EXPLORING THE APPLICATION OF DRONE TECHNOLOGY FOR CONSTRUCTION SITES MANAGEMENT IN MALAYSIA

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

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DECLARATION

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

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **“EXPLORING THE APPLICATION OF DRONE TECHNOLOGY FOR CONSTRUCTION SITES MANAGEMENT IN MALAYSIA”** was prepared by **CHOOI YEN SING** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Science (Honours) Quantity Surveying at Universiti Tunku Abdul Rahman.

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ABSTRACT

The construction industry is an essential sector that provides economic and social stability to the country. As construction projects continue to grow in complexity and size, the adaptation of modern technology is necessary to achieve the current standards of construction projects. In particular, this research will focus on drone technology as one of the technologies of the fourth industrial revolution to be utilised for construction site management. Therefore, the aim of this study is to explore the applications of drone technology for construction site management in Malaysia. Literature review was conducted to identify all the applications, benefits and barriers of utilising drone technology for construction site management in Malaysia. The research was conducted in the Klang Valley area, where the data collected from the respondents that are made of contractors and consultants who participated in the questionnaire survey. The survey is carried out through convenience sampling followed by snowball sampling. The research was carried out to determine the agreement level of the respondents on the applications, benefits and barriers of drone technology and also to determine if there are any significant differences between the two group. The questionnaire survey uses a 5-Point Likert Scale system for the respondents to rate their agreement level on the applications, benefits and barriers of drone technology in construction site management. The data collected from the respondents was tested to have a good internal consistency and reliability through the Cronbach Alpha reliability Test. From the data, it was identified that the most common application of drone technology is for inspection tasks, as the benefits that seen the highest agreement level is the reduction of safety risks. However, length data processing period has the highest agreement level on being the barrier of using drone technology. This research can be an essential asset for construction stakeholders who wish to improve productivity and quality of their projects and also act as a starting point for future research.

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LIST OF SYMBOLS / ABBREVIATIONS

AI	Artificial Intelligence
BIM	Building Information Modelling
CAAM	Civil Aviation Authority of Malaysia
GPS	Global Positioning System
IoT	Internet of Things
LiDAR	Light Detection and Ranging
SPSS	Statistical Package for the Social Sciences
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
VDC	Virtual Design and Construction
VTOL	Vertical Take-off and Landing
3D	Three-Dimensional

CHAPTER 1

INTRODUCTION

1.1 Introduction

Chapter one introduces the background and the application of drone technology in the construction industry. With a well-defined aim and objective that form the basis of this report, this chapter will consist of sub-sections such as introduction, background of study, problem statement, aim, objectives, research methodology, scope and limitation of the study, chapter outlines and summary.

1.2 Background of Study

In the midst of the 21st century, the world has already entered the fourth industrial revolution where rapid technological advancement and integration such as robotics, cloud computing, Internet of Things (IoT), Artificial Intelligence (AI), and many more allows each industry to benefit from. For the construction industry, every project has its own unique characteristic and complex nature of work with a wide range of projects such as, infrastructure, residential construction, industrial construction and commercial construction. Thus, Industry 4.0 is introduced to meet the demands posed by the construction industry.

Drones, also known as Unmanned Aerial Vehicle (UAV) and Unmanned Aircraft System (UAS) are aircraft that have no on-board pilots and are remotely controlled to perform specific tasks. Mounted with high-definition cameras, AI, and sensors, construction professionals are able to carry out their tasks without having to move around the site. These tasks include project monitoring, tracking, planning, three-dimensional (3D) modelling and many more that are carried out by drones (Aripin, Zawawi and Ismail, 2019). This has led to a safer and cost-effective way to conduct surveillance on a construction site when compared to the traditional way of physically entering the site for surveillance. Especially when considering the safety hazards of a construction site such as excessive noise, collapsing trenches, heavy machinery, tall structures and many more. The utilisation of drone technology is able to mitigate the casualties and safety concerns on construction sites (CIDB, 2023).

Besides, drones can be used in all construction stages such as pre-construction planning, where drones can be utilised by client and contractors to obtain images and data of the project site without stepping a foot into the allocating land. They can also be used for monitoring site progress to detect errors before it becomes too costly to rectify. Majority of the construction companies that use drones with the aim to improve planning, operation and documentation (International Bar Association, 2023). This is especially when construction experts are able to decide on the best approach for their projects provided that all necessary data and information are made available by the drones. Therefore, drones have the ability to carry out tasks efficiently with optimal effort while being capable of bringing an improvement to a project's quality and productivity.

The construction industry has shown an upward trend in the usage of drone technology globally (Bernama, 2024). Furthermore, the Malaysian government has made an announcement regarding the Malaysia Drone Technology Action Plan 2022-2030 that is targeting to develop the drone industry in hope of boosting the country's gross domestic product (The Star, 2023). The construction industry can leverage from the ever-evolving drone technology that has revolutionised the industry with its versatility and flexibility that has the potential to maximise the profitability of construction projects (CIDB, 2023).

1.3 Problem Statement

In Malaysia, the construction industry has the highest record of fatal accidents compared to the other industry (Department of Occupational Safety and Health, 2023). 1201 fatal accidents, 111 permanent disability accidents and 1550 non-permanent disability accidents were reported between the years 2010 to 2021 (Department of Occupational Safety and Health, 2023). This is due to the major safety hazard tied to working at a construction site. Besides implementing safety precautions and practices on construction sites, utilising technologies from the Industry 4.0 to replace certain tasks will reduce site accidents (Aripin, Zawawi and Ismail, 2019). Without any equipment to provide real time information, workers are unable to have a sense of awareness of their surroundings and react to potential life-threatening scenarios due to the harsh environment of a construction site (You and Feng, 2020).

Low productivity of a construction industry has always been an issue due to the lack of data and information for project estimation, planning and management (Bamfo-Agyel, Thwala and Aigbavboa, 2022). For instance, it is time consuming for project managers to be updated on the current progress of the project as they will have to inspect and walk around the construction site. It can be even more timely if the project is a high rise building as the majority of the time will be waiting for the passenger hoist to reach different floors. By utilising drones for inspection, a drone will be able to collect data that is worth a half-day walk within fifteen minutes (Yildiz, Kivrak and Arslan, 2021). As the construction industry is a labour-intensive industry, labour productivity affects the overall progress of a project. The inexperience of supervisors can also contribute to a low productivity as defective work may be left undetected until a later stage where it is time consuming and costly to rectify the defect (Bekr, 2016).

Conventional construction management methods are facing difficulties in keeping up with the information demand of the modern construction industry (Yu, et al., 2018). As construction projects are getting more complex as time progresses, effectively managing the construction site through conventional management methods is no longer viable. It is essential to allow project managers to have precise site control and real time feedback from the construction scene to enable efficient decision-making processes to take place (Yu, et al., 2018). In addition, the productivity of construction projects is influenced by the input, effort, and performance of a human as the primary source of production (Hamza, et al., 2022). For instance, defective work of a construction project is affected by human factors such as overlooked defects and unskilled workers (Alsamarraie, et al., 2022). Hence, the need for adopting innovative technologies to assess the site condition as well as having surveillance on worker activity in real time is necessary.

Therefore, the need to explore tools and alternatives in replacing the conventional method of carrying out construction activities is necessary to boost the performance of the construction industry. With better alternatives and tools to perform construction activities, the productivity of the construction industry will greatly increase while also enhancing the safety at construction site.

1.4 Research Gap

Researchers have made a contribution in researching the literature of drone technology in the construction industry. However, an insufficient number of extensive studies on the application of drone technology in construction sites are conducted based on recent drone technology advancement. This is proven by several research on Malaysia's construction sites that are based on studies that may not align with the recent capabilities of drone technology. For instance, Yahya, et al. (2021) have conducted a thorough study on the implementation and limitation of drones in the construction industry based on research dated back from 2012. In addition, Omar, et al. (2022) study on utilising drone technology for site monitoring and surveying are based on 2010s drone technology, similar to the study for monitoring construction sites done by Abdullah, Seow and Mohamed (2023). Throughout the evolution of drone technology, the applications and functionality of drone have significantly improved from just being able to provide visual aid to processing the imagery and analysing the data through machine learning and open artificial intelligence capabilities. For instance, the use of the data collected from drone technology can be used in decision-making process as well as analysing topographic mapping and land surveying rather than just providing visual of the contour. An extensive study on the application of drone technology in construction site reflecting the latest drone capabilities is yet to be explored. Hence, this study will cover the application of the latest drone technology in managing the construction site.

1.5 Aim

This research aims to explore the application of drone technology in improving and carrying out activities relating to construction sites management in Malaysia and to examine the agreement level of the construction industry as well as the difference in the agreement level between contractor and consultants.

1.6 Objectives

The following objectives have been identified to achieve the aim:

1. To identify the application of drone technology to manage construction sites.
2. To investigate the benefits of utilising drone technology for construction site management.
3. To outline the barriers of utilising drone technology for construction site management.

1.7 Contribution of the Study

This research can be used to raise the awareness of drone technology in the construction industry. Players in the construction industry can gain knowledge and information regarding the application of drone technology as discussed in this study later on. This insight and result gained from this study can be used to further develop drone technology. By understanding the benefits and barriers of utilising drone technology for construction site management, players in the construction industry are able to know what to expect from utilising drone technology.

The construction industry is different compared to other industries due to every construction project having its own distinct characteristic. Despite the construction project being commonly categorised as residential, industrial, infrastructure or commercial project, every construction site differs from the previous in various aspects. With technologies evolving rapidly and at a constant rate, the world will continue to strive in achieving what seemed to be unachievable previously. Hence, this research aims to explore the application of drone technology and its benefits and barriers in managing a construction site.

In addition, the findings in this study can benefit the construction industry by improving efficiency and quality of the project delivery. The construction stakeholders are able to use the findings in this study to increase their awareness level and take an active role in utilising drone technology to future drive the construction industry into modernisation. The applications and benefits outlined in this study can act as incentives for the construction industry to be more involved in the utilisation of drone technology in managing construction sites. The barriers highlighted in this study can also prepare the construction industry to adapt and face any challenges in using drone technology.

Besides, the applications and barriers discussed in this study can help drone manufacturers to further improve and enhance their product to enable drone technology to have more applications in the construction sites as well as helping the construction industry to overcome some of the challenges. This study can also act as feedback for the drone manufacturers to better understand and meet the demand and expectation of the construction stakeholders.

Everything considered, future research is able to refer to this study as an overview of the application of drone technology in construction site management. Additional details on the topic of utilising drone technology in managing construction sites can be provided by the future research. This study can be used as a foundation for future research to further explore into this topic.

1.8 Research Methodology

The research methodology that will be used to collect data is the quantitative approach which will be conducted through questionnaire surveys that allows the respondents to share their view and experience of drone technology in managing construction sites. The questionnaire will be distributed among the construction parties such as contractors, consultants and architects.

To further reinforce the understanding of the topic of this study, a careful comprehension of prior studies through literature review is carried out. Literature review was carried out in the form of reviewing articles, journals, conference papers, previous studies and research, and internet websites related to the adaptation of drone technology in managing construction sites.

The findings from the literature review will then be used in the design of questionnaire and analysed through the Statistical Package for Social Sciences (SPSS) software. The data analysis in the research includes Cronbach’s Alpha reliability test, descriptive analysis and the Mann-Whitney U Test.

1.9 Research Scope

The scope of this research focused on the application of drone technology in Malaysia’s construction site. This includes the construction site of all construction projects such as infrastructure, residential, commercial and industrial projects. Hence, this research will focus on construction parties such as contractors, and consultants which includes Engineers, Quantity Surveyors, and Architects located within the Klang Valley area that have work and tasks located at the construction site to provide their invaluable feedback on utilising drone technology to carry out their tasks. This is because their viewpoints may have a significant impact on the accuracy of the data collected.

1.10 Chapter Outline

A total of five chapters are included in this research. Chapter 1 acts as an introduction to this research as it consists of an overview of the content within this research. This chapter will cover the background and problem statement of the application of drone technology in managing construction sites, as well as the research aim, research objectives, research methodology, research scope and limitation and chapter outline.

Chapter 2 consists of the literature review on previous research regarding drone technology and its application, benefit and barriers. In addition, this chapter will discuss the type and features of drones that allow a better understanding of the technology.

Chapter 3 illustrates the research methodology that will be applied to achieve the aim and objective of this research. This includes a description of data collection and analysis method, as well as the design behind the questionnaire surveys.

Chapter 4 will break down the data collected from the questionnaire and analyse them through a series of statistical tests. The discussion of the data will then be systematically tabulated and presented to achieve the research aim and objectives.

Chapter 5 will bring the research to a conclusion by summarising the result and findings of this research. Recommendations and limitations for future improvement are drawn from this research to improve future related research.

1.11 Summary

This chapter has covered the introduction of this research by giving an insight of the background and problem statement regarding the application of drone technology in managing construction sites. In addition, the research aims and objectives are identified to align to the research methodology and research scope to meet its purpose. Besides, the chapter outline is provided to give an overview of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter 2 involves the literature review of related articles and journals done by previous researchers. This chapter will discuss the evolution and type of drones as well as reviewing the application, benefits and barriers of managing construction sites with drone technology. A summary will conclude and give a brief overview of the chapter.

2.2 Development of Drone Technology

The development of drones was initially designed for military operations before World War II and saw its first full deployment in the early 2000s used for the Iraq War and the Afghan War (Nonami, 2018). Fast forward to today, drones have become more accessible to the public (Li and Liu, 2019). The development of drones has allowed civilians to use drones for enjoyment or for industrial usage (Nonami, 2018). Drones can be applicable in any industry after making the necessary customisation and modification to suit the specific industry (Nonami, 2018).

As for the construction industry, constant advancement of technologies is necessary to cope up with the demand for an improved speed, accuracy and safety on project execution (Mahajan, 2021). Drone technologies are used as a tool to improve quality of work, cost management and safety management (Tkac and Mesaros, 2019). Although drones do not directly influence the speed of project execution, they provide data and information gathered from monitoring the construction site that allow a faster decision-making process (Mahajan, 2021).

It is legal to fly a drone in Malaysia but there are numerous laws and regulations for operating a drone in Malaysian’s airspace. The Civil Aviation Authority of Malaysia (CAAM) protects the Malaysian’s airspace by setting laws and regulations of utilising a drone. The following Table 2.1 states the laws and regulations for commercial drone services by CAAM.

Table 2.1: Laws and Regulations for Commercial Drone Services by CAAM

Regulations	Description
Altitude	Maximum height limit that a drone is permitted is 120 meters.
Authorisation	Requires authorisation from the Director-General to operate an Unmanned Aircraft System (UAS) for aerial work.
Insurance	Aviation liability insurance is not mandatory but recommended for commercial drone operation in Malaysia.
Range	Flight is only permitted in uncontrolled airspace and within 150 meters of the designated area and at least 9260 meters from an aerodrome.
Registration	Unmanned Aerial Vehicle (UAV) and UAS do not require registration unless the UAV or UAS exceed 20 kilograms.
Permit	Drones that do not meet the regulations above must apply for a permit for each flight. The permit application fees are RM250 for drones below 20 kilograms and RM1000 is for drones exceeding 20 kilograms. The Permit has a validity period of only three months.

2.3 Type of Drones

There are several types of drones used in the construction industry with each type serving its own intended purposes. These drones are categorised into three categories, which include fixed wing drones, fixed wing hybrid Vertical Take-off and Landing (VTOL) drones, and multi rotor drones.

2.3.1 Fixed Wing Drones

Fixed wing drones share the physical resemblances and principle of a commercial airplane. They are unable to raise their altitude via vertical thrust as the altitude is controlled by the fixed wings to generate the necessary lift to overcome the force of weight. Hence, a runway is required for a fixed wing drone to take-off and land. The length of the runway is also dependent on the size of the drone to allow the drone to generate enough speed to take-off.

Despite being inconvenient, fixed wing drones have the capabilities to reach high altitude and travel vast distances. As the drone is able to climb high altitude, it can cover a larger ground area in a frame. Therefore, fixed wing drones are a suitable tool for surveying large areas and topographic mapping (Wingtra, 2023).

2.3.2 Fixed Wing Hybrid VTOL Drones

Fixed wing hybrid VTOL drones have similar functionality as the fixed wing drone, and they share the advantages of fixed wing long range flight. However, the main difference between fixed wing hybrid VTOL drones and fixed wing drones is their taking off and landing style. Fixed wing hybrid VTOL drones have the ability to take off and land vertically with its vertical thrust similar to a multi rotor aircraft (JOUAV, 2023).

2.3.3 Multi Rotor Drones

Multi rotor drones operate similarly to a helicopter as they solely rely on their rotors to generate lift and propulsion to stay in the air. In addition, they have the VTOL capabilities that allows them to be both manoeuvrable and stable while hovering in the air, making them suitable for inspecting and monitoring construction sites. Depending on the number of rotors, they are also known as tricopters, quadcopters, hexacopters and octocopters. They are also commonly equipped with Light Detection and Ranging (LiDAR) sensors for aerial mapping (Li and Liu, 2019).

2.4 Application of Drone Technology to Manage Construction Site

The construction industry can take advantage of the technological advancement of drone technology to improve the performance of the construction site. Table 2.2 shows the list of applications of drone technology to manage construction sites found in previous studies.

Table 2.2: Applications of Drone Technology to Manage Construction Sites

Ref.	Applications	Authors	Total
A1	Inspection Tasks	Abdullah, Seow and Mohamed (2023); Elghaish, et al. (2021); Israr, et al. (2021); Jiang, Han and Bai (2021); Li & Liu (2019); Nooralishahi, et al. (2021); Mahajan (2021); Omar, et al. (2022); Rachmawati and Kim (2022); Tjandra, et al. (2022); Tkac and Mesaros (2019); Yahya, et al. (2021)	12
A2	Site Monitoring	Abdullah, Seow and Mohamed (2023); Choi, et al. (2023); Elghaish, et al. (2021); Kaamin, et al. (2023); Lee, et al. (2020); Mahajan (2021); Meshram and Reddy (2022); Omar, et al. (2022); Rachmawati and Kim (2022); Tjandra, et al. (2022); Tkac and Mesaros (2019)	11
A3	Topographic Mapping and Land Surveying	Abdullah, Seow and Mohamed (2023); Choi, et al. (2023); Elghaish, et al. (2021); Li & Liu (2019); Mahajan (2021); Omar, et al. (2022); Tjandra, et al. (2022); Tkac and Mesaros (2019); Yahya, et al. (2021)	9
A4	Safety Management	Abdullah, Seow and Mohamed (2023); Choi, et al. (2023); Dissanayake and Vithana (2021); Elghaish, et al. (2021); Li & Liu (2019); Mahajan (2021); Rachmawati and Kim (2022)	7
A5	Logistics Management	Choi, et al. (2023); Danjou, et al. (2020); Li & Liu (2019); Nooralishahi, et al. (2021); Tjandra, et al. (2022)	5

Table 2.2 (Continued)

Ref.	Applications	Authors	Total
A6	Decision Making and Site Management	Elghaish, et al. (2021); Li & Liu (2019); Mahajan (2021)	3
A7	Building Surveys	Tkac and Mesaros (2019); Omar, et al. (2022)	2
A8	Time Management	Li & Liu (2019)	1

2.4.1 Inspection Tasks

Site inspections are essential to efficiently manage a construction site by ensuring that the tasks and goal has been achieved. Drones have the ability to perform site inspection that is normally done by manual labour (Mahajan, 2021). In addition, drones can perform inspection tasks to allow project members to keep track of the development of the construction site (Omar et al., 2022). As drones are equipped with cameras that can capture high resolution images, drones are able to highlight the details that may be overlooked by manual inspection. An experienced pilot can use a drone to navigate the construction site and perform inspection tasks to identify defects and structural integrity (Tkac and Mesaros, 2019). Inspection done by drone can reach places where it is not convenient for manual labour. Drone also eliminates the tools necessary such as scaffolding and elevation platform to carry out inspection in difficult area (Yahya, et al, 2021). According to Abdullah, Seow and Mohamed (2023), drones are able to carry out tasks in a timely manner and safely. This is because inspection on hazardous sites carried out by drone is able to reduce safety risk for workers as the workers will not be near the hazardous site.

According to Elghaish, et al. (2021), an application has been developed to merge the UAV image processor and Building Information Modelling (BIM) can be used to detect deviation from the design and the built structure, allowing the UAV to detect cracks and defects on the structure. The integration of UAV and BIM can also improve the automation of inspection tasks (Rachmawati and Kim, 2022). Technical errors of the project such as geometric dimension, building facade and bolt fitted incorrectly can be identified by UAV (Tjandra, et al., 2022). A study carried out by Jiang, Han and Bai (2021) on using deep learning technologies to identify defects showed that several deep learning models can identify a variety of defects after undergoing model training. For instance, to identify defects such as cracks, poor workmanship and improper installation of frames can be done by deep learning technologies through crack detection model training and window detection model training. The drone technology can be further enhanced when utilising IoT-enabled UAV as the IoT will compile all the data collected from every drone image and enable the deep learning models to systematically detect defects (Israr, et al., 2021). Other than that, the integration of BIM and LiDAR can be an effective tool for quality control (Nooralishahi, et al., 2021). Hence, inspection of the construction site can also be done more frequently with drones to ensure that the site accurately resembles the construction plan and design.

2.4.2 Site Monitoring

According to Rachmawati and Kim (2022), the conventional method of monitoring the construction site requires a lot of time and effort. Drones provide a high resolution and clear image and can be used to reach high altitude. It allows the pilot of the drones to have a clear aerial overview of the construction site for effective construction site management (Omar et al., 2022). Project managers can use drones to monitor the site frequently to track the development of the project. It allows them to know the condition of the construction site and the necessary action needed to be taken to ensure all work on the construction site is carried out smoothly (Abdullah, Seow and Mohamed, 2023). The utilisation of drones also allows management to track the progress of every construction activity to prevent the project from falling behind schedule. Progress tracking of the project is enabled by integrating the UAV image processor and the project schedule (Tjandra, et al., 2022). According to Lee, et al. (2020), UAV photogrammetry of the construction site is processed by a commercial software named Pix4DMapper and then used to analyse the changes in each image. This is done by comparing the progress of each activity with the project timeline to identify the underlying cause of delay and take necessary action to ensure the project is delivered on time (Choi, et al., 2023). To further improve the performance of monitoring the construction site, machine learning models such as the Auto Regressive Integrated Moving Average (ARIMA) can be used to identify potential problems and enhance data processing capability for managing the construction site (Meshram and Reddy, 2022).

According to Mahajan (2021), drones can frequently capture overview images of the construction site to update the clients of the progress and condition. This is because of the drone’s ability to grant clients access to the drone database and share the flight view with clients. Project managers can also save time from going for physical site walk with clients as the drone's flight view of the construction site can be shared with clients (Tkac and Mesaros, 2019). The study carried out by Elghaish, et al. (2021) on digitising the construction industry presented that drones can be used as a first personal view tool to monitor the construction site and communicate with project members in real time. In short, the utilisation of drone technology to monitor construction sites allows the tracking of site progression accurately (Kaamin, et al., 2023).

2.4.3 Topographic Mapping and Land Surveying

Topographic mapping and land surveying allows the management to know the boundaries and characteristics of the construction site. This is particularly important for managing complicated and large construction projects (Tkac and Mesaros, 2019). Design flaw and issue can be identified early on once the topographic map of the construction site has been developed (Omar et al., 2022). However, the conventional method of developing the topographic maps is expensive and time consuming (Abdullah, Seow and Mohamed, 2023). This is because numerous images and data have to be collected manually by humans and then stored into files for all project members to access. As construction projects get progressively complex in nature, the efforts required to obtain the necessary data for topographic mapping and land surveying increase significantly. By utilising drones, large amounts of data on the landscape and terrain are able to be collected to better plan and manage the construction site. With the right mapping software used with the drone, project members are able to utilise the data and information to assist their strategic planning (Mahajan, 2021). According to Choi, et al. (2023), the drone's LiDAR sensor, thermal sensor, and high-resolution camera is able to precisely reflect the topography of the site on the 3D Model creation. This is because the aerial imagery from a drone is able to capture the site geometry and topographic features used to produce an accurate mapping. By doing so, UAVs are able to address the issue of inaccuracy of geometric measurements between the actual site measurement and 3D modelling (Elghaish, 2021).

According to Li and Liu (2019), the application of drone technology is able to eliminate the need for bulky equipment such as tripods, total stations and Global Positioning System (GPS) equipment to survey the land. Mobile equipment is no longer necessary as the pilot can be stationary at one place while surveying the land with the drone (Yahya, et al., 2021). This is because drones are equipped with sensors, built-in GPS systems and image processors that are used for land surveying. According to Tjandra, et al. (2022), the traditional method of land surveying takes three times longer when compared to using drones. The study also discovered that drones deliver more precise and detailed data than traditional methods of land surveying. Therefore, the usage of drone technology for topographic mapping and land surveying can enhance the management of construction sites by producing an accurate and detailed mapping of the site terrain and characteristics.

2.4.4 Safety Management

Part of managing the construction site involves ensuring the safety of the worker and the site condition. One of the primary concerns of the construction industry is the constant exposure to fatal accidents (Li and Liu, 2019). According to Abdullah, Seow and Mohamed (2023), utilising drones to detect safety issues on the construction site and resolving the issue before disasters occur improves the safety records of the construction site. This is because of the drone’s ability to monitor the condition of the construction site in real time. In addition, the versatility of drones also allows it to be used for identifying hazardous areas and ensuring the workers conform to the safety practices (Mahajan, 2021). For instance, drones can be used to patrol the construction site to check if the workers are equipping their personal protective equipment such as safety helmet, vest and boots (Rachmawati and Kim, 2022). According to Elghaish, et al. (2021), The Unmanned Aircraft System (UAS) can be equipped with a communicating tool to allow voice interaction between safety officers and workers. This will further enforce the safety practices among workers in the construction site.

According to Choi, et al. (2023), the sensors and data processing capabilities enable drones to distinguish hazardous conditions as safety risks such as falling debris, failing structure and equipment break down. These data collected can be used by management to take corrective action to safeguard the safety of the construction site. A study carried out by Dissanayake and Vithana

(2021) on safety inspection drones with machine learning algorithms in Sri Lanka showed that the UAS can integrate with machine learning to identify safety hazards through the data collected by OpenImageV5 application. The application is a gallery of real-world settings that was used in the study to identify smoke, fire and personal protective equipment. During an emergency, drones can also be used to locate the incident area such as fire or person in need of aid with sensors such as thermal sensors (Choi, et al., 2023). In short, the safety condition of the construction site is important as it impacts the productivity of the project.

2.4.5 Logistics Management

According to Li and Liu (2019), an efficient logistic management allows a smooth physical flow within the construction site. A clustered and congested construction site will cause lower productivity due to restricted movement among the material and equipment. A sizable quadcopters drone that is capable of transporting material is an efficient method of transporting material in construction sites with limited space (Choi, et al., 2023). Project managers can also use drones to track material and equipment to ensure that they are located at the designated position. The tracking of material can be done by visual image, GPS tracking and radio frequency identification (Nooralishahi, et al., 2021). According to Danjou, et al. (2020), drones can be set to follow a certain flight plan during a certain time interval to track the physical asset in the construction site. Besides, drones can assess the status and condition of equipment such as tower cranes and update the findings frequently (Tjandra, et al., 2022). It will save time and labour cost as frequently manually checking the condition of tower crane is difficult.

2.4.6 Decision making and Site Management

The ability to manage the construction site plays an important role to ensure a smooth delivery of the project. This includes making a strategic decision after analysing the information and the result, advantage and risks associated with the decision. UAV plays an important role in virtual design and construction (VDC) as it enables project members to visualise the surrounding environment of the construction site (Elghaish, et al., 2021). This allows more data and information to be collected and analysed as it will improve the decision-making process in construction site management. According to Mahajan (2021), drones mapping software and the complex nature of photogrammetry associated with drone technology allow construction managers to make a strategic decision as they will have a clear overview of the construction site. All the data and information collected can be used to create a 3D model of the construction site and simulate various scenarios and decisions to obtain different outcomes. In short, drones enhance the ability to manage construction site effectively due to visualisation of the site enabled by the integration of drone images and augmented reality (Li and Liu, 2019).

2.4.7 Building Surveys

Building inspections are necessary for every construction project as they have to examine if the structure consists of technical flaws or defects. This includes the roof of building structure that has to be examined to determine the technical condition and detect any issue (Tkac and Mesaros, 2019). Drone can survey the entire building without difficulty especially to the top of a high-rise building that may be a safety concern for humans to reach (Omar, et al., 2022). According to Tkac and Mesaros (2019), competent flying skills of the pilot allow the roof structure of the building to be captured in the form of vertical aerial photography which provides aerial images with different angles of view and altitude. This is because drones can reach the top of the building in a matter of minutes while it is time consuming for humans as temporary structures such as scaffolding, and ladders are required to reach the top. By doing so, the cost of managing the construction site is able to be reduced as well as mitigating safety risks associated with building surveying.

2.4.8 Time Management

Time management is more than just completing tasks within the given timeframe, but also minimising cost, resources and time. According to Li and Liu (2019), the data and information collected by drone can be used to refine the 3D BIM models if paired with 4D, 5D and 6D of the time management, cost management and project life-cycle information. The data and information of an event can be used to update the BIM model to calculate the likelihood of delay occurrence or negative effect on project delivery. Furthermore, the drone can capture images of the construction site and the image will be processed by photogrammetry software to detect progress deviations by comparing the project design and as-built model (Li and Liu, 2019). This will allow the management to plan and take necessary action to manage the construction site to ensure the project delivery is on schedule. Drone technology can be used as an effective time management tool in managing construction sites when paired with other technology.

2.5 Benefits of Utilising Drone Technology for Construction Site Management

The advancement of drone technology has allowed the construction industry to benefit from the application of drones in construction sites. Table 2.3 shows the list of benefits of utilising drone technology for construction site management by prior studies.

Table 2.3: Benefits of Utilising Drone technology for Construction Site Management

Ref.	Benefits	Authors	Total
B1	Reduced Safety Risks	Airipin, Zawawi and Ismail (2019); Akinradewo, et al. (2022); Alsamarraie, et al. (2022); Chen and Chang-Richards (2022); Hatoum and Nassereddine (2022); Ibe, Serbescu and Hossain (2023); Jain and Jagtap (2023); Liang, et al. (2023); Onososen, et al. (2023); Umar (2021)	10
B2	Improved Data Collection	Faraji, et al. (2022); Hasegawa, et al. (2023); Jain and Jagtap (2023); Kaamin, et al. (2023); Keong, Sa'ar and Kaliannan (2023); Liang, et al. (2023); Vanathi and Radhika (2022)	7
B3	Improved Planning and Decision-Making Process	Akinradewo, et al. (2022); Chen, et al. (2022); Ibe, Serbescu and Hossain (2023); Le Phu, Trang and Khai (2023); Onososen, et al. (2023); Rahnamayiezekavat, et al. (2022); Varmus and Bosko (2022)	7
B4	Improved Quality Control	Alsamarraie, et al. (2022); Falorca, Miraldes and Lanzinha (2021); Faraji, et al. (2022); Hatoum and Nassereddine (2022); Onososen, et al. (2023); Rahnamayiezekavat, et al. (2022)	6
B5	Cost Effective	Airipin, Zawawi and Ismail (2019); Alsamarraie, et al. (2022); Chen and Chang-Richards (2022); Le Phu, Trang and Khai (2023)	4

Table 2.3 (Continued)

Ref.	Benefits	Authors	Total
B6	Time Saving	Aghimien, et al. (2023); Airipin, Zawawi and Ismail (2019); Akinradewo, et al. (2022); Alsamarraie, et al. (2022)	4
B7	Improved Logistics	Hatoum and Nassereddine (2022)	1

2.5.1 Reduced Safety Risks

Drones are tools of safety administration that are used to prevent unauthorised personnel entering a predetermined hazardous area in the construction site (Alsamarraie, et al., 2022). According to Akinradewo, et al. (2022), the application of drones solves most of the issue regarding workers being exposed to safety risks that are life-threatening or minor injuries. This is because of the drone ability to monitor on-going activities in the construction site (Chen and Chang-Richards, 2022). Drones are able to reach hazardous areas to collect data as drones are equipped with sensors, GPS, cameras and communicating equipment (Umar, 2021). For example, a drone is controlled remotely by a pilot in a safe area while the drone can reach high altitude and viewpoints to capture images of the construction site (Airipin, Zawawi and Ismail, 2019). This will prevent workers from falling from high heights while performing inspection tasks manually. Furthermore, drone technology can be used to create a virtual walkthrough of the construction site to identify potential issues and accidents (Ibe, Serbescu and Hossain, 2023). Real-time monitoring of the construction site allows management to better identify sources of potential accidents (Jain and Jagtap, 2023). This is because of the various sensors equipped by a drone such as TI sensors and LiDAR sensors to detect heat issue and hazardous areas respectively (Liang, et al., 2023). According to Onososen, et al. (2023), safety managers can use drones to monitor the construction site in real time and communicate to the workers through the drone’s audio. Through the audio system of the drone, safety managers can warn the workers who are exposed to safety risks and prevent accidents from occurring (Hatoum and Nassereddine, 2022).

2.5.2 Improved Data Collection

According to Jain and Jagtap (2023), the accuracy of data collection from UAV photogrammetry is higher when compared to the conventional method of data collection for topographic mapping. This is because the LiDAR and GPS sensors equipped by the drone are able to accurately calculate the trajectory of the construction site (Liang, et al., 2023). The combination of UAV and BIM can be used to enhance the efficiency and accuracy in obtaining data and information (Keong, Sa’ar and Kaliannan, 2023). According to Faraji, et al.

(2022), drone technologies have greatly improved the precision and accuracy of data collection which allows the data to be used to influence decision-making. A study conducted by Kaamin, et al. (2023) on calculating the data on earthwork excavation using orthophoto images captured by UAV has shown that the utilisation of drone to obtain, calculate and analyse data in the construction site is a valuable tool for professionals to track the progress and performance of the project. Besides, the use of UAV is an effective method to accurately obtain data on the works of earthwork such as the earthwork volume, estimated cost and time required for completion (Hasegawa, et al., 2023). As the time required for drones to collect data is relatively short, it is an effective method of data collection as it is done accurately and in a timely manner (Vanathi and Radhika, 2022).

2.5.3 Improved Planning and Decision-Making Process

The success of construction projects is influenced by the planning and decisions made on a daily basis as it affects the time, cost and quality of the project activities (Onososen, et al., 2023). Drone can be used to capture images of the site layout and the surrounding of the site to assist the planning and decision making of the project (Rahnamayiezekavat, et al., 2022). When integrating drone technology with BIM, the integration can be used to aid the creation of 3D models of the construction site to allow better planning and visualisation of the site (Ibe, Serbescu and Hossain, 2023). A thorough analysis of the construction site is essential to understand the environment and characteristics of the project (Varmus and Bosko, 2022). Drone technology such as cameras, sensors and GPS act as an essential tool in managing the construction site as it gathers the data and information that enhance the decision-making process (Le Phu, Trang and Khai, 2023). The real time monitoring of the construction site offered by drones allows all project stakeholders to collaborate without needing to be physically present at the construction site (Akinradewo, et al., 2022). This will allow the decision-making process to be improved as regular site visits to the construction site may not be possible for all project stakeholders. In addition, drones can be used to identify material waste that should be removed or salvaged during demolition works (Ibe, Serbescu and Hossain, 2023). According to Chen, et al.

(2022), the visualisation of the construction site is essential in understanding the characteristics of the site and to improve planning for the project.

2.5.4 Improved Quality Control

The integration of UAS and UAV in construction site management can detect deviations of the built structure from the planned design (Alsamarraie, et al., 2022). Previously, the inspector's skill and knowledge largely contributed to the detection of defects and any defect overlooked will affect the overall quality of the structure (Onososen, et al., 2023). According to Rahnamayiezekavat, et al. (2022), the use of drones to capture images in high resolution allow the inspection tasks to be carried out and determine the quality without entering the site. Areas that are difficult to reach can now be accessed due to the drone's manoeuvrability (Falorca, Miraldes and Lanzinha, 2021). It allows the detection of defects that are previously undetectable by the human eye. Drones are able to offer quality control to the project manager as the UAS can generate a timeline of information according to the tasks performed to ensure the physical resemblances of the design and built structure (Hatoum and Nassereddine, 2022). The timeline will allow the project manager to trace the tasks and obtain information needed to rectify any defects. In addition, drones can be used for quality management as the data collected from UAV can be imported into BIM to analyse the constructability and take necessary action to avoid error while executing the project (Faraji, et al., 2022).

2.5.5 Cost Effective

The versatility of the drone is capable of taking on numerous roles and tasks in managing the construction site. The use of drones to replace large and costly equipment on construction sites reduces the project operational costs (Alsamarraie, et al., 2022). This is because the use of drones in construction site to perform certain tasks such as inspection, land surveying and topographic mapping replaces the need for mobile equipment, scaffolding and other necessary equipment to complete the tasks in a conventional method. Drone also improves the mapping capability as it does not require a lot of manual labour to update the database when compared with the conventional method (Le Phu, Trang and Khai, 2023). This will reduce the operational cost of the project as the application of drones reduces the manual labour normally required to complete tasks in a conventional method. According to Airipin, Zawawi and Ismail (2019), the construction industry in Malaysia has a high demand for unskilled foreign workers. The authors also state that the spending on the permits and levy to hire foreign workers have been increased by the government. Thus, using drone technology to reduce manual labour leads to a reduction in operation costs. Furthermore, Chen and Chang-Richards (2022) stated in their study that the use of drone technology to obtain data has better accuracy and quality at a lower cost compared to conventional methods.

2.5.6 Time Saving

The application of drones to collect data and information in the construction site is a timely method to manage the construction site (Alsamarraie, et al., 2022). For instance, an experienced pilot is able to navigate the construction site easily to perform inspection tasks (Airipin, Zawawi and Ismail, 2019). By doing so, time is saved from walking to every point of inspection especially in large construction sites and waiting for passenger hoists to reach the high level of a building. This is because of the drone ability to reach any area of the construction site within a short period of time and gather the data and information necessary (Akinradewo, et al., 2022). According to Aghimien, et al. (2023), using drones to replace manual site visits on the construction site greatly reduces the time needed to complete inspection and monitoring tasks. In addition, the use of drones to identify defects, clashes, and resource utilisation saves time as the time spent on rectifying defects are avoided (Onososen, et al., 2023).

2.5.7 Improved Logistics

The application of drones can act as a tool to manage the materials and equipment on site as keeping track of the materials and equipment of a large project can be hectic and overwhelming. According to Hatoum and Nassereddine (2022), the sensors of drones can determine the type and quantity of the materials on site and the location of equipment such as excavators, loaders, boring machines and compactors. Project managers can easily track the materials and equipment to determine if they are in the right place and quantity.

2.6 Barriers of Utilising Drone Technology for Construction Site Management

Drone technology offers the construction industry numerous benefits to improve the construction site management. However, there are barriers for the construction industry to utilise drone technology in managing construction sites. Table 2.4 shows the previous studies on barriers of utilising drone technology for construction site management.

Table 2.4: Barriers of Utilising Drone technology for Construction Site Management

Ref.	Barriers	Authors	Total
C1	Lack of Knowledge and Skill	Albeaino and Gheisari (2021); Ibe, Serbescu and Hossain (2023); Ikuabe, et al. (2022); Nwaogu, Yang and Chan (2022); Omar, et al. (2022); Szostak, et al. (2023); Tjandra, et al. (2022); Umar (2021); Waqar, et al. (2023); Yahya, et al. (2021)	10
C2	Liability and Legal Concerns	Albeaino and Gheisari (2021); Hatoum and Nassereddine (2022); Ibe, Serbescu and Hossain (2023); Khalid, Namian and Massarra (2021); Nwaogu, Yang and Chan (2022); Omar, et al. (2022); Onososen, et al. (2023); Umar (2021); Waqar, et al. (2023); Yahya, et al. (2021)	10
C3	Safety Concerns	Albeaino and Gheisari (2021); Brophy, et al. (2022); Hatoum and Nassereddine (2022); Jeelani and Gheisari (2021); Khalid, Namian and Massarra (2021); Namian, et al. (2021); Nwaogu, Yang and Chan (2022); Tjandra, et al. (2022); Umar (2021); Yahya, et al. (2021)	10
C4	Environmental Factors	Albeaino and Gheisari (2021); Choi, et al. (2023); Ciampa, De Vito and Rosaria Pecce (2019); Hatoum and Nassereddine (2022); Ibe, Serbescu and Hossain (2023); Lissmatz Van De Laak and Ahmad (2022); Omar, et al. (2022); Yahya, et al. (2021) York, Al-Bayati and Al-Shabbani (2020)	9
C5	Limited Battery Life	Choi, et al. (2023); Ciampa, De Vito and Rosaria Pecce (2019); Hatoum and Nassereddine (2022); Namian, et al. (2021); Omar, et al. (2022); Szostak, et al. (2023); Yahya, et al. (2021); York, Al-Bayati and Al-Shabbani (2020)	8

Table 2.4 (Continued)

Ref.	Barriers	Authors	Total
C6	Low Investment from the Construction Industry	Ibe, Serbescu and Hossain (2023); Ikuabe, et al. (2022); Nwaogu, Yang and Chan (2022); Onososen, et al. (2023); Waqar, et al. (2023)	5
C7	Lengthy Data Processing Period	Albeaino and Gheisari (2021); Ciampa, De Vito and Rosaria Pecce (2019); Ibe, Serbescu and Hossain (2023); Lissmatz Van De Laak and Ahmad (2022)	4
C8	Emotional Impact Caused to Workers	Brophy, et al. (2022); Khalid, Namian and Massarra (2021); Onososen, et al. (2023);	3

2.6.1 Lack of Knowledge and Skill

It is necessary for the operators to understand the drone technologies before utilising drones in the construction site (Umar, 2021). As the need of having a proficient drone operator for complex operation is important, it has also become a barrier for using drones to manage construction sites (Tjandra, et al., 2022). This is due to the fact that the construction industry is lacking the personnel with the skills required to manage the overall aspect of drone technology (Ibe, Serbescu and Hossain, 2023). Without the necessary knowledge, it is difficult for the operator to carry out his tasks with the use of drones (Omar, et al., 2022). This barrier causes construction companies to be hesitant in investing in drones technology due to the lack of skilled operators to manage the drones (Waqar, et al., 2023). According to Ikuabe, et al. (2022), the specialties and training required for drone operation is one of the factors hindering the utilisation of drones in project execution and delivery. This is because an inexperienced drone operator may cause inaccuracy in data collection (Szostak, et al., 2023). In order to effectively operate the drone, a skilled operator is required to conduct UAV operations in the construction site as well as having the knowledge to tackle any technical difficulties faced during the midst of the UAV operations (Albeaino and Gheisari, 2021). For instance, the UAV operator needs to know the solution to resolve any technical difficulties encountered mid-flight such as loss of signal, navigation interferences, system malfunction and battery issue. Human intervention is necessary during an emergency despite the ability of the drone to navigate the construction site on autopilot (Yahya, et al., 2021). Hence, it is important to clearly state the potential technical difficulties before utilising drones in construction sites (Nwaogu, Yang and Chan, 2022).

2.6.2 Liability and Legal Concerns

The laws and regulations regarding the use of drones in construction sites have led to a troublesome process of obtaining the necessary permits (Ibe, Serbescu and Hossain, 2023). According to Albeaino and Gheisari (2021), ethical concerns such as invasion of privacy poses an issue to the public as the public may not wish to have their activity to be monitored. The fear of invasion of privacy from the public sector arises from the fact that drones are able to spy on the victims (Omar, et al., 2022). This is because the drone's ability to capture images with its advanced equipment has become a matter of privacy concerns (Nwaogu, Yang and Chan, 2022). It is inevitable to have unauthorised images of the public when capturing images and collecting data inside the construction site despite the intent to have the drone to only operate inside the site boundaries. Other than that, the operators might make mistakes during the flight of the drone and lead to lawsuits regarding property damage and personal injury of the public sector (Umar, 2021). In some scenarios, the drone operators mistakenly fly the drones into unauthorised territories leading to a case of trespassing (Khalid, Namian and Massarra, 2021). The applications of drone technology in construction sites face many legal obstacles, causing construction companies to be reluctant to invest in drone technology (Waqar, et al., 2023). In addition, the regulations of drones restrict the drones from flying too high up in the sky and entering certain restricted areas such as airports (Onososen, et al. 2023). There are other liability concerns regarding the utilisation of drones for malicious intent such as GPS jamming, cyberterrorism and other illegal action (Hatoum and Nassereddine, 2022). Drone technologies are vulnerable to hacker attacks in which hackers can extract confidential data and documents from the drone network (Yahya, et al., 2021).

2.6.3 Safety Concern

Drone operators need to acknowledge the safety hazards of operating a drone in the construction site (Albeaino and Gheisari, 2021). This is because the use of drones in a construction site puts every construction personnel in danger (Yahya, et al., 2021). According to Umar (2021), drones distract the workers and put them in dangerous situations. This is because the sight and sound of the drone causes the workers to be unable to focus on their tasks and the hazardous work environment they are in (Jeelani and Gheisari, 2021). Besides, it is difficult for drones to manoeuvre in a congested area due to the proximity of objects in the construction site such as material, equipment, tree and powerline (Albeaino and Gheisari, 2021). It is also a safety risk as the drones can potentially cause serious injuries to the workers and damaging equipment when a collision occurs between the drones and the objects (Nwaogu, Yang and Chan, 2022). For instance, the rotors that are spinning at high speed can severely injure any personnel that the drone collided into (Namian, et al., 2021). The risk of collision increases at the later stage of the construction project as more construction entities and personnel are present at the construction site (Brophy, et al., 2022). Depending on the location of the construction site, malfunction of the drone could lead to property damage and personal injury of the public sector (Hatoum and Nassereddine, 2022). The drones might also face signal loss while hovering over the sky and become uncontrollable before plummeting into the ground and colliding with tower cranes, power lines and other entities (Tjandra, et al., 2022). Overall, drones do not have many safety features to prevent drones from malfunctioning and crashing in mid-flight (Khalid, Namian and Massarra, 2021).

2.6.4 Environmental Factors

The environment in which the drones operate yields different results and effectiveness. According to Hatoum and Nassereddine (2022), using drones on rough terrains with mountains surrounding the construction site or using drones in underground tunnels interfere with the connectivity of the drones. The author also states that metallic objects can also interfere with the navigation and communication system. The effectiveness of drones in construction sites is affected by weather conditions as extreme weather will degrade the quality and reliability of the data collected (Albeaino and Gheisari, 2021). In addition, inaccuracy of the data caused by the weather can cause issues in the creation of the BIM model (Ibe, Serbescu and Hossain, 2023). Different weather conditions will also limit the use of drones in performing certain tasks (Umar, 2021). Drones are vulnerable to turbulence when encountered strong winds and can even alter the flight path of the drone (Choi, et al., 2023). Certain weather conditions can damage certain components of the drones and lead to the drones malfunctioning (Omar, et al., 2022). For instance, drones are vulnerable to water as rain can damage the electronic components inside the drone. In addition, drones do not operate effectively in temperatures where it is too hot or cold (Ciampa, De Vito and Rosaria Pecce, 2019). The battery life is lowered when operating in hot temperatures as the battery will gradually deteriorate when overheating (York, Al-Bayati and Al-Shabbani, 2020). Several modifications on the drones are required to overcome these environmental challenges such as replacing the standard cameras with LiDAR sensors (Lissmatz Van De Laak and Ahmad, 2022). In short, the use of drones for data collection is most effective when the weather is clear and not on rough terrain (Yahya, et al., 2021).

2.6.5 Limited Battery Life

The capability of a drone’s flight time is significantly impacted by the battery life (Omar, et al., 2022). Low battery life leads to short drone’s flight duration and prevents drones from carrying out long distance surveillance and inspection tasks (Choi, et al., 2023). According to York, Al-Bayati and Al-Shabbani (2020), modifications made to the drone such as mounting additional equipment will cause the drone to be heavier and require more power from the battery to generate sufficient thrust to keep the drone in the air. This is because the power usage of the drone is determined by the take-off weight of the drone (Hatoum and Nassereddine, 2022). Other than that, it is common for the battery of the drone to overheat and damage the battery until it no longer can store energy efficiently (Namian, et al., 2021). As the flight duration is determined by the battery life, the use of drones to cover large areas requires several drones or additional batteries to complete the tasks (Szostak, et al., 2023). According to Yahya, et al (2021), the limited battery life causes the low capacity of the image and video to be captured. It is necessary to consider the battery capacity before conducting drone operations as loss of power in the middle of the flight will result in the drone falling from the sky (Ciampa, De Vito and Rosaria Pecce, 2019). In short, the battery life of the drone limits the productivity of drone operation as the majority of the time is spent replacing and recharging the battery.

2.6.6 Low Investment from the Construction Industry

The costs of obtaining drones for construction operations includes the capital cost of drones and the associated software, annual licence cost, maintenance cost and replacement cost (Onososen, et al., 2023). According to Nwaogu, Yang and Chan (2022), the majority of the cost for utilising drones in construction sites arises from the initial cost where the project stakeholders have to invest a large sum of money. Construction companies are reluctant to invest in drone technology as the current application of drone technology in managing the construction site is limited (Waqar, et al., 2023). This is especially true when smaller construction companies are unable to afford the high initial capital cost (Ibe, Serbescu and Hossain, 2023). Hence, low investment of drone technology from the construction industry leads to low involvement of drone technology in construction projects (Ikuabe, et al., 2022).

2.6.7 Lengthy Data Processing Period

Construction stakeholders are required to understand how the data is extracted and analysed to suit their intended purposes (Albeaino and Gheisari, 2021). This is because raw data collected by drones is unusable and has no purpose until it is processed into information. The large entry of data provided by the drone requires a lot of time and effort to be processed and analysed to filter out irrelevant information before it can be used to aid the planning and decision-making process (Lissmatz Van De Laak and Ahmad, 2022). The quality of the data processing is also affected by the experience of the personnel processing the data (Ciampa, De Vito and Rosaria Pecce, 2019). According to Ibe, Serbescu and Hossain (2023), the process of analysing the large amount of data will be costly and time consuming without the proper tools and skills.

2.6.8 Emotional Impact Caused to Workers

The use of drones to monitor the construction site causes distrust between the management and workers as the workers felt like they are constantly being watched (Onososen, et al., 2023). According to Brophy, et al. (2022), the thought of constantly being monitored can severely impact the mental health of the workers as it causes anxiety and stress. The productivity of the workers is also affected when they are distracted by the sound and sight of drones flying around in the construction site. This is because the construction site is already a hazardous environment and combined with the distraction caused by drones, the workers will be unable to concentrate on their tasks, surroundings, thoughts and decision-making capabilities (Khalid, Namian and Massarra, 2021).

2.7 Summary

This chapter introduced drone technology by discussing the development and type of drones. After reviewing the application, benefits and barriers of using drone technology to manage construction sites from previous authors, a total of 8 applications, 7 benefits and 8 barriers were thoroughly examined.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research methods and approaches used to carry out this research. The design of the research is thoroughly explained to ensure that the means of achieving the results with the data collected are reliable.

3.2 Research Method

Quantitative research and qualitative research are commonly used to carry out research. The difference between quantitative and qualitative research is shown in Table 3.1.

Table 3.1: Difference Between Quantitative and Qualitative Research

Quantitative Research	Qualitative Research
Close-Ended Questions	Open-Ended Questions
Requires Many Respondents	Requires Few Respondents
Test Hypotheses or Theories	Exploring Ideas or Hypotheses
Measure and Test	Observe and Interpret
Statistical Analysis	Non-Statistical Analysis
Outcome-Oriented	Process-Oriented
Less Open to Arguments	Flexible and Adaptive
Longer Time Frame	Shorter Time Frame

Quantitative research is used in this research to obtain the necessary data on the applications, benefits and barriers of utilising drone technology in construction site management. The rationale for selecting a quantitative approach is that a large number of respondents are able to fill up the questionnaire surveys which allows the results to have a more accurate representation of the construction industry as a whole. This is due to the nature of the research that allows quantitative research to identify patterns and evaluate theories through numerical data (Mehrad and Zangeneh, 2019). These data are collected from a sample of the construction industry's members that have or have not utilised drones in construction sites and then analysed by applying statistical techniques. The method of data collection will be done through distributing questionnaire surveys. The questionnaire consists of close ended questions that are designed to meet the aim and objectives of this research. The questionnaire will be prepared in Google Forms and distributed via online to contractors and consultants in Klang Valley.

Other than that, quantitative research enables the respondents to rate their agreement level on the applications, benefits and barriers of using drone technology in construction site management. This allows the results to be more generalised than qualitative research and enables the results to have a more accurate representation of the construction industry.

3.3 Questionnaire Design

The questionnaire consists of 4 sections as shown in Table 3.2. Section A examines the demographic profile of the respondents such as their knowledge, company background, exposure and experience with drone technology. A series of multiple-choice questions is used to determine the demographic profile of the respondents. Section B, Section C and Section D consists of eight applications, seven benefits and eight barriers of using drone technology in construction site management which were derived from the literature review to examine the agreement level of the respondents on the variables of each objective. These sections are designed to be rated by the respondents based on their agreement level. Section B to section D requires the respondents to rate their level of agreement through a 5-Point Likert Scale for the questions presented in each section. As shown in Table 3.3, the 5-Point Likert Scale begins from 1 to 5 as each point indicates the respondents' degree of agreement or disagreement with the questions. At the end of the questionnaire, a polar question is asked to determine if the respondents would use drone technology to manage construction sites. This is to draw up conclusions to determine if the respondents would consider using drone technology after all the factors are considered.

Table 3.2: Questionnaire Design

Section	Item
A	Demographic Profile of the Respondents
B	Applications of Drone Technology for Construction Site Management
C	Benefits of Drone Technology for Construction Site Management
D	Barriers of Drone Technology for Construction Site Management

Table 3.3: 5-Point Likert Scale

Ratings	Agreement Level
1	Strongly Disagree
2	Disagree
3	Neutral/Uncertain
4	Agree
5	Strongly Agree

3.4 Sampling Method and Size

The method of sampling for this research is convenient sampling followed by snowball sampling. Initially, the questionnaire will be distributed to a couple of contractors and consultants that are accessible as the target respondents. The initial respondents will then forward the questionnaire to their respective contacts. This process repeats as respondents continuously forward questionnaires to more potential respondents. The rationale for selecting convenience sampling followed by snowball sampling is to ease the process of distributing the questionnaire to the target respondents as the respondents will refer more target respondents that are previously inaccessible to complete the questionnaire. The difficulty of distributing the questionnaires to the target respondents is significantly reduced as the target respondents gradually increase in number as more respondents are referred (McCombes, 2023). The questionnaires will be distributed to a few respondents working as a contractor and consultants. The contractors will provide their insight and experience on the usage of drone technology in construction site management due to their exposure to the construction site activities. On the other side, the consultants will provide their expertise on the technicality aspect of the construction activities to determine if the perspective of the consultants varies from the perspective of the contractor. Then the initial respondents will share the questionnaires to other contractors or consultants based on their working field until the desired number of respondents is achieved.

By applying the Central Limit Theorem, a minimum of 30 samples are required from each variable. This is to obtain the sample mean and standard deviation on the agreement level from both sample groups that can be used to approximately represent the mean of the construction industry's population. The mean equals to the average agreement level of both sample groups and the standard deviation equal to the difference from the mean of both sample groups. Due to the time constraint, the sample size will be at least a total of sixty (60) respondents. The number of respondents for contractors and consultants requires at least thirty (30) respondents each. This is to ensure that the perspective of both parties is equally represented in this research.

3.5 Research Flow

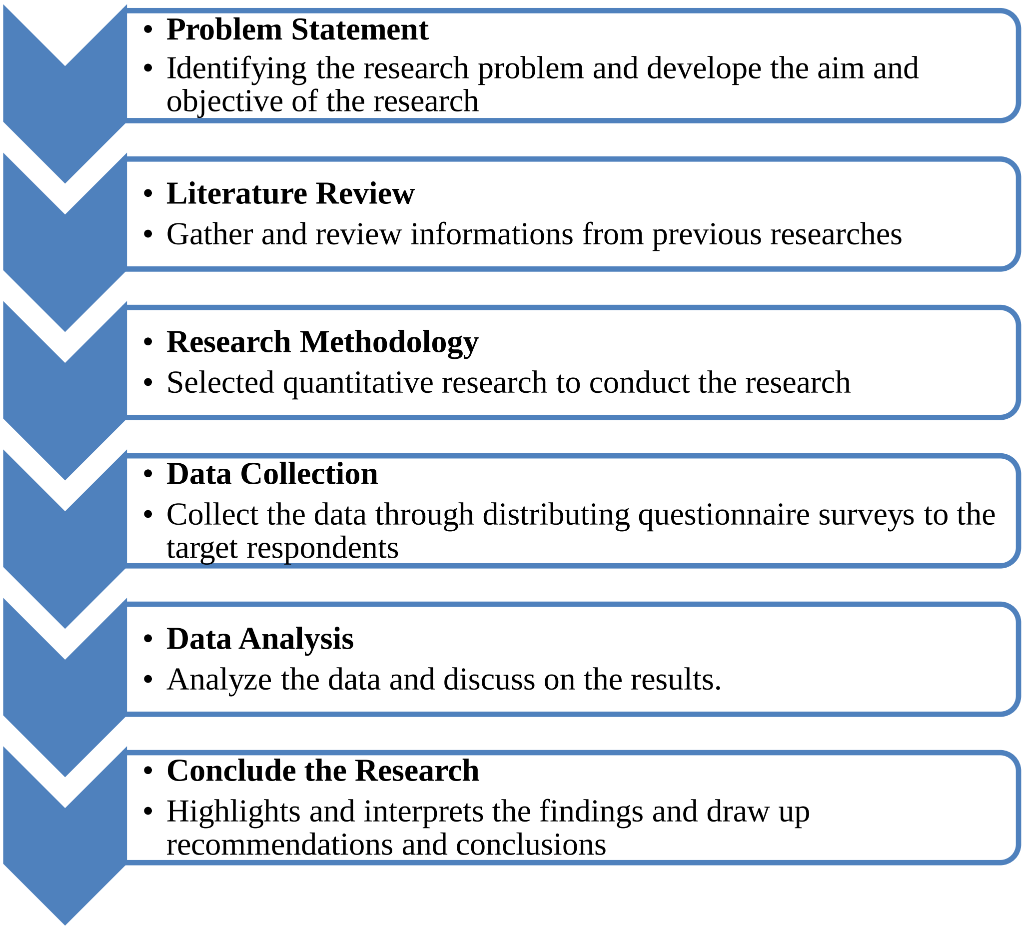

Figure 3.1: Research Flow.

The research began by identifying the research problem and research gap before developing the aim and objectives of the research. Once the aim and objectives has been established, a comprehensive literature review were carried out on previous research. Once the findings were derived from the literature review, the findings will also be used in designing the questionnaire. The questionnaire will then be collected and analysed through the SPSS software where the findings and results will be highlighted and interpreted.

3.6 Data Analysis

The data collected are analysed via several tests through the Statistical Package for the Social Sciences (SPSS) software. These tests to analyse the data are essential in achieving the objectives of the research. These tests consist of Cronbach's Alpha reliability test, descriptive analysis and the Mann-Whitney U Test.

3.6.1 Cronbach's Alpha Reliability Test

As the hypothesis of the research is developed, the latent variable is unable to be measured directly. Hence, a scale on a group of questions is used to measure the latent variable. The purpose of the Cronbach's Alpha Reliability Test is to determine if the questions correlate with every other question and act as a measurement for the internal consistency and reliability of a scale. The following equation is used for the Cronbach's Alpha Reliability Test (UCLA, n.d.).

$$a = \frac{Nc}{V + (N-1)c}$$

where,
N = Number of Items
c = Average inter-item covariance among the items
V = Average variance

The value obtained after using the equation as mentioned above determines the internal consistency and reliability of the data. The value ranges from 0.0 to 1.0. As the value is closer to 1.0, it indicates that the data has the maximum value of reliability. A minimum value of 0.7 is required to be considered as acceptable internal consistency. Table 3.4 shows the rule of thumb for the value of Cronbach's Alpha.

Table 3.4: Rule of Thumb for the Value of Cronbach's Alpha

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

[Source: UCLA, n.d.]

3.6.2 Descriptive Analysis

The use of descriptive analysis is to summarise the raw data provided by the questionnaires as it is difficult to process the agreement level of the respondents. Descriptive analysis measures and analyses the frequency, percentage, variance, standard deviation, mean, median and mode from each variable and ranks them according to the agreement level of the respondents from the most agreed to least agreed applications, benefits and barriers of using drone technology in construction site management. This is done by calculating the mean value of all the variables as all the values in the data set are extracted from the 5-Point Likert Scale and totalled up before dividing it with the number of values in the data set. The mean score with a high value represents a high agreement level of the respondents while a low value represents a low agreement level of the respondents. Then, the variables will be ranked accordingly to the mean value. In short, descriptive analysis is an essential tool to summarise raw data by measuring variables on a continuous scale.

3.6.3 Mann-Whitney U Test

The Mann-Whitney U Test is a non-parametric statistical test that compares the median of two independent samples to examine if there is a significant difference between the two samples (McClenaghan, 2022). In addition, the use of Mann-Whitney U Test is suitable for ordinal variables such as the Likert scale to rank categories. Besides, the absence of a relationship between each sample fulfils the requirements of independence of observations. For this research, The Mann-Whitney U Test is used to determine if the contractors' response is different from the consultants' response on all three objectives of this research. By doing so, the results show their similarity or difference on their agreement level of the applications, benefits and barriers of using drone technology for construction site management. The basis of Mann-Whitney U Test derives from the hypotheses of null hypothesis (H0) and alternative hypothesis (H1). Null hypothesis (H0) indicates that the two samples are the same while the alternative hypothesis (H1) indicates that the two samples consists of significant differences. The alternative hypothesis (H1) is only accepted if the null hypothesis (H0) is rejected due to the asymptotic significance value being less than or equal to 0.05. In short, the null hypothesis is only rejected when there is significant difference between both samples.

3.7 Summary

This chapter explains the research methodology applied and the approach to data collection and analysis. A flowchart of the research flow is presented, and the method of data analysis is thoroughly explained. All of the data collected through questionnaires are analysed via the SPSS software for further discussion and evaluation in Chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the three objectives of this research will be discussed and analysed via the data collected from the questionnaire survey that has been distributed. Firstly, the data will be determined by the Cronbach's Alpha Reliability Test on whether the data have an acceptable internal consistency. The data will then be analysed through the descriptive analysis to rank the variables according to the agreement level of the respondents. The results will then be compared using the Mann-Whitney U Test to detect any significant differences between contractors and consultants.

4.2 Demographic Profile of the Respondents

The first section of the questionnaire survey is used to filter out respondents that do not qualify or meet the requirements to provide the data necessary to carry out the research. A total of 121 respondents has been collected and will be filtered out to ensure the data used in the research is relevant and accurate.

Table 4.1: Summary of Respondents' Background

Description	Response
Exposure to Construction Site	All 121 respondents have exposure.
Knowledge of Drone Technology	119 respondents have knowledge, 2 respondents do not.
Respondents Profession	61 Contractors and 58 Consultants

All 121 respondents have worked in the construction industry and have been exposed to the construction site's activities and management. The questionnaire survey is able to reach the targeted respondents due to the sampling method applied in this research which is convenient sampling followed by snowball sampling. However, table 4.1 shows that there are 2 respondents who do not have knowledge regarding the use of drone technology in construction sites. This causes the data of the 2 respondents to be removed from the dataset to improve the accuracy of the data by only using data from the respondents with the knowledge of drone technology. Hence, only the data from the 119 respondents will be used out of the 121 respondents. There are 119 respondents who qualified to participate in this questionnaire survey consists of 61 contractors and 58 consultants. These respondents will be able to represent the construction industry as a whole as there is only a slight difference in number between contractors and consultants.

4.3 Cronbach's Alpha Reliability Test

The feedback from the 119 respondents was analysed by the SPSS to determine Cronbach's Alpha value for each of the objectives. The Cronbach's Alpha value for all of the variables from each objective are within the range of $0.9 > a \geq 0.8$, this indicates a good internal consistency and reliability between the variables.

Table 4.2: Reliability Statistics for the Applications of Drone Technology

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.838	.838	8

Table 4.2 shows the Cronbach's Alpha value of 0.838 for the 8 applications of drone technology to manage construction sites. As the value is within the range $0.9 > a \geq 0.8$, this indicates that the data have good internal consistency and reliability.

Table 4.3: Reliability Statistics for the Benefits of Utilising Drone Technology

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.818	.818	7

Table 4.3 shows the Cronbach's Alpha value of 0.818 for the 7 benefits of utilising drone technology for construction site management. The Cronbach's Alpha value lies within the range of $0.9 > a \geq 0.8$, denoting that the data have good internal consistency and reliability.

Table 4.4: Reliability Statistics for the Barriers of Utilising Drone Technology

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.884	.884	8

Table 4.4 shows the Cronbach's Alpha value of 0.884 for the 8 barriers of utilising drone technology for construction site management. As the value is within the range $0.9 > a \geq 0.8$, this indicates that the data have good internal consistency and reliability.

4.4 Applications of Drone Technology to Manage Construction Site

This section aims to identify the applications of drone technology to manage construction site. The variables are ranked according to the respondent's agreement level and tested to determine if there is any significant difference between contractor and consultants.

4.4.1 Descriptive Analysis for the Applications of Drone Technology to Manage Construction Site

Table 4.5: Descriptive Statistics for the Application of Drone Technology to Manage Construction Site

Descriptive Statistics					
Description	Mean	Mode	Std. Deviation	Variance	Ranking
Inspection Tasks	3.60	5	1.434	2.056	1
Site Monitoring	3.53	5	1.425	2.031	2
Topographic Mapping and Land Surveying	3.30	4	1.356	1.840	3
Safety Management	3.18	4	1.300	1.689	4
Decision Making and Site Management	3.11	5	1.389	1.929	5
Building Surveys	3.04	3	1.285	1.651	6
Time Management	2.92	2	1.470	2.162	7
Logistics Management	2.84	2	1.372	1.881	8

Table 4.5 shows the descriptive statistics for 8 applications of drone technology to manage construction sites. The applications are ranked according to the agreement level of the respondents via SPSS.

"Inspection Tasks" as the application of drone technology is ranked first with a mean value of 3.60. This indicates that the inspection task is the most agreed upon application of drone technology to manage construction sites among the respondents. The mode of 5 shows that the rating 5 (Strongly Agree) is selected most frequently on the 5-Point Likert Scale. It has a standard deviation of 1.434 which outlines the dataset's average amount of dispersion around the mean. Drones are able to replace the need for manual labour on certain tasks such as inspection tasks (Mahajan, 2021). This is because of the constant improvement of technologies that allows the image of the built structure captured by drones to be analysed and detect any deviation from the planned model (Elghaish, et al., 2021). The use of drones for inspection tasks was demonstrated in the case study by Falorca, Miraldes and Lanzinha (2021) showed that the drones are able to access difficult areas with ease due to their excellent manoeuvrability.

Besides, "Site Monitoring" is ranked second on the application of drone technology with a mean value of 3.53. It has a mode of 5 which shows that the rating 5 (Strongly Agree) is selected most frequently on the 5-Point Likert Scale. The standard deviation of 1.425 indicates the dataset's average amount of dispersion around the mean. The use of drones to monitor the site can significantly save time and human resources (Kaamin, et al., 2023). According to Omar, et al. (2022), drones can have a clear overview of the construction site simply by hovering at high altitude. By doing so, project managers are able to effectively keep track of the ongoing activities in the construction site as well as to ensure that the construction activities are being carried out according to the plan (Abdullah, Seow and Mohamed, 2023).

In addition, "Topographic Mapping and Land Surveying" is ranked third on the applications of drone technology with a mean value of 3.30. It has a mode of 4 which shows that the rating 4 (Agree) is selected most frequently on the 5-Point Likert Scale. The standard deviation of 1.356 indicates the dataset's average amount of dispersion around the mean. According to Choi, et al. (2023) the use of drones for topographic mapping and land surveying can be done by installing the suitable software and hardware such as LiDAR sensors, high-resolution camera and mapping software. Li and Liu (2019) mentioned that the use of drone technology to carry out construction tasks remove the need for bulky tools such as tripods, theodolite, prisms and survey markers. By using drones, the time needed to survey the land can be sped up by up to three times faster compared to the conventional method of land surveying (Tjandra, et al., 2022).

Ranked fourth on the applications of drone technology is "Safety Management" with a mean value of 3.18. It also has a mode of 4 that indicates the most frequently selected rating is 4 (Agree). It has a 1.300 standard deviation that shows the dispersion of the data around the mean value. According to Abdullah, Seow and Mohamed (2023), drones can be used for safety management as they are capable of detecting hazardous conditions and highlights the issue before accidents occurred. This is because of the technological advancement that allows drone technologies to use machine learning algorithms to recognise hazardous patterns that led to disasters (Dissanayake and Vithana, 2021). Safety officers are also able to use drones to patrol the construction site to ensure that all personnel are following the safety protocols (Rachmawati and Kim, 2022).

Other than that, “Decision Making and Site Management” is ranked fifth on the application of drone technology with a mean value of 3.11. However, the mode for this application is 5 (Strongly Agree) with a standard deviation of 1.389. This indicates that despite the most frequent selected rating of 5, the dataset is relatively dispersed around the mean value. Having sufficient information regarding the construction site at all times is essential in the decision-making process. According to Elghaish, et al. (2021), drone technology can be used to provide the necessary data for software such as Virtual Design and Construction (VDC) to simulate the construction site and reflect the outcome of each decision made. This is because the data collected can be used to create an accurate virtual model of the actual construction site.

Ranked sixth on the applications of drone technology is “Building Surveys” with a mean value of 3.04. It has a mode of 3 (Neutral) with a standard deviation of 1.285 which is the lowest standard deviation among other applications. This highlights that the data collected on “Buildings Surveys” is the closest to the mean value. Tkac and Mesaros (2019) highlights that drones can be used to survey buildings by hovering over the existing buildings to check for any defects. By doing so, the need for manual labours to climb up the roof top or hazardous area to check for defects is no longer required.

Furthermore, ranked seventh on the applications of drone technology is “Time Management” with a mean value of 2.92. The mode for this application is 2 (Disagree) with the highest standard deviation of 1.470. The highest standard deviation among these applications shows that the agreement level of the respondents collected on “Time Management” is the most dispersed. According to Li and Liu (2019), the image of the construction site can be captured by drones to be processed and used to compare with project design to detect progress deviations. By doing so, project managers can be aware of the activities falling behind schedule and take necessary action to prevent project delay.

Finally, “Logistics Management” is ranked last on the applications of drone technology with a mean value of 2.84. The mode for this application is 2 (Disagree) with a standard deviation of 1.372. Li and Liu (2019) believed that an efficient logistic management will improve the traffic and productivity of the construction site. According to Nooralishahi, et al. (2021), drones can be used to track material and equipment in the construction site via visual image, GPS tracking and radio frequency identification. The use of drones in tracking material and equipment can be done by arranging fixed drones flight schedules (Tjandra, et al., 2022).

4.4.2 Mann-Whitney U Test for the Applications of Drone Technology to Manage Construction Site

Table 4.6: Mann-Whitney U Test for the Applications of Drone Technology to Manage Construction Site

Code	Description	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
A1	Logistics Management	1406.500	3117.500	-1.972	**.049***
A2	Safety Management	1564.000	3275.000	-1.122	.262
A3	Building Surveys	1627.000	3338.000	-.776	.438

Table 4.6 (Continued)

Code	Description	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
A4	Site Monitoring	1689.000	3400.000	-.439	.660
A5	Decision Making and Site Management	1689.000	3400.000	-.434	.664
A6	Inspection Tasks	1693.500	3584.500	-417	.677
A7	Time Management	1701.500	3412.500	-.367	.714
A8	Topographic Mapping and Land Surveying	1733.000	3444.000	-.196	.844

As shown in Table 4.6, A1 “Logistics Management” is the only application which has a P value less than 0.05. This causes the alternative hypothesis (H1) to be accepted for A1 as it has a P value of 0.049. Therefore, there is a significant difference between contractors and consultants in the point of view against A1 “Logistics Management”. According to Table 4.7, the contractors have a higher level of agreement compared to the consultants. Contractor gains experience and knowledge through working in the construction site and carrying out various construction activities to ensure the completion of the project is able to be met (Upwork, 2023). On the other hand, consultants do not have as much exposure to the construction site. This may result in consultants does not understand how drone’s tracking and monitoring capabilities is able to assist in logistics management. This can also be said as consultants do not fully understand the complexity of logistics management and how drones tracking and monitoring capabilities can be used effectively.

Table 4.7: Mean Rank of Applications of Drone Technology to Difference background

Code	Description	Background	Mean Rank	Sum of Rank
A1	Logistics Management	**Contractor**	**65.94**	**4022.50**
		Consultant	53.75	3117.50

On the other hand, the P values for the remaining of the applications such as A2 “Safety Management”, A3 “Building Surveys”, A4 “Site Monitoring”, A5 “Decision Making and Site Management”, A6 “Inspection Tasks”, A7 “Time Management” and A8 “Topographic Mapping and Land Surveying” are greater than 0.05. This indicates that all the applications besides A1 will accept the null hypothesis (H0) where there are no significant differences between the contractors and consultants in the point of view on the applications. Besides A1 “Logistics Management”, other applications have no significant differences may be due to the common knowledge shared between the contractor and consultants. This is said because these applications that are commonly carried out by the contractor does not require much personal experience to understand the tasks and scope embedded within each application. Hence, both contractor and consultants have similar perceptions on how drone technology can be used in managing construction sites.

4.5 Benefits of Utilising Drone Technology for Construction Site Management

This section aims to investigate the benefits of utilising drone technology for construction site management. The variables are ranked according to the respondent’s agreement level and tested to determine if there is any significant difference between contractor and consultants.

4.5.1 Descriptive Analysis for the Benefits of Utilising Drone Technology for Construction Site Management

Table 4.8: Descriptive Statistics for the Benefits of Utilising Drone Technology for Construction Site Management

Descriptive Statistics					
Description	Mean	Mode	Std. Deviation	Variance	Ranking
Reduce Safety Risks	3.71	5	1.398	1.955	1
Improve Data Collection	3.66	5	1.393	1.940	2
Improved Planning and Decision-Making Process	3.28	4	1.365	1.863	3
Improved Quality Control	3.15	4	1.388	1.926	4
Time Saving	3.08	4	1.391	2.076	5
Cost Effective	2.97	4	1.441	1.935	6
Improved Logistics	2.76	1	1.414	1.999	7

Table 4.8 shows the descriptive statistics for 7 benefits of utilising drone technology for construction site management. The benefits are ranked according to the agreement level of the respondents via SPSS.

"Reduce Safety Risks" is ranked first on the benefit for using drone technology in construction site management with a mean value of 3.71. This highlights that "Reduce Safety Risks" is the most agreed benefit for utilising drone technology to manage construction sites among the respondents. The mode of 5 shows that the rating 5 (Strongly Agree) is selected most frequently on the 5-Point Likert Scale. It has a standard deviation of 1.398 which outlines the dataset's average amount of dispersion around the mean. According to Akinradewo, et al. (2022), the utilisation of drones in construction sites significantly reduces safety risks that workers are commonly exposed to. This is because of the drones' ability to navigate through the hazardous conditions of the construction site with ease while the drone operator can be located at a safe area (Airipin, Zawawi and Ismail, 2019). Besides, Safety officers are also able to use drones to monitor the construction site and establish a more efficient line of communication with every personnel on the construction site through the audio system embedded within the drone (Hatoum and Nassereddine, 2022).

In addition, “Improve Data Collection” is ranked second on the benefits for utilising drone technology with a mean value of 3.66. The mode for this benefit is 5 (Strongly Agree) with a standard deviation of 1.393. A study carried out by Kaamin, et al. (2023) showed that the use of drone technologies in data collection is proven to be an effective and valuable tool for professionals to utilise. This is because of the constant improvement of technologies that has significantly enhanced the accuracy and efficiency of data collection and conveying the said data into valuable information (Faraji, et al., 2022). Hence, the collecting data via utilising drones is now more superior in terms of accuracy and speed compared to the conventional method of data collection (Vanathi and Radhika, 2022).

Ranked third on the benefits of utilising drone technology is “Improved Planning and Decision-Making Process” with a mean value of 3.28. The mode for this benefit is 4 (Agree) and the standard deviation is 1.365. According to Onososen, et al. (2023), a well laid out plan is crucial in determining the success of any project. By utilising drones to monitor the construction site, precise and accurate data and information is available for the planning and decision-making of the project (Le Phu, Trang and Khai, 2023). A study by Akinradewo, et al. (2022) shows that project stakeholders are able to plan and make decisions more efficiently as they are able to access the construction site condition conveniently without needing to step foot into the construction site.

Other than that, ranked fourth on the benefits of utilising drone technology is “Improved Quality Control” with a mean value of 3.15. The most frequently selected rating for this benefit is 4 (Agree). The dispersion of the dataset is shown by the standard deviation of 1.388. A study by Onososen, et al. (2023) shows that in the conventional method of inspection tasks, the overall performance and quality of the project heavily rely on the inspectors’ skill and knowledge to detect any defects. The use of drone technology to perform inspection tasks can offer higher quality control as drones are able to reach difficult and hazardous areas and capture images while creating a detailed timeline in which it can be used to track defects needed to be rectified (Hatoum and Nassereddine, 2022).

Furthermore, “Time saving” is ranked fifth among the respondents on the benefit for utilising drone technology. It has a mean value of 3.08 with the mode being 4 (Agree). The dispersion of the data around the mean value is 1.391. According to Airipin, Zawawi and Ismail (2019), an experienced drone operator can save time when carrying out inspection and monitoring tasks as idling time and traveling time are mitigated. In addition, drones that detect defects that were previously unable to be detected by the conventional method can save the project a significant amount of time by avoiding the need to rectify the defects at a later stage (Onososen, et al., 2023).

Ranked sixth on the benefits of utilising drone technology is “Cost Effective” with the mean value of 2.97. Similarly to the other higher ranked benefits, the mode is 4 (Agree) but it has the highest standard deviation of 1.441. This shows that despite the most frequently selected rating being 4 (Agree) the dataset is widely dispersed among the other ratings. The study carried out by Falorca, Miraldes and Lanzinha (2021) highlights that when construction activities are carried out by drone in a timely manner can save cost by reducing the need for rectification.

Last but not least, “Improved Logistics” is ranked last on the benefits for utilising drone technology in managing construction sites. The mean value is 2.76 with the mode being 1 (Strongly Disagree). A study by Hatoum and Nasseredine (2022) shows that the sensors equipped on the drone can identify and track the materials and equipment in the construction site which drastically improves the flow of logistics.

4.5.2 Mann-Whitney U Test for the Benefits of Utilising Drone Technology for Construction Site Management

Table 4.9: Mann-Whitney U Test for the Benefits of Utilising Drone Technology for Construction Site Management

Code	Description	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
B1	Improved Planning and Decision-Making Process	1528.500	3419.500	-1.317	.188
B2	Reduce Safety Risks	1564.000	3275.000	-1.141	.254
B3	Improved Logistics	1563.000	3274.000	-1.121	.262
B4	Cost Effective	1573.000	3284.000	-1.068	.285
B5	Improve Data Collection	1638.000	3529.000	-.725	.468
B6	Improved Quality Control	1693.000	3404.000	-.415	.678
B7	Time Saving	1759.500	3470.500	-.052	.959

Based on Table 4.9, the P values for all the benefits are greater than 0.05 which indicates that the null hypothesis (H0) will be failed to reject. Hence, there is no significant difference between the contractors and consultants as they share the same agreement level in all 7 benefits. The role of both contractor and consultant differs as consultant acts in the interest of their client's needs, and the contractor perform the work themselves. However, they share the common knowledge on how drone technology can benefit construction site management. Hence, both contractor and consultants share the similar ranking perception on the usage of drone technology in construction site management.

4.6 Barriers of Utilising Drone Technology for Construction Site Management

This section aims to outline the barriers of utilising drone technology for construction site management. The variables are ranked according to the respondent's agreement level and tested to determine if there is any significant difference between contractor and consultants.

4.6.1 Descriptive Analysis for the Barriers of Utilising Drone Technology for Construction Site Management

Table 4.10: Descriptive Statistics for the Barriers of Utilising Drone Technology for Construction Site Management

Descriptive Statistics					
Description	Mean	Mode	Std. Deviation	Variance	Ranking
Lengthy Data Processing Period	3.53	5	1.478	2.183	1
Lack of Knowledge and Skill	3.40	4	1.422	2.022	2
Liability and Legal Concerns	3.29	4	1.440	2.074	3
Environmental Factors	3.21	4	1.425	2.032	4
Limited Battery Life	3.11	3	1.326	1.759	5
Low Investment from the Construction Industry	3.11	4	1.407	1.979	6
Safety Concerns	2.97	3	1.429	2.042	7
Emotional Impact Caused to Workers	2.71	1	1.421	2.019	8

Table 4.10 shows the descriptive statistics for 8 barriers of utilising drone technology for construction site management. The benefits are ranked according to the agreement level of the respondents via SPSS.

"Length Data Processing Period" is ranked first on the barriers of utilising drone technology with a mean value of 3.53. The rating 5 (Strongly Agree) is selected the most by the respondents. It has a standard deviation of 1.478 that measures the average amount of dispersion around the mean. Despite the fact that drones are able to collect valuable data, the complexity behind analysing the data will have an impact on the accuracy and reliability of the dataset (Liang, et al., 2023). Because of the lengthy data processing period, companies may be reluctant to opt for using drone technology as they have the impression that the time spent on processing the data is unnecessary. This is because raw data collected by drones serve no purpose until it is analysed and processed into information (Albeaino and Gheisari, 2021). This might potentially cause resistant to change among companies that have no experience with drone technology in fear that the cost for training or hiring professionals to manage the data obtained by drone is unable to yield a greater return on investment.

In addition, the barrier of utilising drone technology being ranked second is "Lack of Knowledge and Skill" with a mean value of 3.40. The mode is 4 (Agree) with a standard deviation of 1.422. Drone operators need to go through specialised training before operating a drone as well as undergo data management and analysis to ensure that drones are utilised efficiently (Liang, et al., 2023). This is especially true when trained drone operators play an important role in complex construction projects as their skill and knowledge impact the outcome of the project (Tjandra, et al., 2022). According to Waqar, et al. (2023), construction companies are hesitant to use drone technology as the skill and knowledge needed to operate drones are essential. This is because drones are vulnerable to damage and maintenance are regularly required, resulting in the need of a skilled operator to tackle any technical difficulties encountered (Albeaino and Gheisari, 2021).

Ranked third on the barriers of utilising drone technology is "Liability and Legal Concerns" with a mean value of 3.29. The rating 4 (Agree) is frequently selected by the respondents with a standard deviation of 1.440. Depending on the nature of the construction project, it can be difficult to obtain permits for operating certain types of drones to meet the requirement (Liang, et al., 2023). Besides, because of drones' ability to travel through the airspace easily and invade the privacy of the public, it can easily cause lawsuits when operating a drone carelessly (Nwaogu, Yang and Chan, 2022). Therefore, it is important for companies to understand and comply with the regulations and laws bound to the usage of drones before carrying out any drone operations. According to Waqar, et al. (2023) many companies find it troublesome to utilise drone technology in construction sites due to the complicated legal issues bound to using a drone.

Furthermore, "Environmental Factors" is ranked fourth on the barriers of utilising drone technology with a mean value of 3.21. The mode is 4 (Agree) with a standard deviation of 1.425. According to Albeaino and Gheisari (2021), drone operations are heavily impacted by weather conditions as bad weather such as heavy rain will damage the electrical component of the drones. As Malaysia is a tropical country, hot weather is a common occurrence and will cause deterioration in the drone's battery life due to prolonged exposure to hot temperatures (York, Al-Bayati and Al-Shabbani, 2020).

Other than that, the barriers "Limited Battery Life" and "Low Investment from the Construction Industry" show the same mean value of 3.11. In the event where the mean value is the same, the variables with the lowest standard deviation will be ranked higher as the data is more clustered tightly around the mean. This means that "Limited Battery Life" will be ranked fifth as it has a lower standard deviation of 1.326 compared to "Low Investment from the Construction Industry" which will be ranked sixth with a standard deviation of 1.407. According to Szostak, et al. (2023), the limited battery life of a drone determines the maximum flight time of the drones. Hence, it is important to consider the flight duration and the time needed to recharge the drone (Ciampa, De Vito and Rosaria Pecce, 2019). However, other construction companies may feel that the investment in drone technology is not justified due to the limited application of drone technology it is able to offer (Waqar, et al., 2023).

In addition, “Safety Concern” will be ranked seventh on the barriers of utilising drone technology for construction site management with a mean value of 2.97. The mode is 3 (Neutral) with a standard deviation of 1.429. According to Yahya, et al. (2021), improper and careless usage of drones in a construction site is hazardous and may cause accidents. A study by Umar (2021) shows that drones have the potential to distract workers and put them in a dangerous situation. Other than that, the risk of the drone collision in the construction site can cause accidents as well (Nwaogu, Yang and Chan, 2022). At a later stage of the construction project, it is even more dangerous when more entities and objects are in the construction site (Brophy, et al., 2022).

Ranked last on the barriers of utilising drone technology is “Emotional Impact Caused to Workers” with a mean value of 2.71. The rating 1 (Strongly Disagree) is the most frequently selected rating by the respondents with a standard deviation of 1.421. Few studies such as Khalid, Namian and Massarra (2021) and Brophy, et al. (2022) shows that the constant monitoring of workers through the drone can cause distraction and discomfort as the workers will feel a sense of distrust.

4.6.2 Mann-Whitney U Test for the Barriers of Utilising Drone Technology for Construction Site Management

Table 4.11: Mann-Whitney U Test for the Barriers of Utilising Drone Technology for Construction Site Management

Code	Description	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
C1	Liability and Legal Concerns	1449.000	3340.000	-1.744	.081
C2	Safety Concerns	1489.000	3200.000	-1.521	.128
C3	Lack of Knowledge and Skill	1548.500	3439.500	-1.208	.227
C4	Emotional Impact Caused to Workers	1629.500	3340.500	-.760	.447
C5	Environmental Factors	1645.500	3356.500	-.672	.502
C6	Lengthy Data Processing Period	1670.500	3561.500	-.543	.587
C7	Limited battery life	1712.500	3423.500	-.308	.758
C8	Low Investment from the Construction Industry Players	1755.000	3646.000	-.076	.939

Table 4.11 shows that the P values of all the barriers are greater than 0.05. This indicates that the null hypothesis (H0) is accepted whereby the contractors and consultants have no significant differences on their point of

view in all 8 barriers. Hence, the contractors and consultants share the same agreement level on all 8 barriers. Both contractors and consultants share a similar perception on the challenges faced by drone technology in construction site management. This is because of their common knowledge in the construction industry.

4.7 Summary

In this chapter, the data collected from 121 respondents were examined and analysed. Only the data collected from 119 respondents out of 121 respondents were qualified to be further analysed. The Cronbach Alpha Reliability Test showed that the data have good internal consistency and reliability. The dataset is then ranked accordingly to the agreement level of the respondents via descriptive analysis. Mann-Whitney U Test also showed that the agreement level on only one of the applications, A1 “logistic management”, has a significant difference between the contractors and consultants. While on the other hand, the agreement level for the remaining applications, benefits and barriers has no significant differences between the contractors and consultants.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter summarises the findings in this research study by outlining the results according to the aim and objectives of the research. The implication of this study as well as the limitation will be highlighted for future researchers to have a better grasp of knowledge regarding the usage of drone technology in construction sites. In addition, the research recommendations also will be included in this chapter to enable future studies to discover more regarding the application of drone technology in construction industry as well as the benefits and barriers for utilising drone technology.

5.2 Conclusions

The construction industry plays an important role in driving Malaysia’s economic growth. As construction projects grow in complexity and size, the need for technologies to adapt to today’s building standards is essential for the growth of the country. Therefore, the fourth industrial revolution presents technologies such as drone technology that can benefit the construction industry. The utilisation of drone technology in the construction industry, especially in the construction site can be an essential asset that could help the construction industry to thrive in the sector. This is due to the advancement of technology that has greatly improved the efficiency and performance of the construction industry. Hence, the construction industry must adapt to the latest trend of technology as it not only helps the industry to keep up with the ever-changing complexity of the project but also thrive to success.

The aim of this research is to explore the application of drone technology for construction site management in Malaysia. The objectives for this research are (1) to identify the application of drone technology to manage construction sites, (2) to investigate the benefits of utilising drone technology for construction site management and (3) to outline the barriers of utilising drone technology for construction site management.

A thorough literature review on all the objectives was carried out in order to have a better grasp of knowledge regarding drone technology from existing research and studies. After that, the knowledge and information gained from literature review is used to design the questionnaire survey that was distributed to contractors and consultants of the construction industry through convenient sampling followed by snowball sampling. A total of 121 respondents participated in the questionnaire survey but only 119 respondents whose data are eligible to be used in this research. The reliability of the data collected from the respondents were first tested by Cronbach Alpha Reliability Test before being analysed through other tests such as descriptive analysis and Mann-Whitney U Test by the SPSS software.

In the first objective, (1) to identify the application of drone technology to manage construction sites, the respondents were given the opportunity to rate 8 applications according to their agreement level. Through descriptive analysis, the top three applications agreed among the respondents are highlighted.

For the Mann-Whitney U Test, all the applications except for Logistics Management have P-values More than 0.05, indicating there is no significant differences on the agreement level among the contractors and consultants. However, the P-value for logistics management is lesser than 0.05, indicating that there is a significant difference on the agreement level between the contractors and consultants whereby the contractors have a higher agreement level compared to the consultants. It is important to note that as time progresses, drone technology will continue to improve, and more applications will be available for the construction industry to utilise. The reason for the applications highlighted in descriptive analysis are the most agreed upon applications among the respondents could be the drone’s ability to provide visual imagery without hassle. The top 3 applications shared a characteristic of requiring observation from professionals such as engineers, quantity surveyors, and even architect. It is also the simplicity of these applications that does not require any output from the technology of drone, as the imagery gathered by the drone is the only input required by the professionals. There may be concerns of whether the data and information generated by the drone technology may be reliable. Hence, the usage of drone allows these professionals to observe the site condition without having to move physically.

Other than that, for the second objective, (2) to investigate the benefits of utilising drone technology for construction site management, the respondents were also tasked with rating the 7 benefits of drone technology according to their agreement level.

After being tested through the Mann-Whitney U Test, it can be seen that there are no significant differences between contractors and consultants on all the benefits as all the variables have P-values more than 0.05. The utilisation of drone technology in managing the construction site offers many benefits that can be taken advantage by the construction industry to further improve efficiency and safety. This is partly due to the hazardous and complex nature of construction site which further enhance the usage of drone technology. Drone technology essential improves the work of the professional as they are able to carry out their tasks quickly and from a safe area.

For the last objective, (3) to outline the barriers of utilising drone technology for construction site management, a total of 8 barriers are rated by the respondents based on their agreement level.

The Mann-Whitney U Test for this objective shows that there are no significant differences between contractors and consultants on all the barriers as the P-values for all the variables exceed 0.05. Some companies may be hesitant to opt for the usage of drone technology due to the barriers presented in this research. It is essential that these barriers are carefully looked into and finding viable solutions to ensure the smooth adaptation of drone technology. Despite that drone technology has many applications and benefits that can be enjoyed by construction stakeholders, the lack of usage by many other construction stakeholders may be their reluctant to try new things that may result in new obstacles. Instead, they rather remain in performing their activities in the conventional method in an attempt to avoid dealing with uncertainty.

In conclusion, the findings and results of this research has highlighted the applications, benefits and barriers of the drone technology in construction site management as well and the agreement level of the respondents have ranked them accordingly. The results from the Mann-Whitney U Test for all the variables in this research are concluded as failed to reject the null hypothesis except for logistic management as there is not any significant difference between the contractor and consultant.

5.3 Limitations of the Study

This study has several limitations that have to be taken into consideration. For instance, the research done in this study is limited to the contractors and consultants in the Klang Valley area. Hence, this research does not represent the global perspective on the applications of drone technology as the data are only collected from a small sample size. Due to this reason, the research reflects more on the tropical climates such as high heat and humidity rather than other climates such as dry climates, temperate climates, continental climates and polar climates.

Other than that, the credibility of the data collected from the questionnaire response are not able to be verified. This is because there is no way of knowing the qualifications and experience of the respondents when they participate in the questionnaire survey. From the descriptive analysis, it can be seen that the standard deviation is in the mid-range where all the respondents have different agreement levels on the topic of drone technology.

Lastly, as technologies are advancing at a fast pace, the validity period of the findings in this study is uncertain as this study may be outdated in the future when further improvement has been made to the drone technology. The validity of this research has to be taken into consideration if it is to be used in future research in order for the capability of drone technology in this research to be able to reflect the future's technological advancement.

5.4 Recommendations for Future Studies

There are several recommendations suggested for future exploration on the application of drone technology in construction site management such as time delegation. Sufficient time is needed to secure a larger sample size and cover a larger area rather than just the Klang Valley area. This is because a large sample size will be more accurate in reflecting the population and a larger coverage area will give more perspective on the applications of drone technology. In addition, the increase in sample size will also improve the reliability of the data collected in which quantitative approach prioritises in collecting and analysing numerical data to identify patterns in order to make predictions. It is also recommended that specific type of projects such as infrastructure, residential and commercial building and industrial project should be focused on future research.

Besides that, the use of both qualitative and quantitative research approaches can be used to provide more detailed information regarding drone technology. This is because drone technology is constantly evolving and interviewing experts in the field of drone technology can be beneficial as they are more experienced and well equipped with the necessary knowledge for the research. The advantage of applying both qualitative and quantitative research approaches is that a more comprehensive understanding and deeper insight of the topic is possible through triangulation of data via combining qualitative data and quantitative data.

Last but not least, it is essential to have a better understanding with the other industry 4.0 technologies such as artificial intelligence, big data, cloud computing and internet of things. This is because drones are also a part of the industry 4.0 technologies, and all the technologies can be integrated or connected with one another. The interconnectivity of the technologies greatly surpass what one component of the industry 4.0 technologies alone can do. Through integration of other technologies with drone technology, the possibility of what drone technology can achieve in the construction industry is beyond imagination.

5.5 Summary

In conclusion, the findings of this study have been outlined in this chapter. This includes the study’s contribution to the construction industry as well as the limitation of the study. Moreover, recommendations aimed to improve the findings of future research have been suggested.

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APPENDICES

Appendix A: Questionnaire Survey

Section A: Demographic Profile

Please select which of the following apply (select only one).

1. Have you ever worked in the construction industry?
   [ ] Yes
   [ ] No, thank you for your participation

2. Do you have exposure to the activities and management that take places in a construction site.
   [ ] Yes
   [ ] No, thank you for your participation

3. Do you have knowledge regarding the use drone technology in construction site.
   [ ] Yes
   [ ] No, thank you for your participation

4. Which is your company background in the construction industry?
   [ ] Contractor
   [ ] Consultant
   [ ] None of the above, thank you for your participation

Section B: Application of Drone Technology to Manage Construction Sites

Please indicate your level of agreement or disagreement with each of these applications

Application of Drone Technology to Manage Construction Sites	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Inspection tasks *e.g. Quality Control, Defects Detection*					
Site monitoring *e.g. Progress Tracking, Identify Problems*					
Topographic mapping and land surveying					
Safety management					
Logistics management *e.g. Equipment and Material Tracking*					
Decision making and site management *e.g. Collect site data in real time*					
Building surveys *e.g. Covers a large span of housing units without the need of scaffolding*					
Time management *e.g. Comparison of planned and built structure to detect progress deviation*					

Section C: Benefits of Utilising Drone Technology for Construction Site Management

Please indicate your level of agreement or disagreement with each of these benefits

Benefits of Utilising Drone Technology for Construction Site Management	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Reduce safety risks *e.g. Reducing the need to access the hazardous site for inspection work*					
Improve data collection *e.g. Faster and accurate data collection*					
Improved planning and decision-making process					
Improved quality control *e.g. Ability to inspect area that are previously difficult to reach*					
Cost effective *e.g. Reducing the need for scaffolding and other equipment to carry out tasks*					
Time saving *e.g. Drone act as a tool that enhances construction site management*					
Improved logistics e.g. Better coordination of materials and equipments					

Section D: Barriers of Utilising Drone Technology for Construction Site Management

Please indicate your level of agreement or disagreement with each of these barriers

Barriers of Utilising Drone Technology for Construction Site Management	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Lack of knowledge and skill					
Liability and legal concerns *e.g. Difficulty in obtaining drone permits, Invasion of privacy*					
Safety concerns *e.g. Distracts workers, Drones collision with other equipments*					
Environmental factors such as strong winds, rainstorm, and bad weathers					
Limited battery life					
Low investment from the construction industry players					
Lengthy data processing period *e.g. Large amount of data needed to be processed and analysed*					
Emotional impact caused to workers in the construction site *e.g. Cause distrust among workers due to constant monitoring*					