 5, 8 and 9
IoT Application	Statement 4, 6, 7 and 10

Section C consists of a matrix question to uncover the potential challenges for IoT implementation. Respondents are required to rate nine challenges from not important at all to extremely important towards IoT adoption. The data collected is analysed to identify the potential obstacles for IoT adoption in local construction industry.

Lastly, Section D collects the demography data of respondents. The data collects includes organisation business activities, role, age, working experiences and the type of client and building they get involved in. these are independent variables to reveal the relationship with the dependent variables collected in other section. Table 3.3 showed the summary of the questions assessed in Section D.

Table 3.3: Respondent's Attributes Assesses in Section D

No.	Type of Question	Factor Assessed
D1	List Question	Organisation's business activities
D2	List Question	Respondent's role in project
D3	Category Question	Respondent's age
D4	Category Question	Respondent's working experience
D5	List Question	Type of client experienced
D6	List Question	Type of product experienced

3.4 Sampling Size

This research assumes a confidence level of 95 % (Z = 1.96) with marginal error of 5 % (e = 0.05). The questionnaire design is using a seven Likert scale and the p value is equivalent to 0.14, which indicates the probability of each choice being picked by the respondents. A sampling size of 186 is required as demonstrated by the following calculation (Cochran, 1963):

$$n = \frac{Z^2 p(1-p)}{e^2} \tag{3.1}$$

$$n = \frac{1.96^2(0.14)(1-0.14)}{0.05^2} = 186$$

where

n = sampling size

Z = level of confidence

p = estimated proportion of an attribute in the population

e = tolerated margin of error

Convenience sampling is adopted for data collection. It is a non-random sample where respondents are selected based on their availability and convenience (Neuman, 2014).

3.4.1 Target Respondents

The target respondents for this research are the personnel working in Malaysian construction industry. This is to ensure the respondents have sufficient industrial knowledge and experience to understand the IoT usage stated in questionnaire.

3.5 Data Analysis

Statistically significant tests are adopted to analyse the data collected from questionnaire to generalise the findings. Descriptive and inferential statistic are utilised to analyse the finding.

3.5.1 Descriptive Analysis

For Section A and C, mean ranks of the statements are computed using Friedman test. The mean rank revealed the agreement of the respondents towards the statements in the questionnaire. The mean rank indicates the degree of acknowledgement on the statement from respondents. The statements are rearranged according to their mean rank in the descending order to evaluate the perception of respondents towards IoT application.

In Section B, frequency of respondents rating “collect now” and “using now” are computed. The data collection methods and activities adopting IoT are ranked according to the frequency to reveal the current practices and IoT adoption level in Malaysian construction industry.

3.5.2 Reliability Analysis

Reliability test is carried out for all the matrix questions from Section A to Section C to assess the construct of questionnaire. The internal consistency is measured by correlating the responses collected by each question using Cronbach’s alpha test (Saunders, Lewis and Adrian, 2016). The value of alpha coefficient is range from 0 to 1. Alpha coefficient value that greater than 0.7 indicates the set of questions are assessing the same item and the data is reliable.

3.5.3 Non-Parametric Analysis

K-independent-samples test is adopted to reveal the relationship among the independent variables and dependent variables as more than three variables are assessed in the questionnaire (Cooper and Schindler, 2014). Kruskal-Wallis test is adopted to assess the significant differences among the independent variables and dependent variables to generalise the findings. The null hypotheses are tested to identify the rejected null hypothesis for the statements in Section A and Section C.

Next, pairwise comparison is carried out for the rejected null hypothesis to reveal the pairs of sample groups with significant different in their perception. The relationship between the statements and the sample pairs is analysed and discussed in the following chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter reports the result of the field survey, analyses the results obtained and infers the result for generalisation. The attributes of respondents are introduced in Section 4.2. Section 4.3 to Section 4.7 reports the results of data collected which are arranged according to perception towards IoT application in construction industry, knowledge level of IoT applications, organisations' data collection methods, application of IoT in organisations' activities and lastly challenges for IoT implementation. Lastly, Section 4.8 discusses the findings and compares the findings with literature reviewed.

4.2 Respondents Background

Out of 800 sets of questionnaire distributed, 204 sets of questionnaire are received through social media including email, Facebook, WhatsApp and LinkedIn and delivered by hand. The details of the respondents' attributes are summarised in Table 4.1 below.

Nearly half of respondents are from contractor firms (46.6 %) and most of the respondents work as engineers (34.3 %). Majority of the respondents are in the age group of between 25 to 30 years old (44.6 %) and 38.7 % of them have working experience less than 2 years.

Table 4.1: Attributes of Respondents (N=204)

General Information	Categories	Frequency	Percentage (%)
Organisation Business Activities	Developer	44	21.6
	Consultant	60	29.4
	Contractor	95	46.6
	Sub-Contractor	4	2.0
	Supplier	1	0.5
Role in Project	Client	17	8.3
	Architect	6	2.9
	Engineer	70	34.3
	Quantity Surveyor	69	33.8
	Manager	42	20.6

Table 4.1 (Continued)

Age	Below 25 years old	31	15.2
	25 – 30 years old	91	44.6
	31 – 40 years old	47	23.0
	41 – 50 years old	27	13.2
	51 and above	8	3.9
Working Experience	Less than 2 years	79	38.7
	2 – 5 years	69	33.8
	5 – 10 years	30	14.7
	Above 10 years	26	12.7

4.3 Perception towards Usefulness of IoT Applications

The mean ranks of the perceived usefulness of IoT devices in construction industry are reported in Table 4.2. The reliability test for the six statements showed Cronbach's Alpha value of 0.888 which indicated that the statements in the questionnaire construct are internally consistent. Friedman Test results revealed the differences of the mean rank are statistically significant ($\chi 2$ = 274.883, df = 5, N = 204, p = .000). The perceived usefulness of IoT applications ranked in descending order is: information sharing platform (4.60), drone (4.01), monitoring sensor (3.97), 3D printing (3.15), wearable technology (2.94) and construction site robot (2.34).

Table 4.2: Ranking for the Perception towards Usefulness of IoT Applications in Construction Industry (N=204)

IoT Application	Mean Rank	Chi-Square	Asymp. Sig.
Information Sharing Platform	4.60	274.883	.000
Drone	4.01		
Monitoring Sensor	3.97		
3D Printing	3.15		
Wearable Technology	2.94		
Construction Site Robot	2.34		

Note: N = number of respondents; df = degree of freedom

Post hoc tests are conducted for perception on IoT usefulness in construction industry on all the respondents' attributes and the list of significant null hypotheses is reported in Table 4.3.

Table 4.3: Rejected Null Hypotheses for the Perception towards Usefulness of IoT Applications in Construction Industry

Null Hypothesis	Sig.
The perception on the usefulness of information sharing platform in construction industry is same between the group perceiving IoT is “very likely” and “not likely” in transforming the organisation.	.005
The perception on the usefulness of information sharing platform in construction industry is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation.	.002
The perception on the usefulness of information sharing platform in construction industry is same between the age group of “25 to 30 years old” and “less than 25 years old”.	.016
The perception on the usefulness of information sharing platform in construction industry is same between the group with “2 to 5 years” and “more than 10 years” working experience.	.026
The perception on the usefulness of drone in construction industry is same between the group perceiving IoT is “very likely” and “not likely” in transforming the organisation.	.013
The perception on the usefulness of drone in construction industry is same between the age group of “25 to 30 years old” and “less than 25 years old”.	.002
The perception on the usefulness of drone in construction industry is same between the group with “2 to 5 years” and “more than 10 years” working experience.	.037
The perception on the usefulness of monitoring sensor in construction industry is same between the group perceiving IoT is “very likely” and “not likely” in transforming the organisation.	.036
The perception on the usefulness of monitoring sensor in construction industry is same between the group with “2 to 5 years” and “more than 10 years” working experience.	.014
The perception on the usefulness of monitoring sensor in construction industry is same between the group of “engineer” and “quantity surveyor”.	.018
The perception on the usefulness of wearable technology in construction industry is same between the group perceiving IoT is “very likely” and “not likely” in transforming the organisation.	.018
The perception on the usefulness of construction site robot in construction industry is same between the age group of “25 to 30 years old” and “less than 31 to 40 years old”.	.011

From the above significant tests, the following pairs of respondents have statistically significant different in perception towards usefulness of IoT in construction industry:

(i) The group perceived IoT is very likely in transforming the organisation business perceived

a. higher usefulness of information sharing platform (mean rank = 125.27) than the group perceived IoT is not likely (mean rank = 70.93) and somewhat likely (mean rank = 93.65) in transforming the organisation business.

b. higher usefulness of drone (mean rank = 123.58) than the group perceived IoT is not likely (mean rank = 73.63) in transforming the organisation business.

c. higher usefulness of monitoring sensors (mean rank = 117.12) than the group perceived IoT is not likely (mean rank = 72.27) in transforming the organisation business.

d. higher usefulness of wearable technology (mean rank = 116.40) than the group perceived IoT is not likely (mean rank = 67.43) in transforming the organisation business.

(ii) The age group of 25 to 30 years old perceived

a. higher usefulness of information sharing platform (mean rank = 115.57) than the age group of less than 25 years old (mean rank = 78.11).

b. higher usefulness of drone (mean rank = 116.59) than the age group of less than 25 years old (mean rank = 72.76).

c. higher usefulness of construction site robot (mean rank = 118.49) than the age group of 31 to 40 years old (mean rank = 84.35).

(iii) The group with 2 to 5 years working experience perceived

a. higher usefulness of information sharing platform (mean rank = 112.12) than the group with more than 10 years working experience (mean rank = 74.75).

b. higher usefulness of drone (mean rank = 114.84) than the group with more than 10 years working experience (mean rank = 78.62).

c. higher usefulness of monitoring sensors (mean rank = 78.62) than the group with more than 10 years working experience (mean rank = 73.71).

(iv) The group of engineer (mean rank = 118.49) perceived higher usefulness of monitoring sensors than the group quantity surveyor (mean rank = 88.08).

4.4 Knowledge Level on IoT Application

Table 4.4 presents the knowledge level on IoT applications in construction industry. The 25 statements under this section are internally consistence as the Cronbach Alpha value is 0.962. The differences of mean rank presented are statistically significant ($\chi 2$ = 944.282, df = 24, N = 204, p = .000). The top three functions of IoT application recognised by construction practitioners are “utilisation of drone in capturing construction work progress” (mean rank = 18.64), “utilisation of smart phone or tablet in accessing, updating and reviewing updated documents and drawings” (mean rank = 17.76) and “utilisation of information sharing platform in providing prompt respond upon queries” (mean rank = 17.53).

Table 4.4: Ranking for the Knowledge Level on IoT Applications in Construction Industry (N=204)

Function of IoT Application	Mean Rank	Chi-Square	Asymp. Sig.
Drone can be used to capture construction work progress.	18.64	944.282	.000
Smart phone or tablet can access, update and view updated documents and drawings.	17.76		
Information sharing platform help the project team to provide prompt respond upon queries.	17.53		
Drone can be used to carry out roof condition survey for maintenance purpose.	16.39		

Table 4.4 (Continued)

Information sharing platform improve the job site connectivity.	16.31
Drone can be used to monitor hazardous area at construction site.	15.17
Monitoring sensor can be used to monitor the real-time temperature and strength of concrete casted.	14.17
Monitoring sensor can be used to update the real time location and process of prefabrication components.	13.88
Monitoring sensor can shut down the system that is idle automatically when building is not occupied.	13.59
Monitoring sensor can detect the potential causes of failure for construction equipment.	13.36
Drone can be used for resource allocation.	13.28
Monitoring sensor can be used to detect the best timing for slab tensioning.	13.20
Autonomous machines save times in computing work done.	12.88
Wearable technology can be used to notify management team when site worker is slipped, fallen or tripped.	12.25
Wearable technology can be used to detect the humidity and temperature surrounds the worker.	12.17
Wearable technology can be used to detect site workers' current location and body condition.	12.10
Wearable technology can be used to warn site workers on the potential hazards around according to the location of site workers.	12.02
3D printer can be used to print building components.	11.99
Autonomous machines can be used to carry out site clearing, earth cutting and filling work.	11.12
3D printer can be used to print houses.	10.99
3D printer can create metal structures.	9.98

Table 4.4 (Continued)

3D printer can be used to print bridges.	9.54
Robot can be used in plastering.	9.41
Robot can be used in brick laying.	9.00
Robot can be used to tie rebar.	8.24

4.4.1 Knowledge Level on Applications of Information Sharing Platform

Table 4.5 is the rejected null hypotheses regarding the agreement towards applications of information sharing platform after conducted the post hoc test to pairwise comparing differences of the knowledge level against the respondents' attributes.

Table 4.5: Rejected Null Hypotheses for the Knowledge Level on Applications of Information Sharing Platform in Construction Industry

Null Hypothesis	Sig.
The agreement on the application of information sharing platform in improving job site connectivity is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.008
The agreement on the application of information sharing platform in improving job site connectivity is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.001
The agreement on the application of information sharing platform in accessing, updating and viewing updated documents and drawings is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.000
The agreement on the application of information sharing platform in accessing, updating and viewing updated documents and drawings is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.016
The agreement on the application of information sharing platform in helping the project team to provide prompt respond upon queries is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.000

Table 4.5 (Continued)

The agreement on the application of information sharing platform in helping the project team to provide prompt respond upon queries is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.012
The agreement on the application of information sharing platform in helping the project team to provide prompt respond upon queries is same between the group perceiving IoT is "somewhat likely" and "not likely" in transforming the organisation business.	.040

From the above significant tests, the following pairs of respondents have statistically significant different in knowledge level on applications of information sharing platform:

(i) The group perceived IoT is very likely in transforming the organisation business perceived

a. higher agreement on the application of information sharing platform in improving job site connectivity (mean rank = 126.49) than the group perceived IoT is not likely (mean rank = 75.40) and somewhat likely (mean rank = 92.30) in transforming the organisation business.

b. higher agreement on the application of information sharing platform in accessing, updating and viewing updated documents and drawings (mean rank = 124.51) than the group perceived IoT is not likely (mean rank = 58.23) and somewhat likely (mean rank = 97.48) in transforming the organisation business.

c. higher agreement on the application of information sharing platform in helping the project team to provide prompt respond upon queries (mean rank = 123.58) than the group perceived IoT is not likely (mean rank = 55.50) and somewhat likely (mean rank = 97.08) in transforming the organisation business.

4.4.2 Knowledge Level on Applications of Drone

Table 4.6 is the rejected null hypotheses regarding the agreement towards drone applications after conducted the post hoc test to pairwise comparing differences of the knowledge level against the respondents' attributes.

Table 4.6: Rejected Null Hypotheses for the Knowledge Level on Applications of Drone in Construction Industry

Null Hypothesis	Sig.
The agreement on the application of drone in monitoring hazardous area at construction site is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.006
The agreement on the application of drone in monitoring hazardous area at construction site is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.012
The agreement on the application of drone in carrying out roof condition survey for maintenance purpose is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.017
The agreement on the application of drone in carrying out roof condition survey for maintenance purpose is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.009
The agreement on the application of drone in in resource allocation is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.013
The agreement on the application of drone in in resource allocation is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.001
The agreement on the application of drone in capturing construction work progress is same between the age group of "25 to 30 years old" and "less than 25 years old".	.006
The agreement on the application of drone in capturing construction work progress is same between the age group of "31 to 40 years old" and "less than 25 years old".	.007
The agreement on the application drone in capturing construction work progress is same between the group of "engineer" and "quantity surveyor".	.044

From the above significant tests, the following pairs of respondents have statistically significant different in knowledge level on applications of drone:

(i) The group perceived IoT is very likely in transforming the organisation business perceived

a. higher agreement on the application of drone in monitoring hazardous area at construction site (mean rank = 122.48) than the group perceived IoT is not likely (mean rank = 71.43) and somewhat likely (mean rank = 95.36) in transforming the organisation business.

b. higher agreement on the application of drone in carrying out roof condition survey for maintenance purpose (mean rank = 123.78) than the group perceived IoT is not likely (mean rank = 76.10) and somewhat likely (mean rank = 96.22) in transforming the organisation business.

c. higher agreement on the application of drone in resource allocation (mean rank = 127.64) than the group perceived IoT is not likely (mean rank = 77.63) and somewhat likely (mean rank = 93.14) in transforming the organisation business.

(ii) The age group of 25 to 30 years old perceived higher agreement on the application of drone in capturing construction work progress (mean rank = 111.15) than the age group of less than 25 years old (mean rank = 72.63).

(iii) The age group of 31 to 40 years old perceived higher agreement on the application of drone in capturing construction work progress (mean rank = 115.12) than the age group of less than 25 years old (mean rank = 72.63).

(iv) The group of engineer (mean rank = 115.02) perceived higher agreement on the application of drone in capturing construction work progress than the group of quantity surveyor (mean rank = 88.86).

4.4.3 Knowledge Level on Applications of Monitoring Sensor

Table 4.7 is the rejected null hypotheses regarding the agreement towards applications of monitoring sensor after conducted the post hoc test to pairwise comparing differences of the knowledge level against the respondents' attributes.

Table 4.7: Rejected Null Hypotheses for the Knowledge Level on Applications of Monitoring Sensor in Construction Industry

Null Hypothesis	Sig.
The agreement on the application of monitoring sensor in updating the real time location and process of prefabrication components is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.036
The agreement on the application of monitoring sensor in updating the real time location and process of prefabrication components is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.009
The agreement on the application of monitoring sensor in monitoring the real-time temperature and strength of concrete casted is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.019
The agreement on the application of monitoring sensor in detecting the best timing for slab tensioning is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.003
The agreement on the application of monitoring sensor in detecting the potential causes of failure for construction equipment is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.033
The agreement on the application of monitoring sensor in shutting down idle system automatically when building is not occupied is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.000

From the above significant tests, the following pairs of respondents have statistically significant different in knowledge level on applications of monitoring sensor:

(i) The group perceived IoT is very likely in transforming the organisation business perceived

a. higher agreement on the application of monitoring sensor in updating the real time location and process of prefabrication components (mean rank = 122.41) than the group perceived IoT is not likely (mean rank = 78.10) and somewhat likely (mean rank = 94.68) in transforming the organisation business.

b. higher agreement on the application of monitoring sensor in monitoring the real-time temperature and strength of concrete casted (mean rank = 121.82) than the group perceived IoT is somewhat likely (mean rank = 95.85) in transforming the organisation business.

c. higher agreement on the application of monitoring sensor in detecting the best timing for slab tensioning (mean rank = 122.35) than the group perceived IoT is somewhat likely (mean rank = 91.70) in transforming the organisation business.

d. higher agreement on the application of monitoring sensor in detecting the potential causes of failure for construction equipment (mean rank = 118.76) than the group perceived IoT is somewhat likely (mean rank = 94.22) in transforming the organisation business.

e. higher agreement on the application of monitoring sensor in shutting down idle system automatically when building is not occupied (mean rank = 127.39) than the group perceived IoT is somewhat likely (mean rank = 90.01) in transforming the organisation business.

4.4.4 Knowledge Level on Applications of 3D Printer

Table 4.8 is the rejected null hypotheses regarding the agreement towards applications of 3D printer after conducted the post hoc test to pairwise comparing differences of the knowledge level against the respondents' attributes.

Table 4.8: Rejected Null Hypotheses for the Knowledge Level on Applications of 3D Printer in Construction Industry

Null Hypothesis	Sig.
The agreement on the application of 3D printer in printing building components is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.006

Table 4.8 (Continued)

The agreement on the application of 3D printer in printing houses is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.031
The agreement on the application of 3D printer in printing houses is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.043
The agreement on the application of 3D printer in printing bridges is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.029
The agreement on the application of 3D printer in printing bridges is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.007
The agreement on the application of 3D printer in creating metal structures is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.018

From the above significant tests, the following pairs of respondents have statistically significant different in knowledge level on applications of 3D printer:

(i) The group perceived IoT is very likely in transforming the organisation business perceived

a. higher agreement on the application of 3D printer in printing building components (mean rank = 121.37) than the group perceived IoT is somewhat likely (mean rank = 92.17) in transforming the organisation business.

b. higher agreement on the application of 3D printer in printing houses (mean rank = 118.44) than the group perceived IoT is not likely (mean rank = 72.73) and somewhat likely (mean rank = 94.52) in transforming the organisation business.

c. higher agreement on the application of 3D printer in printing bridges (mean rank = 120.96) than the group perceived IoT is not likely (mean rank = 74.77) and somewhat likely (mean rank = 91.81) in transforming the organisation business.

d. higher agreement on the application of 3D printer in creating metal structures (mean rank = 118.54) than the group perceived IoT is not likely (mean rank = 69.73) in transforming the organisation business.

4.4.5 Knowledge Level on Applications of Wearable Technology

Table 4.9 is the rejected null hypotheses regarding the agreement towards applications of wearable technology after conducted the post hoc test to pairwise comparing differences of the knowledge level against the respondents' attributes.

Table 4.9: Rejected Null Hypotheses for the Knowledge Level on Applications of Wearable Technology in Construction Industry

Null Hypothesis	Sig.
The agreement on the application of wearable technology in detecting site workers' current location and body condition is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.006
The agreement on the application of wearable technology in detecting site workers' current location and body condition is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.026
The agreement on the application of wearable technology in detecting site workers' current location and body condition is same between the age group of "25 to 30 years old" and "31 to 40 years old".	.001
The agreement on the application of wearable technology in detecting the humidity and temperature surrounds the worker is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.016
The agreement on the application of wearable technology in warning site workers on the potential hazards around according to the location of site workers is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.008
The agreement on the application of wearable technology in warning site workers on the potential hazards around according to the location of site workers is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.014
The agreement on the application of wearable technology in notifying management team when site worker is slipped, fallen or tripped is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.023

From the above significant tests, the following pairs of respondents have statistically significant different in knowledge level on applications of wearable technology:

(i) The group perceived IoT is very likely in transforming the organisation business perceived

a. higher agreement on the application of wearable technology in detecting site workers' current location and body condition (mean rank = 121.38) than the group perceived IoT is not likely (mean rank = 68.17) and somewhat likely (mean rank = 96.25) in transforming the organisation business.

b. higher agreement on the application of wearable technology in detecting the humidity and temperature surrounds the worker (mean rank = 119.65) than the group perceived IoT is not likely (mean rank = 71.03) in transforming the organisation business.

c. higher agreement on the application of wearable technology in warning site workers on the potential hazards around according to the location of site workers (mean rank = 122.56) than the group perceived IoT is not likely (mean rank = 70.53) and somewhat likely (mean rank = 95.75) in transforming the organisation business.

d. higher agreement on the application of wearable technology in notifying management team when site worker is slipped, fallen or tripped (mean rank = 118.09) than the group perceived IoT is not likely (mean rank = 71.17) in transforming the organisation business.

(ii) The age group of 25 to 30 years old perceived higher agreement on the application of wearable technology in detecting site workers' current location and body condition (mean rank = 120.43) than the age group of 31 to 40 years old (mean rank = 83.65).

4.4.6 Knowledge Level on Applications of Construction Site Robot

Table 4.10 is the rejected null hypotheses regarding the agreement towards applications of construction site robot after conducted the post hoc test to pairwise comparing differences of the knowledge level against the respondents' attributes.

Table 4.10: Rejected Null Hypotheses for the Knowledge Level on Applications of Construction Site Robot in Construction Industry

Null Hypothesis	Sig.
The agreement on the application of construction site robot in computing work done is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.031
The agreement on the application of construction site robot in in laying brick is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.048
The agreement on the application of construction site robot in laying brick is same between the age group of "25 to 30 years old" and "31 to 40 years old".	.042
The agreement on the application of construction site robot in laying brick is same between the group with "less than 2 years" "2 to 5 years" working experience.	.048
The agreement on the application of construction site robot in in tying rebar is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.003
The agreement on the application of construction site robot in tying rebar is same between the age group of "25 to 30 years old" and "31 to 40 years old".	.026
The agreement on the application of construction site robot in in tying rebar is same between the group perceiving IoT is "very likely" and "somewhat likely" in transforming the organisation business.	.038
The agreement on the application of construction site robot in in plastering is same between the group perceiving IoT is "very likely" and "not likely" in transforming the organisation business.	.006
The agreement on the application of construction site robot in carrying out site clearing, earth cutting and filling work is same between the age group of "25 to 30 years old" and "31 to 40 years old".	.000

From the above significant tests, the following pairs of respondents have statistically significant different in knowledge level on applications of construction site robot:

(i) The group perceived IoT is very likely in transforming the organisation business perceived

a. higher agreement on the application of construction site robot in computing work done (mean rank = 120.81) than the group perceived IoT is somewhat likely (mean rank = 96.17) in transforming the organisation business.

b. higher agreement on the application of construction site robot in laying brick (mean rank = 118.82) than the group perceived IoT is not likely (mean rank = 75.27) in transforming the organisation business.

c. higher agreement on the application of construction site robot in tying rebar (mean rank = 120.85) than the group perceived IoT is not likely (mean rank = 64.10) and somewhat likely (mean rank = 96.45) in transforming the organisation business.

d. higher agreement on the application of construction site robot in plastering (mean rank = 119.26) than the group perceived IoT is not likely (mean rank = 65.23) in transforming the organisation business.

(ii) The age group of 25 to 30 years old perceived

a. higher agreement on the application of construction site robot in carrying out site clearing, earth cutting and filling work (mean rank = 127.64) than the age group of 31 to 40 years old (mean rank = 77.02).

b. higher agreement on the application of construction site robot in laying brick (mean rank = 113.76) than the age group of 31 to 40 years old (mean rank = 84.04).

c. higher agreement on the application of construction site robot in tying rebar (mean rank = 115.00) than the age group of 31 to 40 years old (mean rank = 80.21).

(iii) The group with less than 2 years working experience perceived higher agreement on the application of construction site robot in laying brick (mean rank = 118.84) than the group with 2 to 5 years working experience (mean rank = 93.59).

4.5 Source of Data Collection for Organisation

The frequency of data collection method currently adopted by organisation is summarised in Table 4.11. The differences in the source of data collection is statistically significantly ($\chi2$ = 253.869, df = 9, N = 204, p = .000) and the questionnaire construct is internally consistence (α-value = 0.890). Three quarters of organisations using email (74.5 %) in collecting data, followed by still image or video (63.2 %) and phone (60.8 %).

Table 4.11: Frequency of Sources of Data Collection Currently Using by Organisation (N=204)

Source of Data Collection	Frequency	Percentage (%)	Chi-Square	Asymp. Sig.
Emails	152	74.5	253.869	.000
Still Image/Video	129	63.2		
Phone Usage	124	60.8		
Log	115	56.4		
Social Media	97	47.5		
Audio	86	42.2		
Sensors	70	34.3		
Free-form Text	69	33.8		
Barcode	60	29.4		
RFID Tag	59	28.9		

4.6 Adoption of IoT in Organisation’s Activities

The frequency of organisation’s activities using IoT devices are presented in Table 4.12. All the data are internally consistent with alpha coefficient of 0.935 and statistically significant ($\chi2$ = 161.771, df = 10, N = 204, p = .000). The top three activities adopting IoT are: documentation (60.3 %), construction progress monitoring (56.9 %) and site inspection (48.0 %).

Table 4.12: Frequency of Organisation’ Activities Currently Adopting IoT Application (N=204)

Organisation’s Activity	Frequency	Percentage (%)	Chi-Square	Asymp. Sig.
Documentation	123	60.3	161.771	.000
Construction progress monitoring	116	56.9		

Table 4.12 (Continued)

Site inspection	98	48.0
Quantity taking off	96	47.1
Resource management	91	44.6
Construction work	90	44.1
Safety and health	87	42.6
Logistic	79	38.7
Maintenance work	72	35.3
Energy harvesting	54	26.5

4.7 Challenges in Adoption of IoT

Table 4.13 presented the factors affecting adoption of IoT in construction industry. The nine barriers under this section are internally consistence as the Cronbach Alpha value is 0.964. The differences of mean rank presented are statistically significant ($\chi 2 = 111.149$, df = 8, N = 204, p = .000). The top three challenges of IoT adoption recognised by the construction practitioners are accuracy of data (mean rank = 5.60), implementation cost (mean rank = 5.38) and professional skill (mean rank = 5.36).

Table 4.13: Ranking for Factors Affecting IoT Implementation in Construction Industry (N=204)

Factors	Mean Rank	Chi-Square	Asymp. Sig.
Accuracy of data	5.60	111.149	.000
Implementation cost	5.38		
Professional skill	5.36		
Network security	5.22		
Communication requirement	5.20		
Authentication and access control	5.13		
Energy efficiency	4.78		
Impact towards society	4.18		
Physical protection	4.15		

Table 4.14 are the rejected null hypotheses regarding the perception towards challenges of IoT adoption in local construction industry after conducted the post hoc test to pairwise comparing differences of the knowledge level against the respondents' attributes.

Table 4.14: Rejected Null Hypothesis for the Factors Affecting IoT Implementation in Construction Industry

Null Hypothesis	Sig.
The concern on the accuracy of data of IoT devices is same between the group perceiving IoT is “very likely” and “not likely” in transforming the organisation business.	.049
The concern on the accuracy of data of IoT devices is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation business.	.000
The concern on the implementation cost of IoT devices is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation business.	.001
The concern on the professional skill required for IoT devices is same between the group perceiving IoT “very likely” and “not likely” in transforming the organisation business.	.044
The concern on the professional skill required for IoT devices is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation business.	.000
The concern on the network security of IoT devices is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation business.	.000
The concern on the communication requirement of IoT devices is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation business.	.000
The concern on the authentication and access control of IoT devices is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation business.	.000
The concern on the energy efficiency of IoT devices is same between the group perceiving IoT is “very likely” and “not likely” in transforming the organisation business.	.000
The concern on the energy efficiency of IoT devices is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation business.	.000
The concern on the society impact of IoT devices is same between the group perceiving IoT is “very likely” and “not likely” in transforming the organisation business.	.005
The concern on the society impact of IoT devices is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation business.	.000

Table 4.14 (Continued)

The concern on the physical protection of IoT devices is same between the group perceiving IoT is “very likely” and “somewhat likely” in transforming the organisation business.	.000

From the above significant tests, the following pairs of respondents have statistically significant different in the perception towards potential barriers of IoT adoption:

(i) The group perceived IoT is very likely in transforming the organisation business perceived

a. higher concern on the accuracy of data of IoT devices (mean rank = 130.82) than the group perceived IoT is not likely (mean rank = 88.67) and somewhat likely (mean rank = 90.10) in transforming the organisation business.

b. higher concern on the implementation cost of IoT devices (mean rank = 125.87) than the group perceived IoT is somewhat likely (mean rank = 91.59) in transforming the organisation business.

c. higher concern on the professional skill required for IoT devices (mean rank = 131.35) than the group perceived IoT is not likely (mean rank = 88.30) and somewhat likely (mean rank = 89.70) in transforming the organisation business.

d. higher concern on the network security of IoT devices (mean rank = 131.89) than the group perceived IoT is somewhat likely (mean rank = 87.22) in transforming the organisation business.

e. higher concern on the communication requirement of IoT devices (mean rank = 126.55) than the group perceived IoT is somewhat likely (mean rank = 87.88) in transforming the organisation business.

f. higher concern on the authentication and access control of IoT devices (mean rank = 131.37) than the group perceived IoT is somewhat likely (mean rank = 85.62) in transforming the organisation business.

g. higher concern on the energy efficiency of IoT devices (mean rank = 135.79) than the group perceived IoT is not likely (mean rank = 71.57) and somewhat likely (mean rank = 87.01) in transforming the organisation business.

h. higher concern on the society impact of IoT devices (mean rank = 127.97) than the group perceived IoT is not likely (mean rank = 73.77 and somewhat likely (mean rank = 90.88) in transforming the organisation business.

i. higher concern on the physical protection of IoT devices (mean rank = 130.59) than the group perceived IoT is somewhat likely (mean rank = 85.47) in transforming the organisation business.

4.8 Discussion

The findings revealed from the descriptive and inferential analysis are discussed and compared with the literature review in the following section.

4.8.1 Awareness towards IoT Development

Local construction community perceived that information sharing platform is the most relevant IoT application to be applied in construction activities. The applications of information sharing platform on “access, update and review updated documents”, “provide prompt responds upon queries” and “improve job site connectivity” are the top three applications of information sharing platform recognised by respondents. Information sharing platform improves the overall connection among the project team (Higgins, 2017). Variation of work is commonly occurred in almost every construction project. Many parties are involved when variation of work arises. Hence, the connectivity among the parties in construction project is a major concern of the industry.

Next, drone ranked the second among the IoT devices in their applications towards construction activities. Drone applications in capturing construction work progress and carrying out roof maintenance survey are ranked among the top five IoT applications agreed by construction community. Drone adoption eases the preparation of site progress report (Autodesk BIM 360, 2018). Site progress report is a drudge work for contractors as well as the parties monitoring the works progress.

Traditionally, the parties required to walk through the site and take picture on the work concerned. The innovation of drone reduces this tedious work.

4.8.2 Readiness towards IoT Adoption

The top three data collection methods of construction organisation are emails, still image or video and phone. These data collection methods are the conventional method that currently adopting in construction industry. According to Sfar et al. (2018), sensors and RFID tag are two of the objects usually integrated in IoT to collect data. However, only 34.3 % of construction organisations collecting data from sensors and 28.9 % collecting through RFID tag. This finding revealed the low readiness of local construction organisations towards IoT adoption.

4.8.3 IoT Adoption Level in Local Construction Industry

Out of the ten construction activities evaluated in Section 4.6, more than half of the Malaysian construction organisations adopt information sharing platform in managing project's documents and drone in monitoring construction progress onsite. However, only some organisations adopting IoT in the other eight construction activities discussed. This finding discovered that the overall IoT adoption level in local construction organisation is still low.

4.8.4 Awareness towards Challenges in IoT Adoption

The respondents most concern on the accuracy of data when adopting IoT in construction activities. Reyna, et al. (2018) stated that the performance of IoT devices directly affect the accuracy of data collected. The unreliable information collected during the construction process may lead to losses and caused project delay. There is lack in successful IoT adoption cases in Malaysia. Most of the local construction organisations, especially big enterprises refuse in to invest in IoT industry as they are not confident with the IoT technologies (Noordin, 2017).

4.8.5 Relationship between Perception towards IoT in Business Transformation and Awareness in IoT Development

The group perceived IoT application is "very likely" in transforming their organisation business have higher awareness towards IoT development when compared with the group perceiving IoT application is "not likely" or "somewhat likely" in transforming their organisation business. This shows that those able to visualise IoT application is "very likely" in transforming their organisation business perceived higher usefulness on the application of IoT in construction industry and they tends to agree the applications of IoT in construction activities and foresee the potential issues and barriers on the implementation of IoT in local construction activities.

The respondents perceived higher potentials of IoT applications in the industry tend to be more aggressive in exploring the development of IoT. The respondents who concern about IoT development in construction industry tends to appreciate the opportunity to learn the latest IoT technology developed.

4.8.6 Relationship between Age and Awareness in IoT Development

The findings reveal that the age group of "25 to 30 years old" has a higher exposure towards IoT development than the age group of "31 to 40 years old" and "less than 25 years old". Among all the age group, the age group of "25 to 30 years old" has the highest agreement on the usefulness and applications of IoT in construction industry. This is concurred with the study of Meyer (2008) who found workers with age 30 and below have higher acceptability towards the new technology. This might also related to their academic background as IoT is a new technology introduced in the recent years. The age group of "25 to 30 years old" have at least completed a project lifecycle and thus they are able to integrate the new technology learnt into their organisation practices.

However, the age group of "less than 25 years old" has a lower consensus towards IoT applications. The construction community within this age group are fresh graduates who just entered the industry. They are still exploring the practice of construction industry. Hence, it is difficult for this age group to visualise the applications of IoT in the industry as they have not experiences the full lifecycle of construction project.

The age group of "31 to 40 years old" have been working in construction industry for more than five years. According to Djordjević, Ivanović-Djukić and Lepojević (2017), the age group of 31 to 40 years old has the lowest job satisfaction. During this age, workers require more commitment towards their family and tend to lose passion towards the job. Besides, the five years of working experience in the construction industry built their working habit. Challenges and struggles are always followed behind changes. These two influences lead to the unwillingness of construction practitioner within this age group in learning IoT technology.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This is the last but not the least chapter of this research. The accomplishment on research objectives is reviewed in Section 5.2. Implications of this research are discussed in Section 5.3, follows by research limitations and recommendations for future research in Section 5.4 and Section 5.5 respectively.

5.2 Accomplishment on Research Objectives

This research presented a brief account of IoT, its development, applications and challenges encountered in the construction industry in Chapter 2. A theoretical framework of IoT adoption was developed from the literature reviewed and presented in Figure 2.2. The framework of questionnaire design in Figure 3.1 is developed based on the theoretical framework. Questionnaire survey was conducted and 204 duly answered questionnaires were used in the analysis and discussion. The findings are presented by descriptive statistics and tested by inferential statistics as reported in Chapter 4.

The research findings revealed that, the construction community perceived "IoT applications are very likely in transforming the organisation business" has better visualisation towards the potential applications and relatively more alert of the challenges of IoT adoption in local construction industry. The young generation, within age group of 25 to 30 years old have relatively higher awareness towards the IoT development in construction industry.

The IoT applications identified in this research includes drone, construction site robot, wearable technology, monitoring sensors, 3D printing and information sharing platform. The findings discovered that local construction community have higher awareness on the usage of information sharing platform and drone. Approximately 60 % of the construction organisations in Malaysia are adopting information sharing platform for documentation purpose. Most of the local construction firms are utilising conventional data collection methods such as email, still image or video and phone. The major barrier of IoT application is the reliability of data collected by IoT devices as perceived by the respondents. The following Figure 5.1 summarise the key findings of this study.

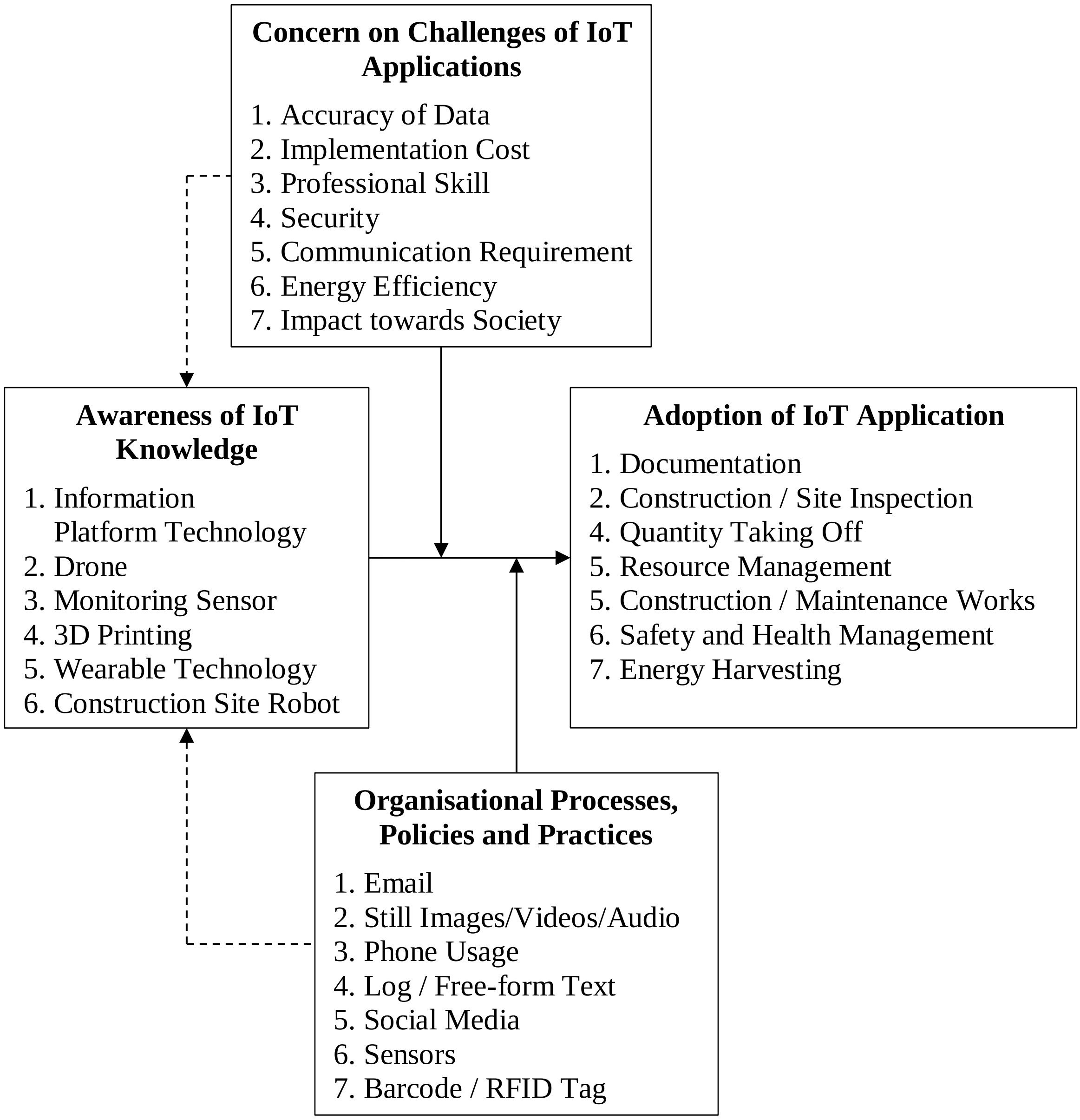

Figure 5.1: Current Status Quo for IoT Adoption in Malaysian Construction Industry

Note: Items in the box are ranked from highest to lowest according to this study.

5.3 Research Implications

This research provides a fundamental knowledge of IoT to construction community. Awareness on IoT development in construction industry is enhanced through this research. The further findings of this research are expected to benefit the construction organisations in equipping themselves towards the new era of digitalization of everything.

In addition, this research will helps in accelerating the government's initiative to enhance the digital economy in Malaysia. The construction industry is used being perceived as one of the industries slow in adoption of new technology.

Lastly, this research acts as a fundamental research for academicians or researchers as it provides an overview on the current condition of the construction industry. This is likewise useful for researchers to gain insights for future research on similar topic.

5.4 Research Limitations

There are some limitations in this research. The convenience sampling adopted in this research may not be the best choice. The respondents are selected based on their availability and convenience. Thus, the structure of respondents may not reflect the population structure. Besides, the questionnaire design for this research is too lengthy and respondents tend to lose their patient when answering the questionnaire.

In addition, the Information and Communications Technology (ICT) development is too fast to be keeping up-to-date. The new development of ICT may introduce some additional IoT applications to the construction industry which this study is not able to foreseen.

5.5 Research Recommendations

Stratified random sampling is recommended as the sampling technique in future research. Stratified random sampling allows accurate representative sample groups that are meaningful and appropriate to the research topic by predetermined the number of respondents required in each stratum. Next, a more precise scope shall be defined in future research. A precise research scope helps researcher in focusing in the specific topic. A more concise questionnaire can be produced with the guide of the research scope.

REFERENCES

Albishi, S., Soh, B., Ullah, A. and Algarni, F., 2017. Challenges and Solutions for Applications and Technologies in the Internet of Things. *Procedia Computer Science*, 124, pp.608-614.

Ambrose, R., 2018. 3D Printing Used to Create Stainless Steel Bridge and Other Assemblies. *Welding Journal*, 97(9), pp. 12-15.

Ashton, K., 2009. That ‘Internet of Things’ Thing. *RFID Journal*, 22(7), pp.97-114.

Atzori, L., Iera, A. and Morabito, G., 2010. The Internet of Things: A Survey. *Computer Networks*, 54(15), pp. 2787-2805.

Autodesk BIM 360, 2018. *Connected Workflows: Drones in Construction.* [online] Available at: <https://info.bim360.autodesk.com/hubfs/Drones_in_Construction/Connected_Workflows_Drones_in_Construction.pdf?mktvar002=743992&utm_medium=email&utm_source=nur-intro&utm_campaign=amer-aec-bim-360--drones-in-construction&utm_id=743992&leadid=336542791&mkt_to> [Accessed 5 August 2018].

Ayemba, D., 2018. *Utilizing Drone Technology in Construction*. [online] Available at: <https://constructionreviewonline.com/2018/03/drones-in-construction/> [Accessed 2 August 2018].

Bernama, 2018. Malaysia on Right Track to Realise Smart Cities Vision. *Malaysiakini,* [online] 1 Sept. Available at: <https://www.malaysiakini.com/news/441209> [Accessed 31 March 2019].

BIM+, 2019. *More than Half of Construction Firms Now Using Drones*. [online] Available at: <http://www.bimplus.co.uk/news/more-half-construction-firms-now-using-drones-capt/> [Accessed 23 January 2019].

Buchanan, C. and Gardner, L., 2019. Metal 3D printing in construction: A Review of Methods, Research, Applications, Opportunities and Challenges. *Engineering Structures,* 180, pp.332-348.

Chaouchi, H., 2010. Introduction to the Internet of Things. In: Chaouchi, H., ed. 2010. *The Internet of Things: Connecting Objects to the Web.* London: ISTE Ltd, pp. 1-21.

Chen, S., Xu, H., Liu, D., Hu, B. and Wang, H., 2014. A Vision of IoT: Applications, Challenges, and Opportunities with China Perspective. *IEEE Internet of Things Journal*, 1(4), pp.349-359.

Cochran, W. G., 1963. *Sampling Techniques*. 2nd Ed. New York: John Wiley and Sons, Inc.

Conti, M., Dehghantanha, A., Franke, K. and Watson, S., 2018. Internet of Things Security and Forensics: Challenges and Opportunities. *Future Generation Computer Systems*, 78(2), pp. 544-546.

Cooper, D. R. and Schindler, P. S., 2014. *Business Research Method*. 12th ed. New York: McGraw-Hill.

Creswell, J. W., 2009. *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*. 3rd ed. California: SAGE Publications Inc.

Djordjević, B., Ivanović-Djukić, M. and Lepojević, V., 2017. Relationship of Ages and Gender of the Employees in Organisations in the Republic of Serbia and Their Job Satisfaction. *Economic Themes*, 55(2), pp. 263-280.

Dormehl, L., 2017. *SAM is A Construction Robot That Can Lay Bricks 6 Times Faster Than You Can*. [online] Available at: <https://www.digitaltrends.com/cool-tech/sam-bricklaying-robot-6x-faster-than-you-can/> [Accessed 1 April 2019].

Farhan, L., Kharel, R., Kaiwartya, O., Quiroz-Castellanos, M., Alissa, A. and Abdulsalam, M., 2018, July. A Concise Review on Internet of Things (IoT)-Problems, Challenges and Opportunities. In: *2018 11th International Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP)*. Budapest, Hungary, 18-20 July 2018. IEEE. Available at: <https://ieeexplore-ieee-org.libezp2.utar.edu.my/stamp/stamp.jsp?tp=&arnumber=8471762&tag=1> [Accessed 1 April 2019].

Force Technology, 2016. *IoT and Reliability*. [online] Available at: <https://force technology.com/en/articles/iot-reliability> [Accessed 1 April 2019].

Forsberg, J., Graff, D. and Wernersson, Å., 1995. An Autonomous Plastering Robot for Walls and Ceillings. *IFAC Proceedings Volumes*, 28(11), pp. 301-306.

Gartner, 2017. *Gartner Hype Cycle for Emerging Technologies 2017*. [online] Available at: <https://www.gartner.com/smarterwithgartner/> [Accessed 5 August 2018].

Gartner, 2018. *Hype Cycle*. [online] Available at: <https://www.gartner.com/it-glossary/hype-cycle> [Accessed 5 August 2018].

Gerrard, N., 2018. *UK Construction Will Use Thousands of Drones by 2030*. [online] Available at: <http://www.globalconstructionreview.com/news/uk-construction-will-use-thousands-drones-2030/ > [Accessed 7 June 2018].

Giatec Scientific, 2018. *Problem: Finding an Accurate Way to Monitor Both Concrete Temperature and Strength in the Company's First Post-tensioning Project.* [online] Available at: <https://www.giatecscientific.com/case-study/sf-concrete-contractors/> [Accessed 21 October 2018].

Giatec Scientific, 2018. *Wireless Concrete Temperature Sensor*. [online] Available at: <https://www.giatecscientific.com/products/concrete-sensors/smartrock-maturity-meter/> [Accessed 21 October 2018].

Goidea, A., 2017. *BatiPrint3D Project Report*. [pdf] Copenhagen: 3D Printhuset A/S. Available at: <http://www.3dprintetbyggeri.dk/pdf/bes%C3%B8gsrapporter/Batiprint3D.pdf> [Accessed 31 March 2019].

Granjal, J., Monteiro, E. and Silva, J.S., 2015. Security for the Internet of Things: A Survey of Existing Protocols and Open Research Issues. *IEEE Communications Surveys & Tutorials*, 17(3), pp.1294-1312.

Gubbia, J., Buyya, R., Marusic, S. and Palaniswami, M., 2013. Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions. *Future Generation Computer Systems*, 29(7), pp. 1645-1660.

Hager, I., Golonka, A. and Putanowicz, R., 2016. 3D Printing of Buildings and Building Components as the Future of Sustainable Construction?. *Procedia Engineering*, 151, pp.292-299.

Higgins, A., 2017. *7 Major Construction Technology Innovations to Watch in 2018*. [online] Available at: <https://connect.bim360.autodesk.com/construction-innovation-2017> [Accessed 7 June 2018].

Husain, A., 2017. *The Sentient Machine: The Coming Age of Artificial Intelligence*. New York: Scribner.

IoT Security Foundation, 2019. *Physical Security*. [online] Available at: <https://www.iotsecurityfoundation.org/best-practice-guide-articles/physical-security/> [Accessed 1 April 2019].

Iskandar Regional Development Authority, 2016. *About Smart City Iskandar Malaysia*. [online] Available at: <http://iskandarmalaysia.com.my/SCIM/about.html> [Accessed 31 March 2019].

Ismail, N., 2017. *The 3 Stages of IoT Maturity*. [online] Available at: <https://www.information-age.com/three-stages-iot-maturity-123469664/> [Accessed 3 January 2019].

Jones, K., 2018. *Robots Are Coming to the Construction Site*. [online] Available at: <https://www.constructconnect.com/blog/construction-technology/robots-coming-construction-site/> [Accessed 2 August 2018].

Kamble, S.S., Gunasekaran, A., Parekh, H. and Joshi, S., 2019. Modeling the Internet of Things Adoption Barriers in Food Retail Supply Chains. *Journal of Retailing and Consumer Services*, 48, pp.154-168.

Kashyap, S., 2016. *10 Real World Applications of Internet of Things (IoT) – Explained in Videos.* [online] Available at: <https://www.analyticsvidhya.com/blog/2016/08/10-youtube-videos-explaining-the-real-world-applications-of-internet-of-things-iot/> [Accessed 21 July 2018].

Kathy, B., 2019. IoT Benefits, Challenges for Property Management. *New Straits Time* [online] 17 January. Available at: <https://www.nst.com.my/property/2019/01/451515/iot-benefits-challenges-property-management> [Accessed 5 April 2019].

Kirkpatrick, K., 2018. The Construction Industry in the 21st Century. *Communications of the ACM*, [e-magazine] 61(3), pp. 18-20. Available through: Universiti Tunku Abdul Rahman Library website <http://delivery.acm.org.libezp2.utar.edu.my/10.1145/3180000/3178312/p18-kirkpatrick.pdf?ip=121.123.29.90&id=3178312&acc=ACTIVE%20SERVICE&key=69AF3716A20387ED%2ECB81A03442DECDAF%2E4D4702B0C3E38B35%2E4D4702B0C3E38B35&__acm__=1554041547_17bc5f90a19c513dc21fd459f050827d> [Accessed 31 March 2019].

Levy, J., 2017. *4 Big Ways the IoT is Impacting Design and Construction.* [online] Available at: <https://www.ibm.com/blogs/internet-of-things/4-big-ways-the-iot-is-impacting-design-and-construction/> [Accessed 3 Jun 2018].

Liu, J., Xiao, Y. and Chen, C.P., 2012, June. Authentication and Access Control in the Internet of Things. In: *32nd International Conference on Distributed Computing Systems Workshops*. Macau, China, 18-21 June 2012. IEEE. Available at: <https://www.researchgate.net/publication/261479017_Authentication_and_Access_Control_in_the_Internet_of_Things>[Accessed 1 April 2019].

Luthra, S., Garg, D., Mangla, S.K. and Berwal, Y.P.S., 2018. Analyzing Challenges to Internet of Things (IoT) Adoption and Diffusion: An Indian Context. *Procedia Computer Science*, 125, pp. 733-739.

Mahmud, S.H., Assan, L. and Islam, R., 2018. Potentials of Internet of Things (IoT) in Malaysian Construction Industry. *Annals of Emerging Technologies in Computing (AETiC),* 2(4), pp. 44-52.

Marwedel, P. and Engel, M., 2016. Cyber-Physical Systems: Opportunities, Challenges and (Some) Solutions. In: A. Guerrieri, V. Loscri, A. Rovella, and G Fortino, eds. *Management of Cyber Physical Objects in the Future Internet of Things*, Switzerland: Springer International Publishing. pp. 1-30.

Maw, I., 2019. *Using IIoT-Connected Devices for Worker Health & Safety*. [online] Available at: <https://www.engineering.com/AdvancedManufacturing/ArticleID/18873/Using-IIoT-Connected-Devices-for-Worker-Health-Safety.aspx#.XKBB5p1Ndow.twitter> [Accessed 1 April 2019].

McKendrick, J., 2019. *Beyond Devices: The Second Wave of IoT Emerges*. [online] Available at: <https://www.rtinsights.com/beyond-devices-the-second-wave-of-iot-emerges/> [Accessed 1 April 2019].

Meyer, J., 2008. *The Adoption of New Technologies and the Age Structure of the Workforce*. [online] Available at: <ftp://ftp.zew.de/pub/zew-docs/dp/dp08045.pdf> [Accessed 1 April 2019].

MPDigest, 2018. *The Impact of the IoT on Society*. [online] Available at: <http://www.mpdigest.com/2018/05/25/the-impact-of-the-iot-on-society/> [Accessed 1 April 2019].

Murison, M., 2016. *Australian Construction Firm Uses IoT for 'Smart Helmets' which Keep Workers Safe*. [online] Available at: <https://internetofbusiness.com/australian-construction-firm-uses-iot-for-smart-helmets-which-keep-workers-safe/> [Accessed 5 August 2018].

Neuman, W. L., 2014. *Social Research Methods: Qualitative and Quantitative Approaches*. 7th ed. Edinburgh Gate: Pearson Education Limited.

Noordin, K. A., 2017. IoT: Propelling IoT in Malaysia. *The Edge Malaysia*. [online] Available at: <https://www.theedgemarkets.com/article/iot-propelling-iot-malaysia> [Accessed 5 April 2019].

Panetta, K., 2017. *Top Trends in the Gartner Hype Cycle for Emerging Technologies, 2017*. [online] Available at: <https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/> [Accessed 10 October 2018].

Prime Minister's Department, 2015. *Eleventh Malaysia Plan, 2016-2020: Anchoring Growth on People*. [pdf] Kuala Lumpur: Percetakan Nasional Malaysia Berhad. Available at: <https://policy.asiapacificenergy.org/sites/default/files/11th%20Malaysia%20plan.pdf> [Accessed 31 March 2019].

Reyna, A., Martín, C., Chen, J., Soler, E., and Díaz, M., 2018. On Blockchain and Its Integration with IoT. Challenges and Opportunities. *Future Generation Computer Systems*, 88, pp. 173-190.

Sadeeq, M.A., Zeebaree, S.R., Qashi, R., Ahmed, S.H. and Jacksi, K., 2018. Internet of Things Security: A Survey. In: *2018 International Conference on Advanced Science and Engineering (ICOASE)*. Duhok, Kurdistan. 9-11 Oct 2018 (pp. 162-166). IEEE. Available at: <https://ieeexplore-ieee-org.libezp2.utar.edu.my/stamp/stamp.jsp?tp=&arnumber=8548785> [Accessed 1 April 2019].

Saunders, M., Lewis, P. and Adrian, T., 2016. *Research Methods for Business Students*. 7th ed. Italy: Pearson.

Scully, P., 2018. *The Top 10 IoT Segments in 2018 – Based on 1,600 Real IoT Projects*. [online] Available at: <https://iot-analytics.com/top-10-iot-segments-2018-real-iot-projects/#> [Accessed 22 July 2018].

Sfar, A. R., Natalizio, E., Challal, Y. and Chtourou, Z., 2018. A Roadmap for Security Challenges in the Internet of Things. *Digital Communications and Networks*, 4(2), pp. 118-137.

Statista, 2018. *Internet of Things (IoT) Connected Devices Installed Base Worldwide from 2015 to 2025 (in billions).* [online] Available at: <https://www.statista. com/statistics/471264/iot-number-of-connected-devices-worldwide/> [Accessed 22 July 2018].

Stocking, A. W., 2017. *8 Construction-Technology Innovations That Changed the Game in 2017*. [online] Available at: <https://www.autodesk.com/redshift/ construction-technology-2017/> [Accessed 7 June 2018].

Thryft, A. R., 2014. *3D-Printed Steel Building Structures*. [online] Available at: <https://www.designnews.com/content/3d-printed-steel-building-structures> [Accessed 31 March 2019].

Waters, L. and McAlpine, R., 2016. *Construction as A Career of Choice for Young People*, The Chartered Institute of Building.

Whitepaper, 2017. *Cyber Crime and the Construction Industry*. [online] Available at: <http://rg-group.co.uk/whitepaper-cyber-crime-and-the-construction-industry/> [Accessed 1 July 2018].

Zayas, A. D., García Pérez, C. A., Recio Pérez, Á. M. and Merino, P., 2018. 3GPP Evolution on LTE Connectivity for IoT. In: R. Gravina, C. E. Palau, M. Manso, A. Liotta and G. Fortino, eds. *Integration, Interconnection, and Interoperability of IoT Systems*. Switzerland: Springer International Publishing AG. pp. 1-20.

APPENDICES

APPENDIX A: Survey Questionnaire

To Explore the Adoption of Internet of Things (IoT) in Malaysian Construction Industry

Dear Sir/Madam,

Sincere greetings and best regards to you.

I am a final year undergraduate student pursuing Bachelor of Science (Hons) Quantity Surveying in University Tunku Abdul Rahman (UTAR). I am currently doing a research on “To Explore the Adoption of Internet of Things (IoT) in Malaysian Construction Industry”.

It will be much appreciated if you can answer the following questionnaire regarding this research. The questionnaire is designed to be completed within 15 minutes. All the information collected through this survey will be private and confidential and strictly used for academic purpose only. Should you require any clarification, please do not hesitate to contact me at tzeqing96@gmail.com or 019-5123100.

Your precious time and effort in participating the survey is deeply appreciated.

Thank you.

Yours faithfully,
Ang Tze Qing

<u>Section A: IoT Knowledge</u>

The concept, "Internet of Things" (IoT) was first invented by Kelvin Ashton back in 1999 (Ashton, 2009). This concept aims in connecting everything with everyone all the time regardless their current location. IoT mainly use in providing all inanimate objects with a built in wireless connectivity. This connection will help to link all the objects together and enable them to be controlled, linked and monitored through the internet.

A1) To your best knowledge, how relevant are the listed technologies to the construction industry?

[1 = Not at all, 2 = Slight, 3 = Somewhat, 4 = Quite, 5 = Moderately, 6 = Very, 7 = Extremely]

Statements	1	2	3	4	5	6	7
Drone	○	○	○	○	○	○	○
Construction Site Robot	○	○	○	○	○	○	○
Wearable Technology	○	○	○	○	○	○	○
Monitoring Sensor	○	○	○	○	○	○	○
Information Sharing Platform	○	○	○	○	○	○	○
3D Printing	○	○	○	○	○	○	○

A2) In your perception, to what extent do you agree with the following statements.

[1 = Strongly disagree, 2 = Mostly disagree, 3 = Slightly disagree, 4 = Uncertain, 5 = Slightly agree, 6 = Mostly agree, 7 = Strongly agree]

Statements	1	2	3	4	5	6	7
Drone can be used to monitor hazardous area at construction site.	○	○	○	○	○	○	○
Drone can be used to capture construction work progress.	○	○	○	○	○	○	○
Drone can be used to carry out roof condition survey for maintenance purpose.	○	○	○	○	○	○	○
Drone can be used for resource allocation.	○	○	○	○	○	○	○
Autonomous machines can be used to carry out site clearing, earth cutting and filling work.	○	○	○	○	○	○	○
Autonomous machines save times in computing work done.	○	○	○	○	○	○	○

Robot can be used in brick laying.	○ ○ ○ ○ ○ ○ ○
Robot can be used to tie rebar.	○ ○ ○ ○ ○ ○ ○
Robot can be used in plastering.	○ ○ ○ ○ ○ ○ ○
Wearable technology can be used to detect site workers' current location and body condition.	○ ○ ○ ○ ○ ○ ○
Wearable technology can be used to detect the humidity and temperature surrounds the worker.	○ ○ ○ ○ ○ ○ ○
Wearable technology can be used to warn site workers on the potential hazards around according to the location of site workers.	○ ○ ○ ○ ○ ○ ○
Wearable technology can be used to notify management team when site worker is slipped, fallen or tripped.	○ ○ ○ ○ ○ ○ ○
Monitoring sensor can be used to update the real time location and process of prefabrication components.	○ ○ ○ ○ ○ ○ ○
Monitoring sensor can be used to monitor the real-time temperature and strength of concrete casted.	○ ○ ○ ○ ○ ○ ○
Monitoring sensor can be used to detect the best timing for slab tensioning.	○ ○ ○ ○ ○ ○ ○
Monitoring sensor can detect the potential causes of failure for construction equipment.	○ ○ ○ ○ ○ ○ ○
Monitoring sensor can shut down the system that is idle automatically when building is not occupied.	○ ○ ○ ○ ○ ○ ○
3D printer can be used to print building components.	○ ○ ○ ○ ○ ○ ○
3D printer can be used to print houses.	○ ○ ○ ○ ○ ○ ○
3D printer can be used to print bridges.	○ ○ ○ ○ ○ ○ ○
3D printer can create metal structures.	○ ○ ○ ○ ○ ○ ○
Information sharing platform improve the job site connectivity.	○ ○ ○ ○ ○ ○ ○
Smart phone or tablet can access, update and view updated documents and drawings.	○ ○ ○ ○ ○ ○ ○
Information sharing platform help the project team to provide prompt respond upon queries.	○ ○ ○ ○ ○ ○ ○

<u>Section B: IoT Applications</u>

B1) How likely IoT application will transforms your organisation's business?

- Haven't considered
- Not likely
- Somewhat likely
- Very likely

B2) In your perception, to what extent do you agree with the following statements.

[1 = Collect now, 2 = Expect to collect in 3 years, 3 = Expect to collect in 5 years, 4 = No plans to collect, 5 = Do not know]

Statements	1	2	3	4	5
Log	○	○	○	○	○
Emails	○	○	○	○	○
Social media	○	○	○	○	○
Sensors	○	○	○	○	○
Phone usage	○	○	○	○	○
RFID tag	○	○	○	○	○
Barcode	○	○	○	○	○
Free-form text	○	○	○	○	○
Audio	○	○	○	○	○
Still image/video	○	○	○	○	○

B3) To what extent your organisation is using IoT devices in the following activities?

[1 = Using now, 2 = Expect to use in 3 years, 3 = Expect to use in 5 years, 4 = No plan to use, 5 = Do not know]

Statements	1	2	3	4	5
Design	○	○	○	○	○
Site inspection	○	○	○	○	○
Construction progress monitoring	○	○	○	○	○

Resource management (labour, equipment, material)	○ ○ ○ ○ ○
Logistic	○ ○ ○ ○ ○
Construction work	○ ○ ○ ○ ○
Quantity taking off	○ ○ ○ ○ ○
Documentation	○ ○ ○ ○ ○
Maintenance work	○ ○ ○ ○ ○
Safety and health	○ ○ ○ ○ ○
Energy harvesting	○ ○ ○ ○ ○

Section C: Challenges of IoT Adoption

C1) How important is the following factors towards an IoT devices?

[1 = Not at all, 2 = Slight, 3 = Somewhat, 4 = Quite, 5 = Moderately, 6 = Very, 7 = Extremely]

Statements	1	2	3	4	5	6	7
Communication requirement	○	○	○	○	○	○	○
Network security	○	○	○	○	○	○	○
Physical protection	○	○	○	○	○	○	○
Authentication and access control	○	○	○	○	○	○	○
Accuracy of data	○	○	○	○	○	○	○
Energy efficiency	○	○	○	○	○	○	○
Impact towards society	○	○	○	○	○	○	○
Implementation cost	○	○	○	○	○	○	○
Lack of expertise	○	○	○	○	○	○	○

<u>Section D: About Yourself</u>

D1) Which of the following business activities best describes your organisation?

- Developer
- Consultant
- Contractor
- Sub-Contractor
- Supplier

D2) Which of the following best describes your role in the project?

- Client
- Architect
- Engineer (civil engineer, structurer engineer, mechanical engineer, electrical engineer)
- Quantity Surveyor
- Designer (interior designer, landscape designer)
- Manager (construction manager, site manager, project manager)

D3) What is your age?

- below 25 years
- 25 - 30 years
- 31 - 40 years
- 41 - 50 years
- 51 and above

D4) How long have you been working at your organisation?

- Less than 2 years
- 2 - 5 years
- 5 - 10 years
- Above 10 years

D5) What is the type of client for the project you experienced?

*check all that apply

- ☐ Government Project
- ☐ Private Project

D6) Which of the following type of product best describe the project you experienced?

*check all that apply

- ☐ Residential Buildings (condominium, apartment, landed house)
- ☐ Commercial Buildings (office, shop lot)
- ☐ Mix Development
- ☐ Industrial Construction (factory, power plant)
- ☐ Infrastructure Work (road, railway, bridge, airport)
- ☐ Redevelopment (refurbishment, redevelop existing building)