EXAMINE THE PERCEPTION ON THE INTEGRATION OF BUILDING INFORMATION MODELLING AND ARTIFICIAL INTELLIGENCE IN CONSTRUCTION PROJECTS

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

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DECLARATION

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

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APPROVAL FOR SUBMISSION

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ABSTRACT

Building Information Modelling (BIM) is becoming a growing data respiratory for the whole project lifecycle. However, the is an absence of approaches to utilise this data and generate value for the construction industry. Artificial Intelligence (AI) has the potential to harness this data gathered in the BIM models to aid in the development of BIM and automate BIM processes. Nonetheless, the potentials of integrating these two technologies have only been briefly mentioned in existing studies and the perception of the probable users of this technology are not demystified. What breakthroughs can this integration achieve for BIM? Do construction practitioners think these breakthroughs are beneficial to them? Are they willing to use these advanced BIM applications in the future and if not, what is obstructing them from doing so? This study attempts to answer these questions through the three objectives which are to identify the applications of integrating AI with BIM in construction projects, to determine the barriers of adopting AI with BIM in construction project and to profile the perception of the construction industry towards the integration of AI and BIM in construction projects. The development of the study and major findings are summarised in the theoretical framework. The applications identified in this study include generative design, construction simulation, 3D coordination and clash detection, automated cost estimation and automated site progress monitoring. The mixed mode method is adopted for this study to gather both quantitative and qualitative data. A total of 145 questionnaire responses were collected and three interviewees were interviewed. The findings revealed that construction practitioners are vastly interested in this integration and they are willing to try this technology. Nonetheless, the high cost of investing in advanced software with AI had led them to think twice about this implementation. Besides, construction practitioners are still slowly shifting from traditional 2D CAD software to BIM adoption. These findings are valuable for the development of BIM automation in construction. Future studies are recommended to develop a detailed prototype for the integration of BIM and AI.

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LIST OF SYMBOLS / ABBREVIATIONS

AI	Artificial Intelligence
ALICE	Artificial Intelligence Construction Engineering
ANN	Artificial Neural Network
BEP	BIM Execution Plan
BIM	Building Information Modelling
BPNN	Backpropagation Neural Network
CAD	Computer Aided Design
CBR	Case Base Reasoning
CDT	Construction Digital Twin
CIDB	Construction Industry Development Board
CNN	Convolutional Neural Network
CPM	Critical Path Method
FM	Facility Management
GAN	Generative Adversarial Network
RBM	Restricted Boltzmann Machines
RICS	Royal Institution of Chartered Surveyors
MEP	Mechanical, Electrical and Plumbing
ML	Machine Learning
MVCNN	Multi-view Convolutional Neural Networks
PPE	Personal Protective Equipment

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CHAPTER 1

INTRODUCTION

1.1 Background

Building Information Modelling (BIM) has grown into the backbone of construction technology and has fast-tracked the digitalisation of the construction industry. The future BIM implementation is predicted to widespread and 84 % of construction industry players in Malaysia are keen to implement BIM (CIDB, 2016). BIM is explained as an "IT-enabled approach that entails creating and storing a digital representation of all structure information in the form of a data repository for various stages of the project (Gu and London, 2010)." BIM models gather a large amount of data in geometric and non-geometric aspects of the whole project life cycle and this data is rarely reviewed after the completion of the projects except for facility maintenance purpose. RICS (2020) revealed that estimates show that about 95% of data in the construction industry is wasted and not utilised in spite of the potential of Artificial Intelligence (AI).

AI has the capability to classify and analyse the information in the BIM models to generate insights for decision making, make precise predictions on performance and detect unforeseen circumstances. AI can be described as the creation of programs that show intelligent manners (Franceschetti, 2018). Predictions generated using AI can only be accurate when a sufficient amount of historical data is analysed which makes the information in BIM models a suitable source of data. The gap between information-oriented technology ideas and conventional construction systems can be mended by BIM environments (Sacks, Girolami and Brilakis, 2020).

Also, there has been rising attention on technological approaches integrating AI power-driven algorithms (Blanco, et al., 2018). The Gartner Hype Cycle for emerging technologies 2020 revealed that AI technologies are predicted to be adopted mainstream in 2 to 5 years (Goasduff, 2020). The expected impact of AI will be significant in a way that the Architectural, Engineering and Construction (AEC) industry can no longer ignore it (Blanco, et al., 2018). AI is becoming a reality and there are already various programs customised for construction that have incorporated AI features and demonstrated their potential in improving construction processes such as site monitoring and safety control. For example, Smartvid.io, Holobuilder and Doxel AI are the AI-powered software that facilitates safety management and site progress monitoring.

AI can be incorporated with BIM as a complementary approach to overcome the limitations in the current BIM software and at the same time speed up the development and incorporation of AI in the construction industry. The emergence of BIM has led to large volumes of diverse data to be collected at all project stages which makes it reasonable to carry out AI techniques to utilise this data (Pan and Zhang, 2021). The information in the existing BIM representations can be harnessed as training data for the AI algorithms and in return, AI can facilitate the automation of BIM processes in the future.

1.2 Problem Statement

Al-Ashmori, et al. (2020) studied the relationship between the benefits of BIM and its influence on BIM implementation. It was founded that the benefits which influence the stakeholder's decision in BIM are to increase productivity, assess time and cost during design amendments, prevent design clashes, enhance communication and monitor construction progress. Also, Azhar (2011) discussed the applications of BIM which include visualisation, fabrication, cost estimating, construction sequencing, collision detections and facility management. Zahrizan Zakaria, et al. (2013) disclosed the barriers in BIM adoption which include lack of demand, training, skilled manpower and rooted in 2D practices. It can be observed that studies on BIM have reached an optimum level over the years.

On the other hand, Hong, et al. (2020) outlined the applications of AI along the building life cycle. This study identified stages that AI can be implemented such as design, construction, operation and maintenance, control and renovation. It also mentioned that BIM is one of the applications of machine learning during the construction stage. Schia, et al. (2020) discussed the potential benefits of AI which include scheduling, safety, storing space, detection of trespassers, robots conducting hazardous works and quality assurance by comparing site situation with BIM. Darko et al. (2020)

summarised the AI techniques applicable to construction which include neural network, machine learning, building information modelling, case-based reasoning, support vector machine, convolutional neural network, expert system, evolutionary algorithm and knowledge-based system.

Pan and Zhang (2021) summarised the roles of AI in construction and mentioned that BIM can act as the digital support for AI and the integration of BIM and AI can modify the traditional paper-oriented task to task managed online. It can be seen that based on the existing studies cited above, the idea of collaborating BIM and AI has only been briefly mentioned and limited studies are concentrating and summarising the potential applications of linking AI and BIM. There is also a certain similarity in the application areas of BIM and AI in construction processes. For instance, BIM and AI both have the potential in facilitating automated site progress monitoring, clash detection, and construction simulation. Thus, this study will focus on identifying the applications of combining AI and BIM and attempts to determine the opinion of construction players towards this integration. This study can let construction practitioners understand the benefits of integrating AI and BIM and the perceptions studied may aid policymakers in creating motivational schemes for this technology to be implemented in the industry.

1.3 Aim

The aim of this study is to determine the perception of the construction industry towards the integration of AI and BIM in construction projects.

1.4 Research Objectives

Three research objectives are established to accomplish the research aim are as follows:

1. To identify the applications of integrating AI with BIM in construction projects.
2. To determine the barriers of adopting AI with BIM in construction projects.
3. To profile the perception of the construction industry towards the integration of AI and BIM in construction projects.

1.5 Research Methodology

In this study, the research methodology adopted is the mixed mode method. The questionnaire survey was used to collect quantitative data and qualitative data is collected through interviews. The data collected from the questionnaire was then examined using descriptive and inferential statistics. Table 1.1 summarises the research methods carried out to achieve the three objectives.

Table 1. 1: Summary of Approached Methods

	Stage 1: Literature Review	**Stage 2: Questionnaire survey and interview**
Objective 1	To identify the applications of integrating AI with BIM in construction projects.	
Objective 2	To determine the barriers of adopting AI with BIM in construction projects	
Objective 3		To profile the perception of the construction industry towards the integration of AI and BIM in construction projects.

1.6 Research Scope

This study will concentrate on collecting data from construction professionals in different fields such as architects, quantity surveyors, and engineers. This is because these professionals are expected to have a better understanding of BIM and can provide detailed information on their experiences with BIM.

1.7 Outline of the Study

This study will begin with the introduction in Chapter 1. This chapter comprises the background, problem statement, aim, objectives, research methodology and research scope. It will include a brief discussion of the current trends of BIM and AI and describe the relevance of this study.

Chapter 2 is the literature review which will assess the current studies on the applications of BIM and AI in the construction industry. Existing studies which attempt to provide solutions to combine AI and BIM will be identified. The benefits and barriers of integrating AI and BIM will also be discussed.

Chapter 3 will outline the research methodology adopted in this study and disclose how data is generated and analysed. The reason for choosing the research method and the instruments used will be described in this chapter as well. Besides, target respondents, data collection methods and analysis of data will also be explained.

Chapter 4 will evaluate the data collected and compile the responses from the construction practitioners towards the integration of BIM and AI. The results will be analysed and discussed with the previous findings in Chapter 2.

Chapter 5 will summarise the results of the study. It will disclose the major barriers in the integration of AI and BIM and the perception of construction professionals towards AI and BIM integration. It will review the limitations faced throughout the study and provide suggestions for further studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Firstly, Section 2.2 and 2.3 of this chapter will define Artificial Intelligence (AI) and Building Information Modelling (BIM). Next, Section 2.4 and 2.5 will identify and briefly explain the applications of BIM and AI independently in construction projects.

Finally, Section 2.6 will review the potential applications of integrating AI and BIM. The last two sections will discuss the benefits of this integration towards the construction industry and the barriers to integrating AI and BIM. Table. 2.1 summaries the studies on applications of BIM in construction.

2.2 Definition of Building Information Modelling (BIM)

The National Building Information Modelling Standard (NBIMS) (2007) defines Building Information Modelling (BIM) as “a digital representation of the physical and functional characteristics of a facility”. Similarly, Lévy and Jeffrey (2019) define BIM as a digital interface that represents a structure system using data-rich, three-dimensional geometry. Salman Azhar, Malik Khalfan, Tayyab Maqsood (2012) defines BIM as a common knowledge platform for information about a facility that serves as a solid foundation for decision making during its life cycle. Correspondingly, BIM is realised as a database ranging with various attributes and relationship of building elements (GhaffarianHoseini, et al., 2017). These definitions describe BIM as a digital database storing information on the structure or building.

Additionally, BIM has been argued to be not just merely software, but it is also a process. Glema (2017) states that BIM is an illustration process that creates and stores multi-dimensional, data-rich views during the lifecycle of a project to aid communication, simulation, and optimisation.

In terms of practice in construction, BIM is a modern approach to planning, construction, and facility management in which a digital representation of the building process is used to promote the sharing and interoperability of digitally stored information (Eastman, 2011). It is an instrument for visualising and coordinating construction work which improves productivity (Chen and Luo, 2014).

In the Malaysian context, BIM is a modelling technology and related collection of processes for creating, communicating, analysing, and using digital knowledge models during the life cycle of a construction project (My BIM, 2017).

2.3 Definition of Artificial Intelligence (AI)

The term Artificial Intelligence (AI) can be explained in separate terms which are artificial and intelligence. The Cambridge Dictionary explains the term artificial as a replica of something natural or something made by people. On the other hand, the Oxford Learner's Dictionary describes the term intelligence as the ability to learn, understand and think logically about things. Thus, AI can be interpreted as a replica of intelligence produced by humans.

Chakkravarthy (2019) defines AI as a wide field of science that focuses on having computers carry out work that would typically require human intelligence. Similarly, Rajagopal, et al. (2018) denotes AI as "a broad field of science surrounding a range of subjects from computer science, psychology, philosophy to linguistics and focuses on getting computers to do tasks that would usually require human input." RICS (2017) defines AI as a branch of computer science with the ability to make intelligent decisions, reasoning and problem-solving. Therefore, AI can be described as part of computer science that can interpret and act like humans.

Furthermore, AI is closely linked to machines. Darko et al. (2020) state that AI symbolizes the science and engineering of producing brilliant machines that show learning and knowledge. AI collects data and attempts to interpret the information for trends and improve the ability of machines to replicate human understanding (Vickranth, Bommareddy and Premalatha, 2019).

Machine learning (ML) is a subgroup of AI which can be described as computational methods using experiences to make precise predictions (Mohri, Rostamizadeh and Talwalkar, 2018). Supervised learning, unsupervised learning and reinforcement learning are the further classifications of ML. Supervised learning is when the accurately labelled training data is provided for machine learning algorithms to create classification hypothesis while unsupervised learning has no such labels available and learns hidden patterns and groups data (McArthur, et al., 2018). Moreover, reinforcement learning is a machine learning technique where an agent interacts with an environment that provides reward indicators to aid the agent in decision making (Vasilev, et al., 2019). A further subset within ML in AI is deep learning which imitates the functions of the human brain (Sree, Vyshnavi and Jayapandian, 2019).

2.4 Applications of Building Information Modelling (BIM) in Construction

BIM has evolved from focusing on the project to the entire asset life and practitioners are incorporating "dimensions" to the BIM model (Saxon, 2018). There are five dimensions of BIM which include 3D models for providing geometric information and three- dimensional modelling, 4D models for the planning process, 5D models which relates to cost, 6D models which facilitate sustainability and 7D models which relates to facility management (Charef, Alaka and Emmitt, 2018).

This section will describe the implementation of BIM in schedule management, quantity takeoff, prefabrication planning, quality management and facility management. Table 2.1 summarises the previous studies on the applications of BIM in construction.

2.4.1 Schedule Management

Conventionally, the preparation of the construction schedule is done by using hand-drawn programmes and networks such as critical path methods (CPM) (Gledson and Greenwood, 2016). Nonetheless, Koo and Fischer (2000) pointed out that interpreting and identifying the errors in the CPM schedule can be challenging due to the abundant activities listed and assumptions for the precedence relationships that are not available in the schedule. 4D BIM can provide a visualisation of the schedule in 4D-animation and present the relationships between construction activities (Andersson and Büchmann-Slorup, 2010).

BIM can provide an actual construction animation simulation by specifying the intended completion period (Azhar, 2011). Besides, the collision of various professionals can be checked in advance to mitigate late changes (Li, Xu and Zhang, 2017). Actual work progress can also be tracked and schedule delay effects can be analysed if 4D modelling is combined with onsite production control methods (Jupp, 2017).

2.4.2 Quantity Takeoff

Lee, Kim and Yu (2014) define cost estimation as the practice of estimating project costs and resource needs. Normally, the estimator takes down the quantities manually which can result in human errors and the design discrepancies can be reflected in the cost estimates. BIM allows the material quantity and detailed measurements to be mined straight from the model and all construction documentation and schedules will automatically be corrected when any change is made in the model design (Elbeltagi, et al., 2014).

BIM tools can extract sums of material quantities, area and volume, and input this information in schedules which can provide sufficient information to generate approximate estimates of higher accuracy (Eastman, 2011). For example, the Autodesk Revit and Vectorworks software both enable the automatic generation of quantity takeoffs (BIMplus, 2015; Vectorworks, 2021) Although BIM only automates quantification and is unable to generate direct cost estimates, it can minimise manual takeoffs and provide accurate quantities (Autodesk Inc., 2007).

Furthermore, Eastman (2011) has provided four primary means of extracting quantities from BIM Models which include transferring the quantities to estimating software through reporting features of the BIM interface, using a patented add-in tool, using model exchange formats or exporting BIM object models including geometry to multifunctional construction management software tool.

2.4.3 Prefabrication Planning

Prefabrication will accelerate project delivery by permitting participants to manage projects from design through to real-world assets with the least amount of waste, cost and supply-chain overheads (Autodesk and CIOB). Nevertheless, fabricating the Mechanical, Electrical and Plumbing (MEP) systems are challenging (Tatum and Korman, 2000). The incorporation of BIM facilitates modular building technologies adoption as the entire planning, design, manufacturing process can be streamlined and physical conflicts between MEP system components can be detected and resolved with ease (Lu and Korman, 2010).

Besides, BIM makes automate modelling and detailing of components possible and contractors can communicate efficiently with fabricators using precise information in the BIM models (Eastman, et al., 2018). For instance, the BIM software named Allplan enables the automatic design of precast fabrication to improve the precision in precast concrete planning (ALLPLAN, 2021). Besides, virtual prototyping adopted in BIM can diminish errors and permit fabricators to contribute to preplanning (Eastman, 2011).

2.4.4 Quality Management

BIM has provided a way to enhance overall project quality (Bynum, Issa and Olbina, 2013). Quality management processes require unique, exact, timely, comprehensive, accessible, valid and dependable information to achieve maximum performance (Marsden, 2019). BIM can generate a construction quality model by utilising the design information to ensure information consistency. For instance, errors due to the confusion of cross-reference codes can be prevented by inserting standardised construction codes into the model (Chen and Luo, 2014). Marsden (2019) suggests that coordinating all design information requirements gathered into the BIM Execution Plan (BEP) can mitigate quality management information gaps or eliminate duplicate information. The BEP model will contain the agreement's conditions as well as the criteria for information exchange (Mcpartland, 2017). Also, BIM guarantees timely inspections and visualisation of the entire construction process which allows stakeholders to have a better understanding of the quality requirements acceptance (Chen and Luo, 2014). The Solibri Model Checker link in ArchiCAD software, which checks models, architectural and structural designs for quality and code compliance, is an example of using BIM for quality assurance (GRAPHISOFT, 2021).

2.4.5 Facility Management

Facility management is described as the building stage that covers the financial administration of funds for the operation and upkeep of a facility (Kassem, et al., 2015). 6D modelling can be classified as the incorporation of BIM and facility management (Pärn, Edwards and Sing, 2017). It can improve manual processes of information handover which leads to better-managed facilities (Olapade and Ekemode, 2018). Besides, BIM provides a source of information for facilities that can assist the facility manager in decision making during the building operation (Aziz, Nawawi and Ariff, 2016). Eastman, et al. (2018) described that BIM stores information about basic facility elements like door hardware, finishes, and light fixtures, and maintenance records such as failure areas and issue types which are extensively used in facility management activities.

Besides, Motamedi, Hammad and Asen (2014) helped facility management technicians to solve maintenance problems using BIM visualisation capabilities and Cheng, et al. (2020) improved the viability of implementing a dynamic maintenance strategy in facility maintenance management (FMM) with the use of BIM.

Table 2. 1: Summary of BIM Applications

	Previous Studies														
Applications of BIM	Aftab Hameed Memon, et al. (2014)	Andersson and Rolf Büchmann-Slorup (2010)	Azhar (2011)	Aziz, Nawawi and Ariff (2016)	Bynum, Issa and Olbina (2013)	Chen and Luo (2014)	Cheng, et al. (2020)	Emad Elbeltagi, et al. (2014)	Jupp (2017)	Li, Xu and Zhang (2017)	Lu and Korman (2010)	Marsden (2019)	Motamedi, Hammad and Asen (2014)	Olapade and Ekemode (2018)	Pärn, Edwards and Sing (2017)
Schedule Management	•	•	•						•	•					
Facility Management				•			•						•	•	•
Quality Management					•	•						•			
Quantity Take-off								•							
Prefabrication Planning											•				

2.5 Applications of Artificial Intelligence (AI) in Construction

Besides BIM models, data can be gathered with ease in sites using cloud-based applications and mobile devices. AI can provide unseen visions of these data which is difficult to be interpreted by human understanding to improve the performance, quality and safety aspects of construction (Vickranth, Bommareddy and Premalatha, 2019).

Existing applications of AI in safety management, risk prediction, site progress tracking will be discussed in this section. Potential applications which include constant design optimisation and optimisation of supply chain management and transportation routes are disclosed as well. Table 2.2 shows the AI-based software for construction. Table 2.3 shows the summary of the previous studies for AI applications.

2.5.1 Safety Management

Physical safety is one of the struggles faced by the building industry workforce as hundreds of workers are lost annually due to worksite injuries and fatalities (Nnaji and Karakhan, 2020). AI programs can provide precise data to aid constructors in optimising safety on site (Chakkravarthy, 2019). AI enables the prediction of potential problems and safety managers can direct their planning and training efforts to those problems and pay attention to specific issues during their safety walk (Autodesk and CIOB). Furthermore, AI technologies have emphasised ensuring the safety of site personnel by providing systems that can inform operators with warning messages and using robotics to replace humans in conducting hazardous work (Chakkravarthy, 2019).

Gadd, Keeley and Balmforth (2004) highlighted that AI tools can be utilised to smoothen the hazard identification process. For instance, Goh and Chua (2010) proposed a Case-Based Reasoning (CBR) method to facilitate feedback from past experiences. It included a hazard identification tree that instinctively collects past incidents and removes irrelevant incident events. These records are exploited to facilitate a new hazard identification process (Goh and Chua, 2009). Tixier, et al. (2016) proposed a framework adopting machine learning models such as Stochastic Gradient Tree Boosting (SGTB) and Random Forest (RF) to forecast safety consequences or characteristics such as body part injured and injury type based on contractor injury reports. Both models achieved a high predictive skill which proves the possibility of detecting underlying patterns based on sufficient data sets. Yu, et al. (2019) created a computer vision-based 3D motion capture algorithm using Convolutional Neural Networks (CNN) to model the body part motions of construction workers to automatically assess the joint level physical fatigue of workers. CNN are a form of deep neural networks for analysing visual imagery (Darko, et al., 2020).

Additionally, Fang, et al. (2018) suggested the use of CNN to automatically detect construction workers not wearing hard hats and the method demonstrated high accuracy and speed. Correspondingly, Nath, Behzadan and Paal (2020) adopted CNN to determine whether workers are wearing other personal protective equipment (PPE) such as safety vests. Moreover, there is already software that performs similar functions. To illustrate, Smartvid.io is a software that provides a platform to gather all photos and utilises AI to understand and categorise the photos using 'Smart Tag' engines (Rajagopal, et al., 2018). The primary features of Smartvid.io include safety observations by taking pictures, safety monitoring using construction-tuned AI to review data and predictive analytics which identifies risk using AI-based models (Smartvid.io, Inc., 2020). Also, Agmis developed an Easyflow CV software that detects workers not wearing PPE and alerts the site safety officer immediately (BIMplus, 2019).

2.5.2 Risk Prediction

Risks may be found in various project stages and risk management has a direct influence on the project success in relation to time and cost (Zou, Kiviniemi and Jones, 2017). A huge impact will be brought by ML and AI on reducing the project management risks at the construction site (Autodesk and CIOB). Firstly, Construction IQ in the BIM 360 software harnesses data from BIM 360 Field and adopts analytical techniques and ML to convert data into simple insights (Autodesk, 2020). As an example, if a quality manager notices a problem with a faulty window and records it in the BIM 360 Field, AI algorithms will review the data and mark it as a possible water issue in the dashboard. (Rajagopal, et al., 2018). The daily risk assessment feature uses algorithms to review project issues and to classify and rank the highest risk projects, subcontractors, and issues that require attention (Autodesk, 2020). The example of the dashboard of the risk assessment is shown below in Figure 2.1.

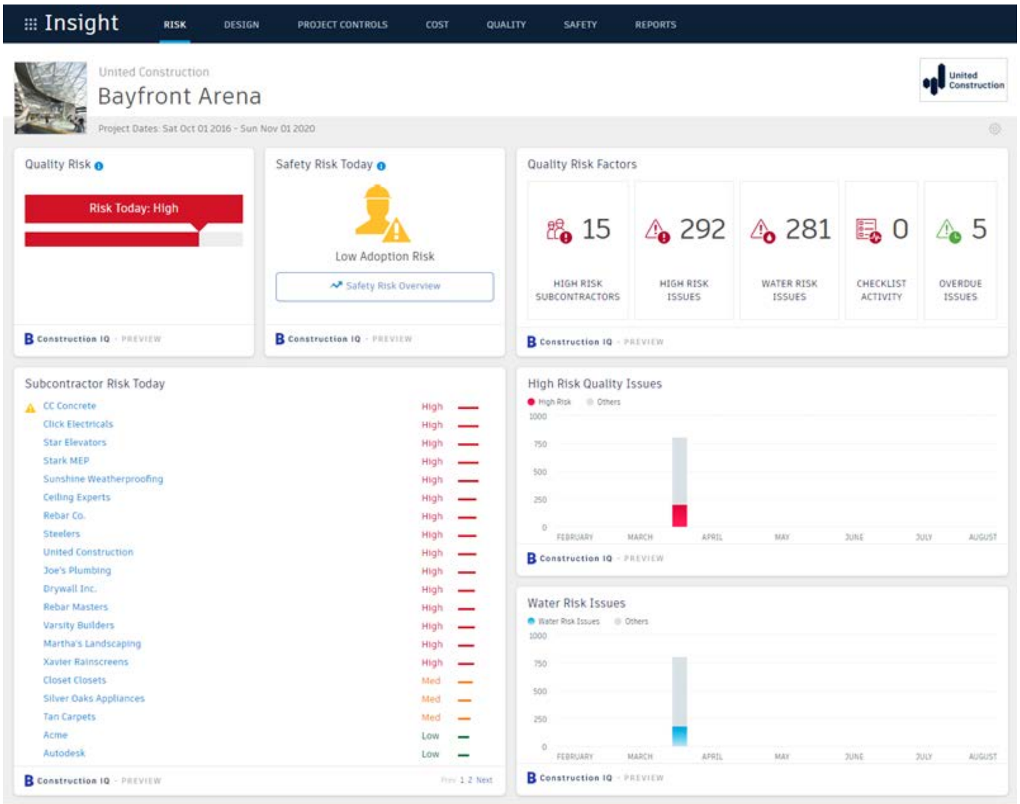

Figure 2. 1: Dashboard of the Risk Assessment

(Source: Autodesk (2020))

Furthermore, Gondia, et al. (2020) conducted a study that used ML algorithms to create delay risk predictive models. This ML analysis approach could allow project managers to determine the time performance of projects in an early stage and continuously update and compute realistic estimates of project duration during construction. Elhag and Wang (2007) proposed a framework for bridge risk evaluation utilising Artificial Neural Networks (ANN) and back-propagation algorithms which can provide valuable data to aid in bridge management and repair decisions. The neural network model can learn complicated relationships between bridge risk and risk factors based on previous experience.

Moreover, Liu, et al. (2020) developed a model for a safety risk optimisation system for prefabricated buildings by combining deep learning algorithms named as Backpropagation neural network and a traditional Modified Teaching- Learning -Based-Optimisation (MTLBO) algorithm to decide the optimum project allocation scheme and enable smart decision-making in prefabricated construction projects.

2.5.3 Site Progress Tracking

AI-based software to facilitate site progress tracking include Site AI by Holo Builder, Doxel AI, Disperse and Indus. Ai. Site AI adopts deep learning to enable progress to be tracked and compared to the actual schedule by analysing building components taken in 360-degree imagery data on the Holo Builder platform (BIM plus, 2018).

Additionally, Doxel AI produces autonomous robots using AI to perform site inspections and gather data on the level of progress (BIM plus, 2018). The robots will capture photos and laser scans daily and AI algorithms will measure the progress and check quality to allow early identification of problems (Doxel, 2020). Correspondingly, Indus Ai provides AI computer vision where the AI engines record and interpret live video streams and photos to detect and report progress and deviations to contractors (Indus.ai, 2018). Disperse is another AI-based construction software that creates an interactive digital twin with analytical features by incorporating schedules, plan drawings, 3D models and site photos and processing them with proprietary AI (Cousins, 2019).

2.5.4 Constant Design Optimisation

Supervised learning techniques like a recommender program can help employers and contractors to make informed decisions by using cluster behaviour production to assess the data needed to make a recommendation on design. Engineers and architects may use this technique to decide on the application of a certain design, such as structural designs or building finishes. (Blanco, et al., 2018). Furthermore, Wang (2020) proposed a design optimisation approach based on AI for asphalt pavement design and this approach produced a better design in terms of adhesion and firmness as competed to traditional methods. Akinosho, et al. (2020) suggested that CNN can be adopted to find the requirements and constraints of the building and Generative Adversarial Networks (GANs) can then be trained using building images and utilised to produce contextual design solutions.

Besides, a global engineering firm named Robert Bird Group developed software to optimise the structural frame of high rise buildings using parametric design or referred to as computer generated design. The software produced organic framing patterns such as an efficient external bracing design which supports the whole frame and minimises the need for thick lift core walls with increased structural performance (BIMplus, 2019).

2.5.5 Optimisation of Supply Chain Management and Transportation Route

Supervised learning applications such as Gradient Boosting Trees can be applied to the building industry due to the widespread of modularisation and off-site construction. Better supply chain management will be required to monitor cost and cash flows (Blanco, et al., 2018). Also, reinforcement learning has the potential to improve optimisation in construction planning and scheduling by examining unlimited options based on similar projects to optimise the best transportation route and provide constant correction (Blanco, et al., 2018). AI predicting algorithms and AI-enhanced project management software can identify possible delays of the construction progress and automatically inform the supply chain to modify their projections (BIMplus, 2020).

Table 2. 2: Summary of Software Powered by AI

Applications of AI	Software
Safety Management	Smartvid.io, Easyflow CV
Risk Prediction	Autodesk BIM 360
Site Progress Tracking	Site AI, Doxel AI, Disperse, Indus.ai
Constant design optimisation	-
Optimisation of supply chain management and transportation route	-

Table 2. 3: Summary of the Previous Framework for AI Applications

Applications of AI	AI techniques/algorithms	Previous Study
Safety Management	- Case-Based Reasoning (CBR)	Goh and Chua (2010)
	- Random Forest (RF) - Stochastic Gradient Tree Boosting (SGTB)	Tixier, et al. (2016)
	- Convolutional Neural Networks (CNN)	Yu, et al. (2019), Fang, et al. (2018), Nath, Behzadan and Paal (2020)
Risk Prediction	- Machine learning algorithms	Gondia, et al. (2020)
	- Artificial neural networks (ANN) - Back-propagation algorithms	Elhag and Wang (2007)
	- Backpropagation neural network - Modified Teaching-Learning -Based-Optimisation (MTLBO) algorithm	Liu, et al. (2020)
Site Progress Tracking	-	-
Constant Design Optimisation	- Generative Adversarial Network (GAN) - Convolutional Neural Networks (CNN)	Akinosho, et al. (2020)
Optimisation of supply chain management and transportation route	- Gradient Tree Boosting (GTB) - Reinforcement Learning	Blanco, et al., 2018

2.6 Applications of integrating Building Information Modelling (BIM) and Artificial Intelligence (AI)

The role of BIM can be reshaped and enhanced by AI by identifying lost components, and prewarming of conditions that have been beforehand recognised as unsafe, potentially inoperable or judged to be undesirable against defined criteria (RICS, 2017). Deep learning will be useful in BIM platforms for code checking, quality checking and design guides. (Eastman, et al., 2018). Applications of BIM and AI integration include generative design, construction simulation, 3D coordination and clash detection, automated cost estimation and automated site progress monitoring. Table 2.4 shows the software integrating AI and BIM available. Table 2.5 shows the summary of the previous study for AI and BIM integration.

2.6.1 Generative Design

BIM can enable the applications of AI and ML to detect patterns and provide solutions using generative design (BIMplus, 2020). Generative design means to automatically produce countless design alternatives based on defined design requirements such as functional specifications, material type, construction process, performance requirements and cost constraints and enables designers to evaluate and review the design produced to their expectations (Bilal, et al., 2016). Sepehr Abrishami, et al. (2013) explains generative design as any design activity in which the designer solves the design problem with certain autonomy using a system, such as a computer programme and proposed a Generative BIM framework for creating alternative conceptual designs, modifying the alternatives with the parametric algorithm in BIM. This enables important decisions to be made during the early conceptual phase and permits the production of complex forms with details and layout which were initially impossible.

Generative design software permits the designers to input their design criteria along with restrictions and the software explores possible permutations of the solutions and design alternatives (Autodesk, 2020). As an example, an Autodesk generative design beta named “Project Refinery” works with Dynamo for Revit and allows designers to generate design choices, set requirements, and optimise the design for those requirements (Vermeulen and Mostafa El Ayoubi, 2020). Figure 2.2 below shows the evolution from traditional design to generative design and the development of design software provided by Autodesk.

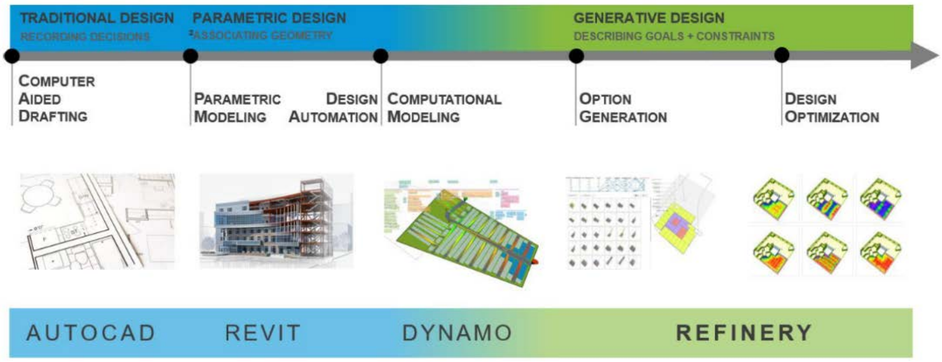

Figure 2. 2: Evolution from Traditional Design to Generative Design (Source: Vermeulen and Mostafa El Ayoubi (2020))

Besides, Autodesk had introduced generative design as a feature in the Revit 2021 software which includes key customisable uses such as Three Box Massing, Maximize Window Views, Workspace Layout and Customisable Studies to enable users to use algorithmic problem solving techniques to make quicker informed decisions (BIMplus, 2020).

2.6.2 Construction Simulation

4D simulation refers to the simulation of the building process by connecting planned construction activities to 3D objects in a building model (Boton, Kubicki and Halin, 2015). 4D scheduling-based models can provide simulations of construction activities which improves the construction timeframe, quality, and safety control (GhaffarianHoseini, et al., 2017). It can be described as a visualisation tool that aids in the early detection of physical limitations and uncertainties, allowing mitigating steps to be implemented on time (Huang, Ninić and Zhang, 2021). As compared to conventional manual scheduling approaches, the ability to use information stored in BIM to facilitate schedule production could help accomplish substantial time savings (Kim, et al., 2013). Feng, Chen and Lu (2018) proposed a machine learning-based simulation and optimisation using process data such as construction cost and duration which had a shorter computing time compared to traditional practices.

Eastman, et al. (2018) suggest that there will be more efficient conversions from designed BIM models to building models using software parametric templates with information on construction methods. The construction models generated can be reviewed for cost and schedule needs and different options can be compared which facilitates construction planning. As an illustration, the Vico Office software provides modules such as Schedule Planner, Takeoff Manager and Cost Planner which can be integrated with 3D models to provide an intergraded platform for estimating, scheduling and design modelling (Trimble, 2020). The BIM approach utilising the Vico Office software allows a faster and easier comparison of cost and construction time (Zoran Pučko, Anja Pavličič and Nataša Šuman, 2017).

Also, an AI-based software for construction planning named Artificial Intelligence Construction Engineering (ALICE) generates detailed schedules and resource allocations using BIM models, which can correctly evaluate the cost and duration of a project. Besides, it can provide interactive visualisation and allow users to adjust a schedule to suit the actual construction (BIM plus, 2018). The ALICE software starts with a BIM model, provides alternative activities, various alternative plans with distinct team structures and technique and suggests the best construction plan (Eastman, et al., 2018).

2.6.3 3D Coordination and Clash Detection

Design clashes include “positioning errors” where structure elements overlap each other when the isolated BIM design models are combined. Initially, clash detection using BIM models is time-consuming as BIM managers need to manually access the BIM models and evaluate the type of clashes before they can be resolved (Pärn, Edwards and Sing, 2018). Moreover, model coordination systems such as EXPRESS Data Manager, Solibri Model Checker, and BIM 360 still need human input (Hsu, et al., 2020).

Hsu, et al. (2020) proposed a knowledge-based system by producing a knowledge model using feedback from contractors and optimising a mechanical, electrical and plumbing (MEP) layout to mitigate clashes. This framework resolved clashes by utilising the clash resolution expertise and using a parallel backpropagation neural network (BPNN) learning procedure to train the collected data. Backpropagation neural network (BPNN) is a well - known ANN

(Liu, Jing and Xu, 2016). The technique of heuristic optimisation was also adopted to minimise the clashes using the application programming interface (API) provided by Revit (Hsu, et al., 2020).

Furthermore, Generative Design MEP or "GenMEP" is an auto-routing software that routes ductwork and piping while avoiding the structural or other MEP information produced (Allen, 2017). ClashMEP is another add on software that inserts clash detection features to Autodesk Revit and eliminates the need to export files to other model collaboration systems such as Autodesk Navisworks (Building System Planning Inc, 2017).

In addition, Liu, et al. (2020) advocated a framework for the automatic creation of clash free reinforcement designs for reinforced concrete joints using BIM and the multi-agent reinforcement learning (MARL) system. This framework showed results that reduce the engineering time, prevent spatial rebar clashes and provide efficient rebar designs compared to the manual arrangement by the designer.

2.6.4 Automated Cost Estimation

A reliable cost estimating system is required to outline budgets and produce financial management plans (Elbeltagi, et al., 2014). BIM models and as-built models store actual cost information for each component in the model which provides a suitable source of data for training ANN for cost estimating (Juszczyk, 2017). Ma and Wei (2012) outlined the fundamental requirements of automatic construction cost estimation based on BIM which include intelligent acquirement of construction information not in the BIM model, sorting of construction elements into cost items automatically and automatic quantity takeoff and proposed a framework using data from the design model and history data to perform these functions. Aram, Eastman and Sacks (2014) proposed a knowledge-based system to produce quantity takeoffs and cost predictions based on 3D parametric models. Lee, Kim and Yu (2014) suggested an ontological inference process to automate the process of searching suitable work items using BIM data and eliminates the need for the input of the cost estimator's opinion.

Traditional construction cost estimation methods often overlook changes in economic variables and indexes which can influence the actual construction cost (Akinosho, et al., 2020). Thus, Rafiei and Adeli (2018) used a deep learning method called Restricted Boltzman Machines (RBM) to consider economic variables and indexes that achieved acceptable accuracy. RBM are neural networks that learn in both supervised and unsupervised ways on input probability distribution, making them useful for detecting variances (Fischer and Igel, 2012).

As for the software providing similar features, Kreo Software Ltd developed an AI-based software programme named Kreo Plan which can take off quantities, generate cost estimates by utilising the information in a BIM model which can operate as a Revit plugin (Chevin, 2018). The Kreo software uses machine learning to categorise BIM model elements and generates its cost database by collecting public data using an AI engine (Kreo Software Ltd, 2020). HoloBIM is another BIM software application using AI for earthquake resistance reinforced concrete buildings (Konstantinidis, 2018). It generates all materials quantity take-off based on the BIM data (Building How, n.d).

2.6.5 Automated Site Progress Monitoring

The procedure of monitoring the progress on site and inserting it in a BIM model is error prone and requires intensive labour due to the abundant amount of site data generated (Pour Rahimian, et al., 2020).

Pour Rahimian, et al. (2020) suggested a hybrid system with the ability to import and process site photos and integrating them into a game like immerse Virtual Reality environment (VRE). The prototype used ML and image processing in eliminating unrelated elements, identifying and harnessing building characteristics and covering these on the equivalent designed elements. However, a large amount of training data containing correctly label images is required to train the ML techniques and generate accurate results and the process of manually labelling site photos can be time-consuming (Braun and Borrmann, 2019) Thus, Braun and Borrmann (2019) proposed the use of automatic labelling by utilising the combined information from the photogrammetric process and the 4D BIM. The training sets generated are used to facilitate the training of CNN in learning the similarities and making assumptions. Figure 2.3 below shows an example of the auto-labelled columns in a site photo.

Figure 2. 3: Example of Auto-labelled Columns

(Source: Braun and Borrmann (2019))

Similarly, Golparvar-Fard, et al. (2015) proposed using daily as-built images for an automated monitoring system by producing an integrated 4D as-built and as-planned model. The study utilised images as training data and trained a classification model to forecast new images and image classification was utilised for progress monitoring. Besides, the study proposed the automated detection of physical progress using a ML method based on a Bayesian probabilistic model. The model proposed utilises both the as-planned models and unorganised site photos to inspect whether constructed building elements are absent due to obstructions or alterations. Figure 2.4 below shows an example of the visualised progress of a project in the 4D augmented reality environment.

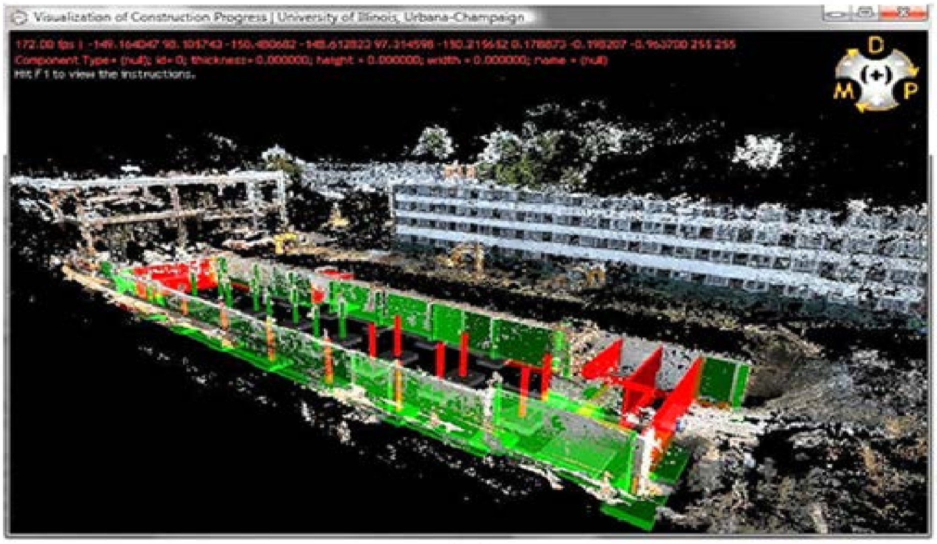

Figure 2. 4: Visualised Progress of a Project

(Source: Golparvar-Fard, Peña-Mora and Savarese (2015))

The elements which are on schedule are colour coded in green while the missing elements are coded in red. The elements remain grey if the information on the progress on site is not available.

Automated progress monitoring software includes ReCap Pro, Scan to BIM and Visual Command Center. ReCap Pro by Autodesk is a scanning software to create 3D models of contemporary site situations using photographs and laser scans (Autodesk, 2020). The 3D model generated can be exported to Revit to be developed into a more detailed design (Autodesk, 2020). Scan to BIM is a software created by Imaginit Technologies and enables point cloud integration with Autodesk Revit. It involves features such as assisting in the creation of Revit elements, automated recognition of pipe and wall batches over a Revit Point Cloud, align existing geometry to match the point cloud and provides workflow based tools to quality check the model with the point cloud (IMAGINiT Technologies, 2021). Additionally, Reconstruct developed a software named Vision Command Center which allows 360-degree images on 3D models to facilitate progress monitoring (Reconstruct, 2019).

Table 2. 4: Summary of Software combining AI and BIM

Applications of AI and BIM integration	Software
Generative Design	Autodesk Revit 2021
Construction Simulation	Vico Ofice, ALICE
3D Coordination and Clash Detection	GenMEP
Cost Estimation	Kreo Plan, HoloBIM
Automated Site Progress Monitoring	ReCap Pro, Scan to BIM, Visual Command Center

Table 2. 5: Summary of the Previous Framework for AI and BIM Integration

Applications of AI and BIM integration	AI technique/algorithms	BIM input	Previous Study
Generative Design	Evolutionary algorithm	Combining generative design with an existing parametric algorithm in BIM tools	Sepehr Abrishami, et al. (2013)
Construction Simulation	-	-	-
3D Coordination and Clash Detection	Backpropagation Neural Network (BPNN) Heuristic Optimisation	Utilising the application programming interface (API) in BIM software as a portal to detect clashes	Hsu, et al. (2020)
	Reinforcement learning algorithm	Extracting information from the BIM model	Liu, et al. (2020)
Automated Cost Estimation	Knowledge based system	Filtering design information from the BIM model to determine cost behaviour	Aram, Eastman and Sacks (2014)
	Ontology-based approach	Using BIM data to search for appropriate work items	Lee, Kim and Yu (2014)
Automated Site Progress Monitoring	Convolutional Neural Networks (CNN)	Combining information from photogrammetry and BIM model	Braun and Borrmann (2019)
	Bayesian probabilistic model	Combining the as-planned model in BIM with site photos to produce an as-built model	Golparvar-Fard, et al. (2015)

2.7 Benefits of integrating Artificial Intelligence (AI) and Building Information Modelling (BIM)

This section will describe the benefits of the applications integrating BIM and AI and the advantages of this integration for the development of construction digital twins.

2.7.1 Benefits of Applications

AI can improve the capabilities of BIM in terms of design and construction (RICS, 2017). First of all, BIM insufficiencies at the conceptual design stage can be resolved by the integration of BIM and generative design (Sepehr Abrishami, et al., 2013). Designers can promptly review possible design solutions and different alternatives which saves time through generative systems (Narahara and Terzidis, 2006). Next, 4D simulation by linking the BIM model to the schedule can facilitate the communication of schedules between employees by providing a clearer understanding and can also assist in resource management by providing a summary of the material and labour resources (Vico Office, n.d).

Furthermore, clashes in the design are unavoidable and it would be tedious to detect and prevent clashes manually (Liu, et al., 2020). Thus, BIM models facilitate visualisation in construction planning and clash detection can detect and eliminate insignificant errors to reduce the risk of cost overruns (Savitri, Juliastuti and Pramudya, 2020). Moreover, although BIM tools can generate the quantities of materials automatically, it is unable to provide information on the cost of building elements and materials. AI can improve BIM by giving ease to the cost estimator to use BIM data (Lee, Kim and Yu, 2014). The construction industry can fully utilise AI and BIM techniques to improve the accuracy of preliminary cost estimates (Soto and Adey, 2016).

Besides, the variations in reporting skills and attitude in recording site information in the conventional method can lead to mistakenness and inconsistency (Elazouni and Salem, 2011). Integrating AI with BIM for automated site progress monitoring can provide an average accuracy of up to 90 % (Han and Golparvar-Fard, 2014). Also, the time needed for gathering as-built data collection, as-planned data collection and discussing the coordinating process can be reduced which leads to improved project control (Golparvar-Fard, Peña-Mora and Savarese, 2015).

2.7.2 Development of Construction Digital Twins (CDT)

Rasheed, San and Kvamsdal (2020) define a digital twin as a digital representation of a physical property that can be used for real-time prediction, optimisation, tracking, control, and enhanced decision making through data and simulators. It enables the exploration of the physical world in a quicker, more economical way with minimised risk and allows ML models to explore and optimise the virtual worlds to identify solutions that exceed human ability. Systems can be tested by exposing them to potential agitations and a disturbed system can be restored to its initial state (BIMplus, 2020). Boje, et al. (2020) outlined the Construction Digital Twin (CDT) smart services which include automated site progress monitoring, real-time visualisation, nD BIM clash detection simulation, optimised construction logistics and scheduling. These smart services are similar to the applications of integrating AI and BIM such as automated site progress monitoring, construction simulation and clash detection.

BIM is considered an important source of data for digital twins and plays a role as a 3D reference model for the digital twin. BIM is equipped with sensor and time data to compute stimulations for energy, safety, user comfort in parallel. (Boje, et al., 2020).

Furthermore, AI enables digital twins to forecast, optimise and make decisions enthusiastically (Boje, et al., 2020) and using ML and AI for smart data analysis is predicted to play a significant role in digital twins (Rasheed, San and Kvamsdal, 2020). For example, generators trained within GAN have the ability to generate data that is indistinguishable from real data (Hutchison, et al., 2012). Therefore, it has the potential of improving data quality such as improving image resolution and filling missing data which are suitable in the digital twin aspect (Goodfellow, et al., 2014). Also, the supervised algorithm can make forecasts or perform sensitivity or what if analysis (Rasheed, San and Kvamsdal, 2020).

2.8 Barriers to the integration of Building Information Modelling (BIM) and Artificial Intelligence (AI) in Construction

This section will discuss the barriers hindering the integration of AI with BIM which include the resistance to change, lack of detailed information in BIM models, cost considerations, shortage of skilled labour and training, lack of knowledge of technology and concerns on data security.

2.8.1 Resistance to Change

Olawumi, et al. (2018) and Roy and Firdaus (2020) founded out that the resistance of change by construction practitioners to shift from conventional working practices is the primary barrier to implementing BIM in projects. Thus, it is recommended for core construction stakeholders such as top management and construction firms to adopt encouraging attitudes to transformation and for employers of mega projects to become proactive in using BIM (Evans and Farrell, 2021).

2.8.2 Lack of Knowledge on Technology

Adli Abbas Basaif, et al. (2020) discovered that most Malaysian construction practitioners lacked knowledge about AI. Besides, Othman, et al. (2021) founded out that the majority of construction firms were not aware of the BIM process and were unclear of the BIM execution procedure.

2.8.3 Cost Considerations

Yaakob, et al. (2018) summarised the cost implications for implementing BIM which include the high investment for upgrading both software and hardware, high cost in altering work process, training for workers is costly and organizations are only keen to invest if long term benefits are secured and training cost is sponsored (Hatem, Abd and Abbas, 2018). The funds needed to purchase the software and hardware necessary for specifications and the cost of training and hiring BIM experts leads to a high initial cost for BIM execution (Hatem, Abd and Abbas, 2018). Also, spending on investment in AI by the construction industry is the lowest compared to other sectors (Blanco, et al., 2018).

2.8.4 Concerns on Data Security

RICS (2020) mentioned that AI is one of the core components of the construction sector but the privacy issues of this technology have to be reviewed. The problem of data privacy is the primary challenge for deep learning researchers (Akinosho, et al., 2020). Besides, construction practitioners have critical concerns about the ownership of BIM models and the information privacy of these models (Othman, et al., 2021). CIDB (2020) revealed that the BIM process allows models to be accessed by many parties and there are no regulations to protect retrieved data against unlawful use. Federated BIM models require designers and contractors to transfer more intellectual properties which raises the issue of data ownership and IP rights licensing on as-built models.

2.8.5 Lack of Detailed Information in BIM models

Most BIM models used for pre-construction coordination or constructability analysis have insufficient detail information for tracking progress on a step-by-step approach and do not provide information on temporary structures such as formworks (Han and Golparvar-Fard, 2014). Besides, the lack of as-built BIM models allocated with the actual cost of the project makes it difficult to source training data for AI algorithms (Juszczyk, 2017). Labelled data is rarely sufficient to train supervised algorithms and machine learning algorithms are not useful when data is insufficient (Rasheed, San and Kvamsdal, 2020).

2.8.6 Lack of Skilled Labour and Training

The lack of competent workers to run the software is the major obstruction of BIM adoption in construction projects (Aftab Hameed Memon, et al., 2014). It is found that the majority of construction firms in Malaysia are not adopting BIM. Nonetheless, the professional knowledge of BIM implementation can only be enhanced through the familiarity of practical BIM application. The technical skills of the team can be greatly improved by interacting with technology (Othman, et al., 2021). According to a survey by McKinsey, the absence of talent with proper skills sets for AI work is ranked the second most critical barrier in adopting AI (Mckinsey, 2018). Adli Abbas Basaif, et al. (2020)

founded out that the majority of construction practitioners in Malaysia were not trained on AI at universities and most companies provided limited formal training and follow up programs regarding AI.

2.9 Proposed Theoretical Framework for the Perception on Building Information Modelling (BIM) and Artificial Intelligence (AI) Integration

The literature review is summarised in Figure 2.5. The applications of combining BIM and AI are identified to act as a foundation for this study. The perception of the construction industry is then determined by identifying the barriers of integrating BIM and AI and studying the behaviours and attitudes of the construction industry.

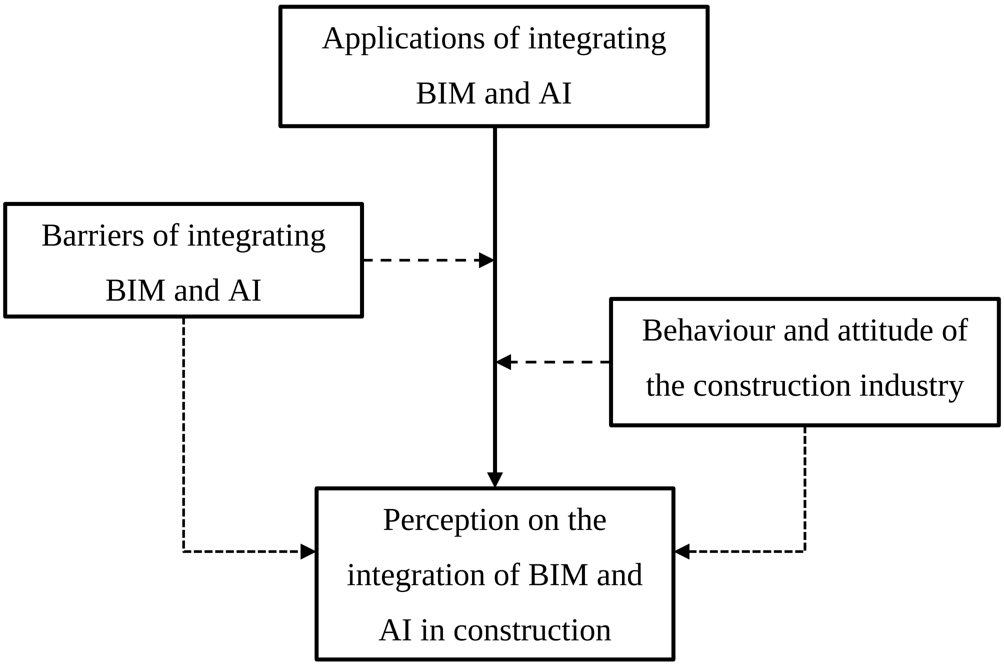

Figure 2. 5: Theoretical Framework for the Integration of AI and BIM

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Definition of Research

The Cambridge English Dictionary (2020) denotes research as a comprehensive study of a topic, particularly to reach a new understanding. Fellows and Liu (2015) describe research as a journey of study, regardless of whether there is a discovery. The discovery does not only include the topic of an investigation but also the process of investigation. Research emphasises particular aspects of a topic such as response to specific questions, solve an issue or test a hypothesis (Naoum, 2007).

Saunders, Lewis and Thornhill (2015) defined research as a process performed in a systematic way to find out things and enhance knowledge. Characteristics of research include data are collected and interpreted systematically and there is a sole purpose which is to discover things.

3.2 Research Method

Research methods are the mode of data collection, analysis and interpretation presented by researchers for particular research (Creswell and Creswell, 2018). Types of research method include the quantitative method, the qualitative method and the mixed mode method.

3.2.1 Quantitative Method

The quantitative method strives to collect truthful data, investigate relationships between facts and how they link with results from existing studies and theories (Fellows and Liu, 2015). The facts are measured by instruments to obtain numbered data. The numbered data is then examined using statistical procedures (Creswell, 2009). The data can include numeric information such as performance data and census data (Creswell and Creswell, 2018). The instruments used include surveys and experiment and the format of the presentation of quantitative methods are structured.

Quantitative tools allow relational data to be kept, retrieved and analysed easily as descriptions of relational chains can be lengthy and confusing. Numbers and graphs utilised in this method enable complex data to be minimised, summarised and systematised. Nonetheless, the shortcomings of this method include it is excessively formal and critical concrete details may be concealed when standardising observations (Crossley, 2010).

3.2.2 Qualitative Method

The qualitative method investigates the understandings and opinions of people (Fellows and Liu, 2015). There is no predetermined list of questions and the data is collected through interviews where participants talk openly regarding a subject or observing the behaviour of individuals at a research site. The type of data collected by this method may be the participant's responses such as interview data and observation data (Creswell and Creswell, 2018). The representation of the results is more flexible as compared to the qualitative method.

The qualitative method enables appreciation and understanding of fundamental causes, principles and behaviours (Fellows and Liu, 2015). However, the limitation of this method is that it overly emphasises concrete particulars, fails to standardise and approaches to identify structure are not provided (Crossley, 2010).

3.2.3 Mixed Mode Method

The mixed mode method can also be referred to as triangulation. This method combines the quantitative and qualitative method and unites the merits of both methods which leads to a multi-dimensional view of the topic (Fellows and Liu, 2015). This method is used when the problems of research are complex and quantitative or qualitative methods are insufficient to address them (Creswell, 2009). This method concurrently or sequentially uses quantitative and qualitative research methods to understand a phenomenon (Viswanath Venkatesh, Brown and Hillol Bala, 2013). It can answer both exploratory and confirmatory questions within one research inquiry, offer better inferences compared to using only quantitative or qualitative method and provide a chance for an improved assortment of divergent and complementary views. To illustrate, the researcher can separate the sample into two parts, analyse the first part for exploratory purposes and the remaining part for confirmatory purposes (Teddlie and Tashakkori, 2009).

In this study, the mixed mode method is adopted. The questionnaire survey is used to gather the general views of construction practitioners towards the integration of BIM and AI and their agreement on the roadblocks of this integration. The semi structured interview is then conducted to obtain a detailed understanding of current practices undertaken by the industry, industry expectations and suggestions and the underlying reasons behind the barriers of this integration.

3.3 Research Design

This study commences with an initial study for determining the research scope. Information and Communications Technology (ICT) in construction was identified as the initial scope of the study. Next, the scope was narrowed down into the two disruptive technologies to the construction industry, BIM and AI. After reviewing the existing studies, it was founded out that the development of BIM and AI in construction could both achieve a greater level through integration. AI requires abundant training data for its development while the automation of BIM processes can be achieved with the assistance of AI.

A research gap was then discovered during the reviewing process. Existing studies have only concentrated on the applications of BIM and AI in improving the building project workflows separately. Although studies are focusing on the development of BIM using specific AI techniques or the utilisation of BIM data for the training of AI, there have been limited studies providing an overview summary of the possibilities and applications of integrating BIM and AI. Besides, the opinions of the construction industry on this integration have not been studied to provide feedbacks for facilitating this integration and the development of related software. Also, the actual needs of the construction practitioners are not determined to ensure that the applications of this integration are practical for them.

The research aim is then formulated to address the research gap. Thus, this study aims to determine the perception of the construction industry towards the integration of AI and BIM. Three objectives were established to accomplish the research aim. The first objective is achieved in Stage 1 of the study which is the literature review. The accomplishment of the second objective will commence in Stage 1 and continue in Stage 2 which is the questionnaire survey and interview stage. The third objective will be fulfilled in Stage 2.

In Stage 1, a literature review was carried out to review existing studies related to AI and BIM in construction. Theories such as the definitions of AI and BIM were explored to obtain a basic understanding of the technologies. Next, literature such as research papers and books were examined. Existing applications of AI and BIM were identified and the researches which integrate AI and BIM in construction were also overviewed.

After Stage 1 is completed, the suitable research method is selected. The mixed mode method is chosen as the research method for this study. The population of the study was decided as professionals in the construction industry. Instruments such as interviews and questionnaire survey were applied to obtain the views of the construction industry towards the integration of BIM and AI.

The quantitative data collected is then analysed and interpreted by descriptive statistics and inferential statistics. The qualitative data from the interviewees are coded, categorised and analysed using thematic analysis. The results are then summarised into the conclusion of the study. Figure 3.1 shows the research flow of the study.

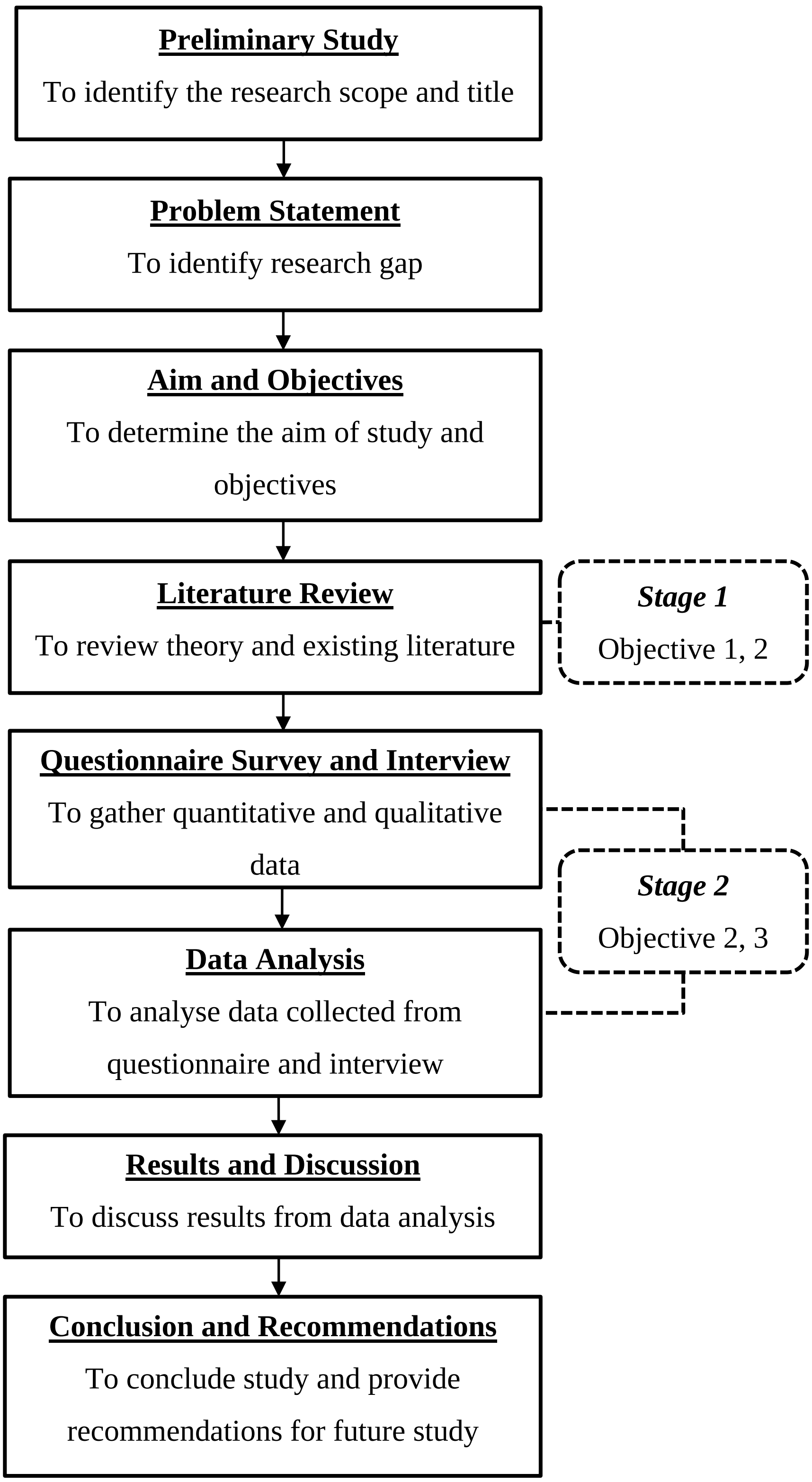

Figure 3. 1: Research Flow

3.4 Research Philosophy

Pragmatism is selected as the appropriate research philosophy for this study. This philosophy seeks to compromise both objectivism and subjectivism by considering theories, ideas, hypothesis and findings as instruments of thought and action and their practical impact on certain situations (Saunders, Lewis and Thornhill, 2015). It suggests that it is possible to use multiple methodologies within a single study and there is no single method that can provide a complete explanation of the research. Pragmatic approaches adopt any methods which can develop a reasonable test of the hypothesis to maximise validity instead of just relying on a particular method (Fellows and Liu, 2015). This philosophy focuses on the research problem instead of the method and utilises all existing methods to best comprehend the research problem (Creswell and Creswell, 2018). Thus, this study utilises both qualitative and quantitative approaches to understand the opinions of construction players towards the integration of BIM and AI.

3.5 Justification of Adopted Research Design and Philosophy

Researches by pragmatist are initiated by a problem and intent to solve this problem by suggesting practical solutions that advise future practice (Saunders, Lewis and Thornhill, 2015). Similarly, this study intends to close the research gap of the absence of studies identifying the possibilities of integrating BIM and AI and determines the perception of the construction industry to facilitate the integration of AI and BIM in construction. Also, the issue of data wastage in the existing BIM models can be addressed by this integration with AI and this study aids the development of this integration. Furthermore, pragmatism emphasises practical research, considers distinct perspectives on a topic to overcome a problem and this philosophy perceives that theory is used to inform practice (Sekaran and Bougie, 2016). Correspondingly, this study suggests a basic integration framework based on the findings from the literature review and data analysis.

Questionnaires and semi structured interviews are both adopted as the instruments to determine the perception of the construction practitioners. This is because pragmatism suggests that it is possible to adopt distinct types of knowledge and using multiple reliable methods might contribute to the completeness of the results (Saunders, Lewis and Thornhill, 2015). As for the research method, the sequential explanatory mixed method is adopted for this study. The quantitative data is collected first using the questionnaire then followed by gathering qualitative data from the semi structured interviews. The data from the questionnaire is prioritised in this study while the data from the interviews act as complementary data to compare the data from the questionnaire. As an illustration, the results from the questionnaire indicates the general trend while the results from the semi structured interview lead to in-depth explanations and illustrations.

3.6 Target Respondents

Construction practitioners such as architects, quantity surveyors and engineers are the target respondents for this study. This group of professionals have relatively higher involvement in BIM practices due to the nature of their profession. Thus, comprehensive information on their experiences and views on BIM and its integration with AI can be obtained. As for the interviews, convenience sampling is adopted to collect data from the interviewees. This sampling technique refers to cases that are selected randomly due to the convenience of attaining a sample (Saunders, Lewis and Thornhill, 2015). Similarly, interviewees in this study are approached through a personal connection which is easily available. Each interviewee has certain experiences in applying BIM in past and current projects.

3.7 Central Limit Theorem

The central limit theorem suggests that the more a sample's distribution resembles the normal distribution, the greater its absolute size of the sample (Saunders, Lewis and Thornhill, 2015). A minimum of 30 samples are obtained for each attribute group for the profession and working experiences of respondents to ensure that the sampling distribution of the sample mean is close to a normal distribution (Sekaran and Bougie, 2016).

3.8 Questionnaire Design

The structure of the questionnaire consists of four major sections. Section A focuses on the respondent’s attributes which include the subsections of age, profession and working experience of the construction practitioners. Section B focuses on the perception of construction practitioners towards the adoption of BIM and AI in construction and is divided into subsections which are personal views, future views and perceptions on the importance of applications integrating BIM and AI. Statements for the personal views focuses on determining the interest and willingness of respondents to adopt AI and BIM and their general perceptions towards these technologies. Statements for the future views focus on determining the respondents' vision on the future implementation of BIM and AI and their agreement on the possible impacts AI might bring to the construction industry. Also, the importance of the applications for BIM, AI and the integration of BIM and AI identified in Section 2.4, 2.5 and 2.6 of the literature review are determined in Section B.

Section C focuses on the current practice in adopting BIM and AI in construction projects and consist of two subsections which are the familiarity and adoption of software. The software listed in this section is those for BIM, AI and the integration of BIM and AI respectively that are identified in Section 2.4, 2.5 and 2.6 of the literature review. The familiarity of the respondents with the software and the usage of the software by respondents are determined in Section C.

Section D concentrates on the barriers hindering the integration of BIM and AI with statements focusing on each barrier identified in Section 2.8 of the literature review. Section B and C covers three aspects which are BIM, AI and the integration of BIM and AI. Five-point Likert scale rating questions are used for each subsection with different scales based on the focus of the subsections. Table 3.1 summarises the themes for statements in Section B and C. Table 3.2 presents the themes for statements in Section D. Table 3.3 shows the Likert scales for each subsection.

Table 3. 1: Themes for Statements for Section B and C

Section	Sub Section	BIM	AI	Integration of BIM and AI
B	Personal View	Statements 1 – 5	Statements 1 – 4, 6 and 7	Statements 8 – 12
	Future View	Statements 1	Statements 2 – 5	-
	Importance of Applications	Application 1 - 5	Application 6 – 12	Application 13 -20
C	Familiarity on software	Software 1 – 5	Software 6 – 11	Software 12 – 21
	Adoption of software	Software 1 – 5	Software 6 – 11	Software 12 – 21

Table 3. 2: Themes for Statements for Section D

Section	Barriers	Statement
D	Resistance to change	1 – 6
	Lack of knowledge of technology	7 – 9
	Cost considerations	10 – 12
	Concerns on data security	13
	Lack of skilled labour and training	14 – 16
	Lack of information in BIM models	17 – 18

Table 3. 3: Likert Scale for each Subsection

Sub Section	1	2	3	4	5
Personal View	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Future View	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Importance of Application	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Familiarity on software	Not at all familiar	Slightly familiar	Moderately familiar	Very familiar	Extremely familiar
Adoption of software	Not at all	Slight	Quite	Usual	All the while
Barriers	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3.9 Interview Design

Semi structured interview is chosen as the interview type for this study. The questions for the interview will be based on the three main themes which are BIM, AI and the integration of BIM and AI. Questions raised may vary from the interview guidelines as semi structured interviews are conducted. As for the subthemes, the current practice of the industry, benefits and problems of current practice and expectations from construction practitioners will be the main focus of the interviews. Table 3.4 below shows the themes focused on the interviews. The interview guidelines are provided in Appendix C.

Table 3. 4: Themes and Sub-Themes for Interview

Theme	Sub Theme
Building Information Modelling (BIM)	Personal Views
	Benefits
	Current practice
	Problems
Artificial Intelligence (AI)	Personal Views
	Future Views
	Benefits
	Current practice
	Coming practice
Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)	Personal Views
	Future Views
	Benefits
	Expectations
	Current practice
	Coming practice
	Barriers
	Suggestions

3.10 Normality Test

The normality test is conducted to verify whether the variable for distribution is statistically different from a comparable normal distribution. The Shapiro - Wilk test which is a statistical test used to calculate the probability that an observed set of values for each segment of a variable varies from a given distribution is selected as the normality test for this study (Saunders, Lewis and Thornhill, 2015). The *p*-value or the significant value indicates the probability. A probability of 0.05 and lower denotes that the data is not normally distributed (Saunders, Lewis and Thornhill, 2015). Parametric statistics depend on the distribution nature of the data obtained (Fellows and Liu, 2015). The non-parametric test will be conducted if the data is non normally distributed and normally distributed data will be analysed using the parametric test.

3.11 Reliability Analysis

The reliability analysis checks for consistency in the responses to all of the items in a questionnaire (Sekaran and Bougie, 2016). The instrument scale items should have intercorrelations and assess the same underlying construct (Creswell, 2009). The internal consistency of responses of each question's subgroup is computed using Cronbach's alpha. An alpha coefficient with a value above 0.7 indicates that there is internal consistency in the set of questions and the subgroups in the questions are measuring the same thing (Saunders, Lewis and Thornhill, 2015).

3.12 Descriptive Statistics

Descriptive statistics are used to numerically interpret and compare variables (Saunders, Lewis and Thornhill, 2015). The frequency, measures of central tendency and dispersion are descriptive statistics for a single variable (Sekaran and Bougie, 2016). Median is selected as the measure of central tendency for descriptive statistics as ordinal data is obtained from the Likert scale questions. The median indicates the point at which half of the cases are higher and half are lower (Neuman, 2014) The perception of construction practitioners, familiarity and adoption of software and barriers are ranked according to the median frequency and percentage of the median.

3.13 Inferential Statistics

Inferential statistics provide statistical evidence in the form of hypothesis testing to determine if a null hypothesis can be rejected to confidently accept an alternate hypothesis and to draw conclusions therefrom (Sekaran and Bougie, 2016). The Kruskal Wallis test is adopted for hypothesis testing to conclude any significant difference between the responses of three or more groups which in this study categorised by working experience and profession. A statistically significant difference between groups is identified when the *p*-value is 0.05 or lesser. The Mann Whitney test determines the probability of difference between values for an ordinal data variable between two independent groups (Saunders, Lewis and Thornhill, 2015). It is conducted as a follow up test for the Kruskal Wallis test to identify the pair of groups with a significant difference.

Moreover, the Spearman's Rank Order Correlation is applied to identify the association between variables and measures the strength of this association (Saunders, Lewis and Thornhill, 2015). The intensity of the relationship between variables is represented by the coefficient of correlation which is between the numbers – 1 and +1 with a value of zero meaning that the variables are perfectly independent (Saunders, Lewis and Thornhill, 2015). A value of – 1 means a perfect negative correlation and a value of 1 means a perfect positive correlation (Pallant, 2016). A correlation is found to be significant if the *p*-value is 0.05 or lesser (Naoum, 2007).

3.14 Thematic Analysis

Thematic analysis is the analysis of narrative data using different iterative techniques such as categorical strategies which provide results in themes (Teddlie and Tashakkori, 2009). This generic approach is adopted to find themes and patterns from a data set to explain theories based on the evident thematic relationships to draw conclusions (Saunders, Lewis and Thornhill, 2015). The interview transcripts are first reviewed and then coded based on themes such as personal views, current practice and barriers and then patterns such as similar personal views are recognised.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Respondents' Background

Initially, 159 sets of questionnaire responses were gathered through platforms such as Facebook, WhatsApp and Linked In. However, 14 sets of responses were excluded due to incomplete and bias data. Thus, 145 sets of responses are used for data analysis. The attributes of respondents are presented in Table 4.1 below. The majority of the respondents are within the age of 18 to 30 years old (80.7%). Only the respondents of 18 years old and above are approached in this study and all of them are considered as adults according to the Age of Majority Act 1971. Over half of the respondents have working experiences of between 0 to 2 years (57.2%), followed by 3 to 5 years (22.1%) and above 6 years of experience (20.7%). Architects are the profession with the highest percentage (37.2%), followed by engineers (33.1%) and lastly quantity surveyors (29.7 %).

Table 4. 1: Respondents' Attributes (N = 145)

General Information	Groups	Frequency	Percentage (%)
Age Group	Above 50 years old	2	1.4
	41 - 50 years old	6	4.1
	31 - 40 years old	20	13.8
	18 - 30 years old	117	80.7
Profession	Quantity Surveyor	43	29.7
	Engineer	48	33.1
	Architect	54	37.2
Working Experience	Above 6 years	30	20.7
	3 - 5 years	32	22.1
	0 - 2 years	83	57.2

N = Total number of respondents

4.2 Normality of Data

Table 4.2 below summarises the Shapiro – Wilk Test results for subsection in the questionnaire. The *p*-value for all sections is lesser than 0.05 which indicates all data is non normally distributed. Thus, non-parametric tests will be performed for inferential statistics. Table 4.2 below summarises the normality test results.

Table 4. 2: Summary of Normality Test Results (N = 145)

Sections	Sub Section	Sig.
A: Respondent Attributes	Age Group	0.000
	Profession	0.000
	Working Experience	0.000
	Personal View *[Statement 1 – 12]*	0.000
B: Perception	Future View *[Statement 1 – 5]*	0.000
	Importance of BIM and AI Applications *[Application 1 – 20]*	0.000
	Familiarity with BIM and AI software *[Software 1 – 21]*	0.000
C: Current practice	Adoption of BIM and AI software *[Software 1 – 21]*	0.000
D: Barriers	Barriers for the integration of BIM and AI *[Statement 1 – 18]*	0.000

4.3 Reliability Analysis

Table 4.3 presents the Cronbach Alpha results for the subsections. All the values of the reliability test exceed the value of 0.7 which indicates that all the variables in each subsection are internally consistent. Therefore, this survey is deemed to be reliable.

Table 4. 3: Summary of Reliability Test Results

Sections	Sub Section	Value
B: Perception	Personal View *[Statement 1 – 12]*	0.871
	Future View *[Statement 1 – 5]*	0.749
	Importance of BIM and AI Applications *[Application 1 – 20]*	0.957
C: Current practice	Familiarity with BIM and AI software *[Software 1 – 21]*	0.947
	Adoption of BIM and AI software *[Software 1 – 21]*	0.927
D: Barriers	Barriers for the integration of BIM and AI *[Statement 1 – 18]*	0.870

4.4 Findings from the Questionnaire

This section will outline the questionnaire findings by analysing each subsection based on descriptive statistics, hypothesis testing and pairwise comparison.

4.4.1 Perception towards Building Information Modelling (BIM) and Artificial Intelligence (AI)

The perception of respondents towards Building Information Modelling (BIM) and Artificial Intelligence (AI) in construction is analysed in terms of their personal view, future view and their perception towards the importance of BIM and AI applications in construction.

(A) Personal View towards BIM and AI

Table 4.4 below shows the ranking of statements related to the personal view towards BIM and AI in construction based on the medians and frequency of the medians for statements.

Table 4. 4: Ranking for Statements on Personal View towards BIM and AI

Statements	Median	Median Frequency	%
I look forward to using BIM or AI in future construction processes	4	74	51.0%
I believe that AI will only assist in human intelligence and not replace it	4	73	50.3%
I am interested in learning more knowledge on BIM or AI	4	71	49.0%
I believe that learning more knowledge of BIM or AI can aid my future career	4	68	46.9%
I take initiatives to propose BIM or AI approaches to my company	4	59	40.7%
I prefer to use AI to only aid in decision making and make the final decision on my own	3	49	33.8%
I think that BIM can be used only for illustration purpose	2	53	36.6%

*1- Strongly Disagree, 2 - Disagree, 3 - Neutral, 4 - Agree, 5 - Strongly Agree

As observed from Table 4.4 above, the statements “I look forward to using BIM or AI in future construction processes (51.0%)” and “I believe that AI will only assist in human intelligence and not replace it (50.3%)” is agreed by around half of the respondents. Moreover, close to half of the respondents (49.0%) agreed on “I am interested in learning more knowledge on BIM or AI”. Besides, 46.9% of the respondents agree on “I believe that learning more knowledge of BIM or AI can aid my future career” while only 40.7% agree on “I take initiatives to propose BIM or AI approaches to my company”. On the contrary, 36.6% of the respondents disagree on “I think that BIM can be used only for illustration purpose” while 33.8% of respondents neither agree nor disagree on “I prefer to use AI to only aid in decision making and make the final decision on my own.”

The Kruskal Wallis test is used to compare the profession against the personal view towards BIM in construction. The Mann Whiney test is then used to conduct pairwise comparisons to identify the groups which are statistically different. Table 4.5 below shows the rejected null hypothesis.

Table 4. 5: Rejected Null Hypothesis for the Personal Views towards BIM

Rejected Null Hypothesis		Sig.
The agreement on the statement '*I think that BIM can be used only for illustration purpose'* is the same between		
a) Groups with profession of		
i.	Architect – Engineer	0.013
ii.	Architect – Quantity Surveyor	0.003

From results reported in Table 4.5, the pairs of respondents that have a statistically significant difference in their "Personal View towards BIM" are summarised below

a) *I think that BIM can be used only for illustration purpose*

i. The group of engineers (Mean rank = 58.88) perceived higher agreement than architects (Mean rank = 44.94) on the statement "*I think that BIM can be used only for illustration purpose"*

ii. The group of quantity surveyors (Mean rank = 58.16) perceived higher agreement than architects (Mean rank = 41.70) on the statement "*I think that BIM can be used only for illustration purpose"*

(B) Future View towards BIM in construction

Table 4.6 below shows the ranking for statements related to the future view towards BIM in construction based on the medians and frequency of the medians for statements.

Table 4. 6: Median for Statements on Future View towards BIM

Statements	Median	Median Frequency	%
The adoption of BIM might become common within the next 10 years	4	71	49.0%

*1- Strongly Disagree, 2 - Disagree, 3 - Neutral, 4 - Agree, 5 - Strongly Agree

As observed from Table 4.6 above, close to half of the respondents (49.0%) agree on “The adoption of BIM might become common within the next 10 years”.

(C) Future View towards AI in construction

Table 4.7 below shows the ranking for statements related to the future view towards AI in construction based on the medians and frequency of the medians for statements.

Table 4. 7: Ranking for Statements on Future View towards AI

Statements	Median	Median Frequency	%
AI might lead to a major change in the operation of the construction industry	4	72	49.7%
The adoption of AI might become common within the next 10 years	4	71	49.0%
There might be a shift in the job scope of construction practitioners due to AI	4	71	49.0%
AI might reduce job opportunities for construction practitioners	3	46	31.7%

*1- Strongly Disagree, 2 - Disagree, 3 - Neutral, 4 - Agree, 5 - Strongly Agree

As observed from Table 4.7 above, close to half of the respondents agree on "AI might lead to a major change in the operation of the construction industry (49.7%)" and "The adoption of AI might become common within the next 10 years (49.0%)". Besides, 49.0% of the respondents agree that "There might be a shift in the job scope of construction practitioners due to AI" while only 31.7% of the respondents neither agree nor disagree on "AI might reduce job opportunities for construction practitioners".

The Kruskal Wallis test is used to examine the working experience against the personal future view towards AI in construction. Mann Whiney test is then used to conduct pairwise comparisons to identify the groups which are statistically different. Table 4.8 below presents the rejected null hypothesis.

Table 4. 8: Rejected Null Hypothesis for the Personal View towards AI

Rejected Null Hypothesis	Sig.
The agreement on the statement "*The adoption of AI might become common within the next 10 years*" is the same between	
a) Groups with working experience of	
i. 0 – 2 years – Above 6 years	0.021

From results reported in Table 4.8, the pairs of respondents that have a statistically significant difference in their "Future View towards AI" are summarised below

a) *The adoption of AI might become common within the next 10 years*

i. The group of 0 -2 years experience (Mean rank = 60.99) perceived higher agreement than the group of above 6 years experience (Mean rank = 45.95) on the statement "*The adoption of AI might become common within the next 10 years*"

(D) Importance of BIM applications

Table 4.9 below shows the ranking for the importance of BIM applications the medians and frequency of the medians.

Table 4. 9: Ranking for the Importance of BIM Applications

Applications	Median	Median Frequency	%
BIM assists in prefabrication planning	4	84	57.9%
BIM assists in schedule management	4	78	53.8%
BIM assists in taking off quantities	4	74	51.0%
BIM assists in quality management	4	67	46.2%
BIM assists in facility management	4	63	43.4%

*1-Not at all important, 2 - Slightly important, 3 - Moderately important, 4 - Very important, 5 - Extremely important

As observed from Table 4.9 above, the respondents perceive that all the BIM applications as very important based on the median. Firstly, above half of the respondents (57.9%) perceived that the BIM assisting in prefabrication planning is very important. The second highest (53.8%) BIM application where the respondents perceive that is very important is where BIM assists in schedule management. The third BIM application where respondents perceive as very important is BIM assisting in the taking off of quantities (51.0%). Furthermore, 46.2% of the respondents perceive that using BIM for quality management is very important. Comparatively, only 43.4% of the respondents perceive that using BIM for facility management is very important.

(E) Importance of AI applications

Table 4.10 below shows the ranking for the importance of AI applications based on the medians and frequency of the medians.

Table 4. 10: Ranking for the Importance of AI Applications

Applications	Median	Median Frequency	%
AI enables transportation route optimisation	4	73	50.3%
AI enables the optimisation of supply chain management	4	69	47.6%
AI enables the risk prediction on quality issues	4	68	46.9%
AI enables the risk prediction on delay	4	66	45.5%
AI assists in site progress monitoring	4	66	45.5%
AI assists in safety management	4	62	42.8%
AI enables constant design optimisation	4	59	40.7%

*1 - Not at all important, 2 - Slightly important, 3 - Moderately important, 4 - Very important, 5 - Extremely important

As observed from Table 4.10 above, the respondents perceive that all the AI applications as very important based on the median. Half of the respondents (50.3%) perceive that AI enabling transportation route optimisation is very important. Furthermore, 47.6% of the respondents think that the optimisation of the supply chain using AI is very important and 46.9% of the respondents consider that AI enabling risk prediction on quality issues as very important. Besides, 45.5 % of the respondents perceive that the applications of AI providing risk prediction in delay and site progress monitoring as very important. AI assisting in safety management (42.8%) and constant design optimisation (40.7%) are considered the least important AI applications by construction practitioners.

4.4.2 Perception towards the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

The perception of respondents towards the integration of BIM and AI in construction is analysed in terms of their personal view, future view and their perception towards the importance of applications integrating BIM and AI.

(A) Personal views towards the integration of BIM and AI

Table 4.11 below shows the ranking of statements related to the personal view towards the integration of BIM and AI in construction based on the medians and frequency of the medians for statements.

Table 4. 11: Ranking for Statements on Personal View towards the Integration of BIM and AI

Statements	Median	Median Frequency	%
I believe that BIM and AI can complement each other through integration	4	86	59.3%
I look forward to using BIM with AI features in future construction processes	4	82	56.6%
I believe that integrating BIM and AI will reduce the shortcomings of BIM	4	82	56.6%
I am interested in learning more knowledge on the integration of BIM and AI	4	81	55.9%
I believe that integrating BIM and AI improve the performance of AI	4	78	53.8%

*1 - Strongly Disagree, 2 - Disagree, 3 - Neutral, 4 - Agree, 5 - Strongly Agree

As observed from Table 4.11 above, above half of the respondents (59.3%) agree on “I believe that BIM and AI can complement each other through integration” The statements “I look forward to using BIM with AI features in future construction processes” and “I believe that integrating BIM and AI will reduce the shortcomings of BIM” are both agreed by 56.6% of the respondents.

Moreover, 55.9% of the respondents agree on “I am interested in learning more knowledge on the integration of BIM and AI” and 53.8% of them agreed on “I believe that integrating BIM and AI improve the performance of AI”.

(B) Importance of applications integrating AI and BIM

Table 4.12 below shows the ranking for the importance of applications integrating BIM and AI-based on the medians and frequency of the medians.

Table 4. 12: Ranking for the Importance of Applications of BIM and AI Integration

Applications	Median	Median Frequency	%
Automated cost estimation to provide more accurate initial estimates	4	69	47.6%
Construction simulation to predict unforeseen circumstances	4	68	46.9%
Automated site progress monitoring to facilitate progress reporting	4	66	45.5%
Automated site progress monitoring assists the as-built model production	4	65	44.8%
Construction simulation to enable project schedule optimisation	4	64	44.1%
Generative design to provide alternative design options	4	64	44.1%
3D coordination and clash detection to identify errors in the BIM model	4	60	41.4%
3D coordination and clash detection to assists in constructability	4	57	39.3%

*1 - Not at all important, 2 - Slightly important, 3 - Moderately important, 4 - Very important, 5 - Extremely important

As observed from Table 4.12 above, the respondents perceive that all the applications integrating BIM and AI as very important based on the median. Automated cost estimation (47.6%) is perceived as the most significant application. Besides, construction simulation to predict unforeseen situations is perceived as the second most (46.9%) important application, followed by automated site progress monitoring to facilitate progress reporting as the third most important application (45.5%). Comparatively, the applications such as generative design to provide alternative design options (44.1%), 3D coordination and clash detection to identify errors in the BIM model (41.4%) and 3D coordination and clash detection to assists in constructability (39.3%) are considered as the least important applications.

The Kruskal Wallis test is used to examine the working experience against the importance of applications integrating BIM and AI. Mann Whiney test is then used to conduct pairwise comparisons to identify the groups which are statistically different. Table 4.13 below shows the rejected null hypothesis.

Table 4. 13: Rejected Null Hypothesis for the Importance of Applications integrating BIM and AI

Rejected Null Hypothesis	Sig.
The opinion on the importance of the application "3D coordination and clash detection to identify errors in the BIM model" is the same between	
a) Groups with working experience of	
i. 0 – 2 years – 3 -5 years	0.026
ii. 3 – 5 years – Above 6 years	0.029

From results reported in Table 4.13, the pairs of respondents which have a statistically significant difference in their opinion on the "Importance of applications integrating BIM and AI" are summarised below

a) 3D coordination and clash detection to identify errors in the BIM model
   i. The group of 3 - 5 years experience (Mean rank = 68.27) perceived higher importance on the application "3D coordination and clash

detection to identify errors in the BIM model" than the group of 0 - 2 years experience (Mean rank = 54.04).

ii. The group of 3 - 5 years experience (Mean rank = 35.97) perceived higher importance on the application "3D coordination and clash detection to identify errors in the BIM model" than the group of above 6 years experience (Mean rank = 26.73).

4.4.3 Current Practice of Building Information Modelling (BIM)

The current practice towards BIM in construction is analysed in terms of the familiarity of the respondents towards the BIM software in the market and their adoption of BIM software.

(A) Familiarity with BIM software

Table 4.14 below shows the ranking for the familiarity with BIM software based on the medians and frequency of the medians.

Table 4. 14: Ranking for Familiarity with BIM Software

Software	Median	Median Frequency	%
Autodesk Revit (versions before 2021)	3	48	33.1%
Sketch Up	3	35	24.1%
ArchiCAD	1	76	52.4%
Vectorworks	1	98	67.6%
Allplan	1	118	81.4%

*1 - Not at all familiar, 2 - Slightly familiar, 3 - Moderately familiar, 4 - Very familiar, 5 - Extremely familiar

As observed from Table 4.14 above, construction practitioners are moderately familiar with the Autodesk Revit (33.1%) and Sketch up (24.1%) software. Nevertheless, the respondents are not at all familiar with the BIM software such as ArchiCAD (52.4%), Vectorworks (67.6%) and Allplan (81.4%).

The Kruskal Wallis test is used to examine the profession and working experience against familiarity with BIM software. Mann Whiney test is then used to conduct pairwise comparisons to identify the groups which are statistically different. Table 4.15 below shows the rejected null hypothesis.

Table 4. 15: Rejected Null Hypothesis for Familiarity with BIM Software

Rejected Null Hypothesis		Sig.
The familiarity on Sketch Up software is the same between		
a) Groups with profession of		
i.	Architect – Engineer	0.000
ii.	Architect – Quantity Surveyor	0.000
The familiarity with ArchiCAD software is the same between		
a) Groups with profession of		
i.	Architect – Engineer	0.013
The familiarity with Vectorworks software is the same between		
a) Groups with profession of		
i.	Architect – Engineer	0.015
ii.	Architect – Quantity Surveyor	0.004
The familiarity with Autodesk Revit (versions before 2021) software is the same between		
a) Groups with working experience of		
i.	3 -5 years – Above 6 years	0.011

From results reported in Table 4.15, the pairs of respondents that have a statistically significant difference in their "Familiarity on BIM software" are summarised below

a) Sketch Up
   i. The group of architects (Mean rank = 69.90) have a higher familiarity with the Sketch Up software than the group of engineers (Mean rank = 30.80).
   ii. The group of architects (Mean rank = 66.83) have a higher familiarity with the Sketch Up software than the group of quantity surveyors (Mean rank = 26.60).

b) ArchiCAD

i. The group of architects (Mean rank = 57.71) have a higher familiarity with the ArchiCAD software than the group of engineers (Mean rank = 44.51).

c) Vectorworks

i. The group of architects (Mean rank = 57.30) have a higher familiarity with the Vectorworks software than the group of engineers (Mean rank = 44.98).

ii. The group of architects (Mean rank = 55.27) have a higher familiarity with the Vectorworks software than the group of quantity surveyors (Mean rank = 41.13).

d) Autodesk Revit (versions before 2021)

i. The group of 3 -5 years experience (Mean rank = 36.95) have a higher familiarity with the Autodesk Revit (versions before 2021) software than the group of above 6 years experience (Mean rank = 25.68).

(B) Adoption of BIM software

Table 4.16 below shows the ranking for the adoption of BIM software based on the medians and frequency of the medians.

Table 4. 16: Ranking for the Adoption of BIM Software

Software	Median	Median Frequency	%
Autodesk Revit (versions before 2021)	3	32	22.1%
Sketch Up	3	14	9.7%
ArchiCAD	1	98	67.6%
Vectorworks	1	118	81.4%
Allplan	1	127	87.6%

*1=Not at all, 2 = Slight, 3 = Quite, 4 = Usual, 5 = All the while

As observed from Table 4.16 above, Autodesk Revit (22.1%) and Sketch up (9.7%) are the BIM software that is quite frequently used by construction practitioners in their projects. Nevertheless, the respondents are not using BIM software such as ArchiCAD (67.6%), Vectorworks (81.4%) and Allplan (87.6%).

The Kruskal Wallis test is used to compare the profession against the adoption of BIM software. Mann Whiney test is then used to conduct pairwise comparisons to identify the groups which are statistically different. Table 4.17 below shows the rejected null hypothesis.

Table 4. 17: Rejected Null Hypothesis for the Adoption of BIM Software

Rejected Null Hypothesis		Sig.
The adoption of Sketch Up software is the same between		
a) Groups with profession of		
i.	Architect – Engineer	0.000
ii.	Architect – Quantity Surveyor	0.000
iii.	Engineer – Quantity Surveyor	0.030

From results reported in Table 4.17, the pairs of respondents that have a statistically significant difference in their “Adoption of BIM software” are summarised below

a) Sketch Up

i. The group of architects (Mean rank = 69.84) have higher adoption of the Sketch Up software than the group of engineers (Mean rank = 30.86).

ii. The group of architects (Mean rank = 66.81) have higher adoption of the Sketch Up software than the group of quantity surveyors (Mean rank = 26.63).

iii. The group of engineers (Mean rank = 51.31) have higher adoption of the Sketch Up software than the group of quantity surveyors (Mean rank = 40.07).

(C) Relationship between familiarity and adoption of BIM software

The results from Spearman's Rank Order Correlation revealed that there is a positive correlation between the familiarity and adoption of BIM software. Table 4.18 shows the correlation coefficient between the familiarity and adoption of each BIM software.

Table 4. 18: Correlation Coefficient between the Familiarity and Adoption of BIM Software.

Software	Correlation coefficient	Sig.
Sketch Up	0.864	0.000
Archicad	0.748	0.000
Autodesk Revit (versions before 2021)	0.723	0.000
Allplan	0.632	0.000
Vectorworks	0.593	0.000

As observed from Table 4.18 above, there is a direct correlation coefficient between the familiarity and adoption of each BIM software.

4.4.4 Current Practice of Artificial Intelligence (AI) in Construction

The current practice towards AI in construction is analysed in terms of the familiarity of the respondents towards the AI software in the market and their adoption of AI software.

(A) Familiarity with AI software

Table 4.19 below shows the ranking for the familiarity with AI software based on the medians and frequency of the medians.

Table 4. 19: Ranking for Familiarity with AI Software

Software	Median	Median Frequency	%
BIM 360	2	20	13.8%
Site AI	1	114	78.6%
Disperse	1	116	80.0%
Smartvid.io	1	118	81.4%
Doxel AI	1	118	81.4%
Easyflow CV	1	118	81.4%

*1 - Not at all familiar, 2 - Slightly familiar, 3 - Moderately familiar, 4 - Very familiar, 5 - Extremely familiar

As observed from Table 4.19 above, only less than a quarter of respondents are slightly familiar with the BIM 360 (13.8%) software. Moreover, most respondents are unfamiliar with the remaining AI software which include Site AI (78.6%), Disperse (80.0%), Smartvid.io (81.4%), Doxel AI (81.4%) and Easyflow CV (81.4%),

(B) Adoption of AI software

Table 4.20 below shows the ranking for the adoption of AI software based on the medians and frequency of the medians.

Table 4. 20: Ranking for the Adoption of AI Software

Software	Median	Median Frequency	%
BIM 360	1	87	60.0%
Site AI	1	125	86.2%
Smartvid.io	1	127	87.6%
Disperse	1	128	88.3%
Easyflow CV	1	128	88.3%
Doxel AI	1	128	88.3%

*1 - Not at all, 2 - Slight, 3 - Quite, 4 - Usual, 5 - All the while

As observed from Table 4.20 above, more than half (60.0%) of the respondents are not familiar with the BIM 360 software. Besides, the majority of the respondents are not using AI software such as Site AI (86.2%), Smartvid.io (87.6%), Disperse (88.3%), Easyflow CV(88.3%) and Doxel AI (88.3%).

The Kruskal Wallis test is used to compare the profession against the adoption of AI software". Mann Whiney test is then used to conduct pairwise comparisons to identify the groups which are statistically different. Table 4.21 below shows the rejected null hypothesis.

Table 4. 21: Rejected Null Hypothesis for the Adoption of AI Software

Rejected Null Hypothesis		Sig.
The adoption of BIM 360 software is the same between		
a) Groups with profession of		
i.	Architect – Engineer	0.027
ii.	Architect – Quantity Surveyor	0.003

From results reported in Table 4.21, the pairs of respondents that have a statistically significant difference in their "Adoption of AI software" are summarised below

a) BIM 360

i. The group of engineers (Mean rank = 57.30) have higher adoption of the BIM 360 software than the group of architects (Mean rank = 46.34).

ii. The group of quantity surveyors (Mean rank = 57.36) have higher adoption of the BIM 360 software than the group of architects (Mean rank = 42.34).

(B) Relationship between familiarity and adoption of AI software

The results from Spearman's Rank Order Correlation shown that there is a positive correlation between the familiarity and adoption of AI software. Table 4.22 shows the correlation coefficient between the familiarity and adoption of each AI software.

Table 4. 22: Correlation Coefficient between the Familiarity and Adoption of AI Software.

Software	Correlation coefficient	Sig.
BIM 360	0.681	0.000
Smartvid.io	0.644	0.000
Easyflow CV	0.612	0.000
Doxel AI	0.607	0.000
Site AI	0.594	0.000
Disperse	0.579	0.000

As observed from Table 4.22 above, there is a direct correlation coefficient between the familiarity and adoption of each AI software.

4.4.5 Current Practice of integrating Building Information Modelling (BIM) and Artificial Intelligence (AI) in Construction

The current practice towards the integration of BIM and AI in construction is analysed in terms of the familiarity of the respondents towards the software integrating BIM and AI in the market and their adoption of this software.

(A) Familiarity with software integrating BIM and AI

Table 4.23 below shows the ranking for the familiarity with software integrating BIM and AI based on the medians and frequency of the medians.

Table 4. 23: Ranking for Familiarity with Software integrating BIM and AI

Software	Median	Median Frequency	%
Autodesk Revit (version 2021)	3	33	22.8%
Other equivalent software	1	88	60.7%
ReCap Pro	1	102	70.3%
Scan to BIM	1	102	70.3%
Visual Command Center	1	110	75.9%
Vico Office	1	115	79.3%
HoloBIM	1	115	79.3%
ALICE	1	120	82.8%
GenMEP	1	121	83.4%
Kreo Plan	1	122	84.1%

*1 - Not at all familiar, 2 - Slightly familiar, 3 - Moderately familiar, 4 - Very familiar, 5 - Extremely familiar

As observed from Table 4.23 above, only 22.8% of the respondents are moderately familiar with the Autodesk Revit version 2021 software. More than half of the respondents (60.7%) are not at all familiar with other equivalent software. 70.3% of the respondents are unfamiliar with the ReCap Pro and Scan to BIM software, followed by software such as Visual Command Center (75.9%), Vico Office (79.3%) and HoloBIM (79.3%). The ALICE (82.8%), GenMep (83.4%) and Kreo Plan (84.1%) software are the least familiar software to the majority of the respondents.

(B) Adoption of software integrating BIM and AI

Table 4.24 below shows the ranking for the adoption of software integrating BIM and AI based on the medians and frequency of the medians.

Table 4. 24: Ranking for the Adoption of Software integrating BIM and AI

Software	Median	Median Frequency	%
Autodesk Revit (version 2021)	2	23	15.9%
Other equivalent software	1	97	66.9%
Scan to BIM	1	117	80.7%
ReCap Pro	1	121	83.4%
Visual Command Center	1	123	84.8%
Vico Office	1	126	86.9%
GenMEP	1	127	87.6%
HoloBIM	1	127	87.6%
Kreo Plan	1	128	88.3%
ALICE	1	128	88.3%

*1 - Not at all, 2 = Slight, 3 - Quite, 4 - Usual, 5 - All the while

As observed from Table 4.24 above, merely 15.9% of the respondents slightly use the Autodesk Revit version 2021 software in their projects. Besides, more than half of the respondents (66.9%) are not using other equivalent software. The majority of the respondents are not using software such as Scan to BIM (80.7%), ReCAP Pro (83.4%), Visual Command Center (84.8%), Vico Office (86.9%), GenMEP (87.6%), HoloBIM (87.6%). Furthermore, Kreo Plan (88.3%) and ALICE (88.3%) are the software least adopted by construction practitioners.

The Kruskal Wallis test is used to compare the profession against the adoption of software integrating BIM and AI. Mann Whiney test is then used to conduct pairwise comparisons to identify the groups which are statistically different. Table 4.25 below shows the rejected null hypothesis.

Table 4. 25: Rejected Null Hypothesis for the Adoption of Software integrating BIM and AI

Rejected Null Hypothesis	Sig.
The adoption of Autodesk Revit (version 2021) software is the same between	
a) Groups with profession of	
i. Architect – Engineer	0.013
The adoption of Scan to BIM software is the same between	
a) Groups with profession of	
i. Architect – Engineer	0.023
ii. Architect – Quantity Surveyor	0.017

From results reported in Table 4.25, the pairs of respondents which have a statistically significant difference in their "Adoption of software integrating AI and BIM" are summarised below

a) Autodesk Revit (version 2021)
   i. The group of engineers (Mean rank = 58.93) have higher adoption of the Autodesk Revit (version 2021) software than the group of architects (Mean rank = 44.90).

b) Scan to BIM
   i. The group of engineers (Mean rank = 56.07) have higher adoption of the Scan to BIM software than the group of architects (Mean rank = 47.44).
   ii. The group of quantity surveyors (Mean rank = 53.94) have higher adoption of the Scan to BIM software than the group of architects (Mean rank = 45.06).

(C) Relationship between familiarity and adoption of software integrating BIM and AI

The results from Spearman's Rank Order Correlation shown that there is a positive correlation between the familiarity and adoption of software integrating

BIM and AI. Table 4.26 shows the correlation coefficient between the familiarity and adoption of each software integrating BIM and AI.

Table 4. 26: Correlation Coefficient between the Familiarity and Adoption of Software integrating AI and BIM

Software	Correlation coefficient	Sig.
Autodesk Revit (version 2021)	0.743	0.000
ReCap Pro	0.682	0.000
Visual Command Center	0.682	0.000
HoloBIM	0.680	0.000
Other equivalent software	0.646	0.000
Kreo Plan	0.644	0.000
ALICE	0.630	0.000
Scan to BIM	0.624	0.000
GenMEP	0.616	0.000
Vico Office	0.581	0.000

As observed from Table 4.26 above, there is a direct correlation coefficient between the familiarity and adoption of each software integrating BIM and AI.

4.4.6 Barriers hindering the integration of Building Information Modelling (BIM) and Artificial Intelligence (AI) in Construction

Table 4.27 below shows the ranking for the barriers hindering the integration of BIM and AI based on the medians and frequency of the medians.

Table 4. 27: Ranking for Barriers for integrating BIM and AI

Barriers	Median	Median Frequency	%
The high initial cost for software and hardware	4	74	51.0%
The additional cost for training workers	4	71	49.0%
My company has insufficient information in existing BIM software to support AI features	4	69	47.6%
The high cost in altering work progress	4	64	44.1%
My company has a lack of trained staff with BIM or AI expertise	4	64	44.1%
I am unfamiliar with the user interface of BIM software with AI features	4	61	42.1%
I am unfamiliar with the AI features provided in the BIM software	4	60	41.4%
I have encountered a bad experience in using BIM or AI	3	71	49.0%
I am comfortable with using BIM software with no AI features	3	69	47.6%
I am uncertain of the output of using BIM or AI	3	63	43.4%
My company is concerned with data security issues in using BIM or AI	3	61	42.1%
I am comfortable with traditional practices	3	57	39.3%
I am not aware of any good software integrating BIM and AI	3	53	36.6%
I am concerned that AI will change my future job scope	3	46	31.7%
The scale of the projects by my company do not require BIM or AI	3	45	31.0%
My company has poor ICT infrastructure	3	44	30.3%
My company has a lack of internal technical support	3	42	29.0%
I predict my workload will increase if I need to learn a new BIM software or AI approach	3	38	26.2%

*1 - Strongly Disagree, 2 - Disagree, 3 - Neutral, 4 - Agree, 5 - Strongly Agree

As observed from Table 4.27 above, around half of the respondents (51.0%) agreed that the high initial cost for the software and hardware is a barrier hindering the integration of AI and BIM in construction. The second highest

(49.0%) barrier agreed by the respondents is the additional cost for training workers. Next, 47.6% of the respondents agreed that their company has insufficient information in existing BIM software to support AI features. Besides, the high cost of altering work progress and the lack of trained staff in their company with BIM or AI with expertise agreed by 44.1% of the respondents as the challenges as well. Furthermore, 42.1% of the respondents agreed that they are unfamiliar with the user interface of BIM software with AI features and 41.4% are unfamiliar with the AI features provided in the BIM software.

The Kruskal Wallis test is used to compare the profession against the perception on the barriers of integrating BIM and AI" is rejected. Mann Whiney test is then used to conduct pairwise comparisons to identify the groups which are statistically different. Table 4.28 below shows the rejected null hypothesis.

Table 4. 28: Rejected Null Hypothesis for the Adoption of Software integrating BIM and AI

Rejected Null Hypothesis	Sig.
The agreement on the statement "*The scale of the projects by my company do not require BIM or AI*" is the same between	
a) Groups with profession of	
i. Engineer – Quantity Surveyor	0.031

From results reported in Table 4.28, the pairs of respondents which have a statistically significant difference in their opinion towards "Barriers hindering the integration of BIM and AI" are summarised below

a) *The scale of the projects by my company do not require BIM or AI*
   i. The group of engineers (Mean rank = 51.42) perceived higher agreement than quantity surveyors (Mean rank = 39.95) on the statement "*The scale of the projects by my company do not require BIM or AI*"

4.4.7 Relationship between the Perception and the Barriers of integrating Building Information Modelling (BIM) and Artificial Intelligence (AI)

The results from the Spearman's Rank order Correlation revealed that there is a correlation between one's perception towards the integration of BIM and AI and the barriers of integrating BIM and AI. Table 4.29 to Table 4.33 shows the results of the Spearman's Rank order Correlation.

Table 4. 29: Correlation between "I am interested in learning more knowledge on the integration of BIM and AI" and the statements on the barriers

Barriers	Correlation Coefficient	Sig.
I predict my workload will increase if I need to learn a new BIM software or AI approach	-0.193	0.020
I have encountered a bad experience in using BIM or AI	-0.171	0.040

As observed from Table 4.29, there is an inverse correlation between one's interest in learning more knowledge on BIM and AI integration and the agreement of one predicting his or her workload will increase if required to learn new software. Similarly, there is an inverse correlation between one's interest in learning more knowledge of BIM and AI integration and the likeliness of one encountering a bad experience with BIM or AI software before.

Table 4. 30: Correlation between "I look forward to using BIM with AI features in future construction processes" and the statements on the barriers

Barriers	Correlation Coefficient	Sig.
I predict my workload will increase if I need to learn a new BIM software or AI approach	-0.194	0.019
I have encountered a bad experience in using BIM or AI	-0.174	0.037

As observed from Table 4.30, there is an inverse correlation between one's anticipation of using BIM with AI features and the agreement of one predicting his or her workload will increase if required to learn new software. Similarly, there is an inverse correlation between one's anticipation of using BIM with AI features and the likeliness of one encountering a bad experience with BIM or AI software before.

Table 4. 31: Correlation between "I believe that integrating BIM and AI will reduce the shortcomings of BIM" and the statements on the barriers

Barriers	Correlation Coefficient	Sig.
I have encountered a bad experience in using BIM or AI	-0.199	0.017

As observed from Table 4.31, there is an inverse correlation between one's belief that integrating BIM and AI will reduce the shortcomings of BIM and the likeliness of one encountering a bad experience with BIM or AI software before.

Table 4. 32: Correlation between "I believe that integrating BIM and AI will improve the performance of AI" and the statements on the barriers

Barriers	Correlation Coefficient	Sig.
I predict my workload will increase if I need to learn a new BIM software or AI approach	-0.240	0.004
I have encountered a bad experience in using BIM or AI	-0.202	0.015

As observed from Table 4.32, there is an inverse correlation between one's belief that integrating BIM and AI will improve the performance of AI and the agreement of one predicting his or her workload will increase if required to learn new software. Similarly, there is an inverse correlation between one's belief that integrating BIM and AI will improve the performance of AI and the likeliness of one encountering a bad experience with BIM or AI software before.

Table 4. 33: Correlation between "I believe that BIM and AI can complement each other through integration" and the statements on the barriers

Barriers	Correlation Coefficient	Sig.
I have encountered a bad experience in using BIM or AI	-0.284	0.001
I predict my workload will increase if I need to learn a new BIM software or AI approach	-0.260	0.002

As observed from Table 4.33, there is an inverse correlation between one's belief that BIM and AI can complement each other through integration and the agreement of one predicting his or her workload will increase if required to learn new software. Similarly, there is an inverse correlation between one's belief that BIM and AI can complement each other through integration and the likeliness of one encountering a bad experience with BIM or AI software before.

4.4.8 Relationship between the Perception towards the Importance of Applications integrating Building Information Modelling (BIM) and Artificial Intelligence (AI) and the Adoption of Software

The results from the Spearman's Rank order Correlation revealed that there is a correlation between one's perception towards the importance of BIM and AI and the adoption of software integrating BIM and AI. Table 4.34 shows the correlation between the importance of "Automated site progress monitoring assists the as-built model production" and the adoption of related software.

Table 4. 34: Correlation between the importance of "Automated site progress monitoring assists the as-built model production" and the Adoption of Software

Software	Correlation Coefficient	Sig.
Scan to BIM	0.171	0.040

As observed from Table 4.34, there is a direct correlation between the agreement on the importance of "Automated site progress monitoring assists the as-built model production" and the adoption of the Scan to BIM software.

4.5 Discussion on Questionnaire Findings

This section will discuss the questionnaire findings in terms of the perception of construction practitioners towards the integration of BIM and AI, the current practice in the industry and the barriers hindering this integration.

4.5.1 Perception towards the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

The findings in Section 4.4.1(a) suggest that around half of the respondents are interested to learn about BIM or AI and anticipate using BIM or AI in their projects. The respondents also perceive that learning more knowledge on BIM and AI will be beneficial to their career development. These findings indicate that construction practitioners are keen to embrace BIM or AI technologies respectively even though both technologies are not integrated. Likewise, the Construction Industry Development Board (CIDB) declared that the majority of construction practitioners are willing to adopt BIM (CIDB, 2016). Besides, it can be observed that respondents working as engineers and quantity surveyors have higher agreement on the statement "*I think that BIM can be used only for illustration purpose*" as compared to respondents working as architects. This variance in perception may be due to architects have a greater familiarity with features in the BIM software such as Sketch Up, ArchiCAD and Vectorworks and adopt BIM software more regularly than other professions which are indicated in the findings in Section 4.4.3 (a). This may also be due to the nature of the architect's profession as a designer. This finding also indicates that engineers and quantity surveyors tend to have a lower understanding of BIM capabilities.

Moreover, approximately half of the respondents foresee that BIM and AI implementation will become norms within the next 10 years in Section 4.4.1(b) and (c). Around half of the respondents agree that AI will have a large impact on the construction industry operations. Similarly, the respondents with

0 - 2 years experience achieved higher agreement than the respondents with above 6 years experience. This indicates that construction practitioners which have just entered the workforce are more aware of the influence that BIM and AI will eventually bring to the construction industry. This may because the fresh graduates tend to have higher acceptance of these disruptive technologies to construction due to modification in course structures of universities to update on the latest trends in the industry. Besides that, they are not accustomed to the traditional ways.

Furthermore, construction practitioners agreed that BIM and AI are able to complement each other through integration and agreed that the shortcoming of BIM can be minimised with the help of AI as revealed in Section 4.4.2 (a). Above half of the respondents are also attracted to learning more knowledge on this integration and using BIM with AI features. These findings indicate that respondents are slightly more captivated by the collaboration of these two technologies as compared to learning BIM and AI independently and are enthusiastic to embrace this integration. Besides, the findings of Section 4.4.2 (b) suggest that the respondents perceived all the applications of BIM and AI integration are very important with automated cost estimation, construction simulation and automated site progress monitoring classified as the three most important applications. Thus, these findings show that the construction practitioners perceived that applications of this integration are significant to enhance current construction processes. Similarly, the findings indicate that construction professionals with 3 to 5 years of experience perceive that clash detection is more important compared to other working experience groups. The reason behind this difference may be because the respondents with 3 to 5 years of working experience have more experience in using BIM software as compared to other groups. For instance, the respondents with working experiences within 3 to 5 years are more familiar with the Autodesk Revit software than those with above 6 years’ experience as described in Section 4.4.3(a).

4.5.2 Current Practice of integrating Building Information Modelling (BIM) and Artificial Intelligence (AI)

As discussed in the literature review, sufficient data in BIM is essential for the integration of BIM and AI. Nonetheless, BIM implementation is still at the early stage in the construction industry. Autodesk Revit versions before 2021 and Sketch Up are the most popular BIM software among the respondents with the Sketch Up software especially familiar to architects. Section 4.4.3(c) has proved that there is an association between familiarity with software and the rate of software adoption, and the greater the familiarity with the software, the higher chance of adoption. This can be illustrated in Section 4.4.3(b) which shows that quantity surveyors and engineers have a lower involvement in adopting BIM software such as Sketch Up in their work processes when compared to architects as they are less familiar with BIM. As for AI software, only 20 respondents are slightly familiar with the BIM 360 software and the majority of the respondents have not adopted the AI software in their projects. This shows that AI adoption is at a low level in the local construction industry. Furthermore, the usage of software integrating AI and BIM is also low as described in Section 4.4.5(b). Autodesk Revit version 2021 integrated generative design as one of the new functions, which is perceived to be attractive to construction practitioners based on their high interest in the integration of BIM and AI as discussed earlier. However, only almost a quarter of respondents are moderately familiar with this software and only 15.9% of the respondents slightly use this software. Similarly, it was founded that architects have a higher usage rate on the software integrating AI and BIM as compared to other professions.

Although the findings suggest that the adoption of the software integrating BIM and AI are barely carried out currently in the construction industry, it should not be implied that this integration is not possible in the future. This low adoption may be due to two constraints. First, construction practitioners have yet to realise the benefits which BIM and AI can bring about and companies are only getting used to BIM, which indicates that there is still a long way to go before BIM with AI features can be practically utilised in projects. Allen (2017) quoted that “the future of BIM will not be BIM” and Building Information Modelling (BIM) may be developed into Building

Information Optimisation in the future with the aid of AI. The idea of Building Information Optimisation is closely related to generative design where the computer is given constraints on buildings requirements and automatically generates alternative designs which fit the constraints. He highlighted that currently, the industry is using BIM software to collect data and design buildings manually which is proven in the findings of this study.

4.5.3 Barriers hindering the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

Section 4.4.6(a) revealed that the burdensome initial cost of the software and hardware and the additional cost of training workers as the top barriers hindering the adoption of BIM and AI. In addition, around half of the respondents disclosed that their company has not secured adequate information in current BIM software to support the AI features available. This may be due to BIM adoption is not extensively used in the Malaysian construction industry as described in Section 4.4.3 (b). Besides, Section 4.4.6 (a) also revealed that around 40% of construction practitioners are unfamiliar with the user interface of BIM software integrated with AI features as well as the AI features in the BIM software.

Additionally, it has been discovered that there is an inverse correlation between the perceptions of construction practitioners towards the integration of BIM and AI in construction and the barriers they agree with. As an illustration, the respondents which had an unsatisfactory experience in using BIM or AI are less enthusiastic about gaining knowledge on the integration of these two technologies as well as using the features from BIM and AI collaboration. Those who envisage their workload will be enlarged due to the need to acquire new learning and skill in BIM or AI, tend to have lower interest in this integration and are not keen to use BIM providing AI features for their work processes. Thus, the reasons which cause respondents to have low expectations on this integration might be due to unsatisfactory experience in the usage of BIM or AI or the fear of handling more work due to the need to adapt and learn these technologies.

4.6 Findings from Interview

A total of three interviewees were interviewed by online platforms and phone calls. Table 4.35 below shows the background of the interviewees.

Table 4. 35: Background of Interviewees

	Interviewee A	**Interviewee B**	**Interviewee C**
Profession	Quantity Surveyor	Civil Engineer	Civil Engineer
Working experience	4 years	1 year	28 years
Level of Management	Senior	Junior	Director
Company Background	Contractor firm	Consultant firm	Manufacturing firm

4.6.1 Personal View towards Building Information Modelling (BIM)

All interviewees have an optimistic view towards BIM in construction.

Interviewee A mentioned that:

"I think that BIM can improve the overall performance of the construction projects "

Interviewee B mentioned that:

"I think that using BIM is more convenient as compared to using 2D CAD software"

Interviewee C said:

"BIM carries a lot of benefits"

4.6.2 Benefits of Building Information Modelling (BIM)

All interviewees coincidentally mentioned clash detection for mechanical and electrical systems and reduction of cost and time as the benefits of BIM.

Interviewee A mentioned that:

"It can reduce human errors such as clash in piping system design and minimise cost and time implications due to rework"

Interviewee B had raised similar statements:

"In some projects not using BIM, there will be issues such as many clashes between the design from the architect and mechanical and electrical systems."

“Using BIM, we can just insert everything in the model and it will automatically detect the clashes”

“Cost and time are can be reduced”

Interviewee C stated that:

“There’s a lot of benefits especially regards to mechanical and electrical aspect”

He gave an example regarding this statement:

“If the M&E contractor does not take care of the project, you will end up with pipes projecting here and there and become ugly, then you need the architects or interior designer to come back and hide it and all these will lead to extra cost.”

“..if BIM is used, the cost can be saved… BIM minimises the errors”

“If you look at 3D, you see if any of the rebars are clashing and if the shape fits or not fits in”

He further mentioned that:

“BIM has a lot of benefits if you go to every detail if you go to the maintenance benefits if you have all the details of building”

4.6.3 Current Practice of Building Information Modelling (BIM)

Interviewee B and C have both use BIM software such as Autodesk Revit and Tekla Structures to create structural models. On the other hand, Interviewee C which is a quantity surveyor uses Cubitcost which is a BIM-based software focusing on quantity takeoff and cost estimation (Cubicost, 2020).

Interviewee A who is using the Cubitcost software stated that:

"This software has been used for 2 years in this company"

"We normally this software to takeoff quantities for reinforcement works and painting which are difficult to take off"

Interviewee B using Autodesk Revit and Civil 3D stated that:

"Autodesk Revit 2020 is used"

"The architectural BIM model and the structural BIM model will then be combined in the software to become a single model."

"Civil3D is used for infrastructure design, water reticulation, sewerage, drainage, earthwork"

Interviewee C using Tekla Structures mentioned that:

"I think that was about 10 years ago, we started to invest in this software."

"Tekla structures is used as it is more suitable for precast concrete"

Nevertheless, the adoption of BIM depends on the project requirements and AutoCAD is still used for the majority of the construction processes and projects.

Interviewee A mentioned that:

"For the remaining elements, we still use Autocad to measure"

Interviewee B mentioned that:

"If the client of the project request for BIM services, the architect will provide BIM model Revit files to engineers"

"adoption of BIM is just like an additional service provided when the client is willing to pay more for BIM usage"

"For projects not adopting BIM, AutoCAD files are prepared by the architect"

"We use BIM during the designing stage, but during the execution of works, physical 2D drawings and AutoCAD files are used by contractors as it is difficult to access the 3D models at the construction site"

Interviewee C mentioned that:

"If we decided to shift, then we shift. We have many projects ongoing at one time, for those projects we find that simple or not suitable for BIM then we don't use, and slowly we have more and more using BIM and we cut off the use of 2D CAD."

Moreover, Interviewee A and B highlighted the involvement of BIM by consultants and contractors is little and only large companies require BIM to be used.

Interviewee A and B both emphasised that:

"There is not much involvement of the contractors and quantity surveyors in BIM"

"not many project developer or even consultant is willing to go full speed on BIM"

"when tendering for large company projects, the adoption of BIM is one of the minimum requirements for participating in the tender."

4.6.4 Problems of Building Information Modelling (BIM)

Each interviewee has stated the issues they have faced when adopting BIM.

Interviewee A specified that:

"I think the main problem is that we are not familiar with the features in the software as the external training we attended only taught us basic skills"

Interviewee B stated that:

"problems is that we are doing repetitive task….we need to draw the design in AutoCAD and then redraw in the Revit software again"

"current software available is not that user friendly"

Interviewee B mentioned that:

"I think most BIM software should be able to give you the estimates"

"If you feed the wrong information in the computer, the quantity will be wrong also."

"I think that the accuracy of the final result is still subject to human error."

Table 4.36 summarises the interview findings for the theme of Building Information Modelling (BIM)

Table 4. 36: Summary of Findings for the Theme of BIM

Theme	Sub Theme	Interviewee A	Interviewee B	Interviewee C
Building Information Modelling (BIM)	Personal Views	Improves performance	Convenient	Many benefits
	Benefits	Clash detection Reduces cost and time	Clash detection Reduces cost and time	Clash detection Quantity taking off Prefabrication planning Facility maintenance Reduces errors and cost
	Current practice	*Software used:* Cubit cost, AutoCAD *Duration of use:* 2 years *Company practice:* Cubitcost used to take-off quantities for reinforcement works and painting AutoCAD used for taking off quantities for remaining elements	*Software used:* Autodesk Revit 2020, AutoCAD, Civil 3D *Duration of use:* At least 1 year *Company practice:* Autodesk Revit used for architectural and structural design modelling Civil3D used for infrastructure design, water reticulation, sewerage, drainage, earthwork	*Software used:* Tekla Structures *Duration of use:* Above10 years *Company practice:* Tekla structures used for precast concrete modelling AutoCAD used for simple projects Slowing added licenses and converted most projects into BIM *Industry status:*

		BIM as an additional service and only adopted if the client requests and pay for this service AutoCAD used for projects not adopting BIM. BIM is used only during the designing stage Physical 2D drawings and AutoCAD files are used by contractors during project execution *Industry status:* Contractor and consultant mostly using AutoCAD BIM is the minimum requirement for tendering in large company projects	Developer and consultant mostly using AutoCAD BIM is the minimum requirement for tendering in large company projects
Problems	Unfamiliar with the features in the software as the external training only taught the basic skills	Repetitive tasks are done due to the need to draw in both Autocad and Autodesk Revit The current software available is not user friendly	The accuracy of the final estimate from software is subject to human error

4.6.5 Personal View towards Artificial Intelligence (AI) in Construction

Three of the interviewees perceive AI as recent and advanced technology and all of them have yet to come across or used any AI technology or software for construction.

Interviewee A, B and C respectively stated that:

“I don’t have much comments in AI as I have not used any of these technologies”

“I’m not sure about the abilities of AI”

“Artificial intelligence is still quite new. I don’t understand how AI can come into constructions and I have not come across it before.”

Nonetheless, all three interviewees have a positive view towards the potential of AI in construction.

Interviewee A mentioned that:

“I think AI has the potential to reduce workload of construction practitioners”

Interviewee B mentioned that:

“I think that AI can aid in decision making…. final decision still has to be decided by the engineer”

Interviewee C mentioned that:

“there are many different applications where AI can help, but it is still the very beginning… It will lead to a lot of improvement. Like machine improve itself.”

4.6.6 Future View towards Artificial Intelligence (AI) in Construction

Three interviewees expressed their concerns on the potential impact of AI on the labour force in construction.

Interviewee A said:

"I think that we will be replaced if we don't learn how to use AI technologies."

"I also think that AI will cause job opportunities to reduce for construction practitioners….there will be less job opportunities, less people in a team to achieve a similar outcome of similar performance."

"I predict that the job scope of construction practitioners will change."

Interviewee B stated that:

"I think that the negative side is that some construction practitioners might be replaced by AI technology"

He further illustrated:

"For example, I noticed that some software can automatically calculate the quantity of materials for reinforcement and concrete after the design is completed in the software."

Interviewee C stated that:

"…repetitive works which don't require a lot of thinking might be possible to be replaced"

"this digitalisation that will be affected will be the blue-collar workers handling repetitive work"

He further clarified that:

"…those which require some thinking and empathy and feel, people will be needed. In addition to that, you need people to manage the computers"

Nevertheless, both Interviewee A and B highlighted the possible positive impacts of AI on the local construction industry as well.

Interviewee A stated that:

"This might be a good phenomenon as we can reduce the number of foreign labours in the Malaysian construction industry"

Interviewee B said:

"the bright side is that AI might help to save cost, shorten the project timeframe and help the project progress smoothly"

As for the adoption of AI, Interviewee A and B have similar views

Both interviewees mentioned that:

"I think that AI technologies can only be implemented after BIM becomes widely used and familiar among construction practitioners in the industry."

"I think that since BIM is not adopted widely, AI might take longer time to be adopted as it is perceived as more advanced technology"

4.6.7 Benefits of Artificial Intelligence (AI) in Construction

The interviewees pointed out the potential benefits AI can bring if it is integrated into the construction environment.

Interviewee A suggested that:

“AI has the potential to reduce workload of construction practitioners”

“The accuracy of the work produced by AI will be better”

He illustrated that:

“For instance, variation orders and post construction claims can be reduced and the final account will be easier to proceed or close”

Interviewee B suggested that:

“AI might help to save cost, shorten the project timeframe and help the project progress smoothly”

Interviewee C suggested that:

“If AI can learn from previous experience, there will be a lot of benefits especially in project management and scheduling”

“We can plan better with the help of AI.”

4.6.8 Current and Coming Practice of Artificial Intelligence (AI) in Construction

All three interviewees revealed that they are not using any AI technologies in their work processes and no strategies have been proposed to implement AI technology. They highlighted that they are still adapting to the use of BIM.

Interviewee A mentioned that:

“We have just invested in the Cubitcost software, so we are focusing on utilising this software.”

Interviewee B mentioned that:

"So far no strategies are proposed."

Interviewee C stated that:

"We only use Tekla structures"

Table 4.37 summarises the interview findings for the theme of Artificial Intelligence (AI)

Table 4. 37: Summary of Findings for the Theme of AI

Theme	Sub Theme	Interviewee A	Interviewee B	Interviewee C
Artificial Intelligence (AI)	Personal Views	Yet to use Potential to reduce workload Training is needed for construction practitioners to adapt More advanced compared to BIM	Yet to use Unfamiliar Potential to aid decision making Interested More advanced compared to BIM	Yet to use New and unfamiliar Many potential applications At the beginning stage
	Future Views	Construction practitioners might be replaced if they don't adapt and learn Change in job scope Foreign labours may be reduced	Construction practitioners might be replaced by AI	Blue collar workers affected Efforts and resources saved
	Benefits	Potential to reduce workload Potential to reduce variations in work Better accuracy of work	Potential to save cost Potential to shorten the project time Smoothen project progress	Potential benefits in project management and scheduling Better project planning
	Current practice	Not adopting AI	Not adopting AI	Not adopting AI
	Coming practice	No plans to adopt	No plans to adopt	No plans to adopt

4.6.9 Personal View towards the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

The three interviewees revealed that they are looking forward towards the integration of BIM and AI.

Interviewee A said:

"I am willing to try BIM with AI features"

Interviewee B mentioned that:

"I am quite interested in this integration and would like to learn more about it"

He added that:

"I am interested to know if this technology can reduce our workload."

Interviewee C stated that:

"if AI can learn from previous experience, there will be a lot of benefits"

4.6.10 Future View towards the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

Interviewee A and B perceived that this integration may not be seen in the near future for the Malaysian construction industry.

Interviewee A claimed that:

"I think it will be achieved after 30 to 40 years from now"

"The Malaysian construction industry is famous for its resistant to change or reluctant to implement new technology."

Interviewee B claimed that:

"I think that in the coming few years, these technologies might not bring a major impact or change to the Malaysian construction industry"

Alternatively, Interviewee C sees this integration as a catalyst for digital transformation in the construction industry.

He mentioned that:

"I think it will definitely be the catalyst for digital transformation"

4.6.11 Benefits of the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

The expected benefits mentioned by construction practitioners on this integration were similar to the benefits of AI in construction.

Interviewee A, B and C mentioned that:

"I think if this integration is implemented, cost, time and errors can be reduced."

Interviewee A further added:

"I can focus on other projects or handle more projects at the same time."

4.6.12 Expectations on the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

Interviewee A and B both addressed their issues on having to use 2D CAD software and BIM software alternatively and suggested a feature for this integration to automatically convert existing 2D CAD drawings to 3D models.

Interviewee A suggested that:

“I would prefer is a software to scan the existing 2D drawings and 3D models can be generated in the existing BIM software”

Similarly, Interviewee B said he was concerned with the fact he has to repeat the design process in both AutoCAD and Autodesk Revit and suggested that:

“It would be great if there is a feature in BIM which allows us to import the AutoCAD drawings into the BIM model, and convert those AutoCAD or 2D files in the drawings”

Furthermore, Interviewee A and C suggested a feature they prefer for their respective field in quantity surveying and precast component manufacturing respectively.

Interviewee A stated that:

“If the BIM model very detailed and specific on the reinforcement layout, then it will ease interpretation and the calculations of quantities for reinforcement work”

He further explained with an example:

“For example, if we can click on a beam and it will reveal the reinforcement by making it transparent”

Interviewee C initially suggested that he has not much expectations as the features he can think of is already equipped in the software.

He mentioned that:

"What we can think of, the software already has. We haven't exploited it to the fullest"

However, he suggested a feature which he think is convenient for prefabrication in the construction industry

He stated that:

"I think if you use the BIM drawings and feed them to the factory computer, and the factory can produce for you automatically, all drawings can fit into the factory side"

"…computer can instruct the robots to do things automatically, that kind of productions in very productive, and very little human labour input"

4.6.13 Current and Coming Practice on the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

As discussed in Section 4.5.3 and Section 4.6.8 on the current and coming practice of BIM and AI respectively. The interviewees have only used BIM-based software for specific projects and have yet to adopt AI technologies in their daily applications. They have highlighted that they are still adopting and learning the features of the current BIM software subscribed by the company and from their knowledge and there are no plans to employ any new software with AI features.

4.6.14 Barriers hindering the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

Cost and resistance to change by construction practitioners are the main challenges mentioned by all three interviewees coincidentally.

Interviewee A stated that:

"The initial cost, training and site adaptation"

Interviewee B stated that:

"The cost is the major barrier"

He further explained:

"For example, the cost for the application of the licence of the software"

Interviewee C stated that:

"software is costly and complicated. The initial investment is high and annual maintenance is high"

Interviewee B and C emphasised that the benefits of implementing this technology have to exceed the cost of investment

They stated that:

"Benefits have to exceed the cost"

"..implementation of BIM will increase if the benefits of using this kind of technology exceed the cost"

Interviewee A, B and C raised similar statements regarding the resistance to change by construction practitioners.

The three of them mentioned respectively:

"Resistant to change, some will think that humans are better and perceive that the traditional way is the best because it's effective and it works."

"Some construction practitioners which have been working in the industry for a long time are also reluctant to accept these technologies"

"Human beings are comfortable with old ways"

Moreover, the further barriers mentioned by the interviewees include unfamiliarity with the software, consideration of client requirements, authority requirements and internal capacity, lack of training and reliance on cheap labour.

Interviewee A further mentioned that:

"I think the main problem is that we are not familiar with the features in the software as the external training we attended only taught us basic skills"

Likewise, Interviewee C mentioned that:

"The more feature you have there will be more complicated."

He further stated there is a lack of skilled labour to implement this technology and the industry is reliance on cheap labour :

"The main problem is are there enough people to handle it….are people motivated enough to change…not many people can get enough drafters"

"Malaysia construction industry in the past has been very much stuck to cheap labour."

Interviewee B mentioned that:

"We also need to take account of the authority and client requirements."

He explained that:

"only clients from large companies will request BIM to be adopted in their projects"

4.6.15 Suggested Solutions for the Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

Government incentives have been suggested by Interviewee A and C for this implementation while Interviewee B suggested raising the awareness of BIM among construction practitioners.

Interviewee A recommended that:

"incentives on these software would be good."

Interviewee B stated that:

"We need to increase the awareness of construction practitioners that BIM is the coming trend to facilitate its implementation"

Interviewee C stated that:

"Government incentives yes"

He further explained that the government plays a vital role in the promotion of using these technologies and it is either a push and pull factor:

"People may be shying away if there are not good people to lead"

"I think a lot of promotion is needed from CIDB, I just finished reading the CIDB Construction 4.0 plan talking about smart construction …..But much if you talk about, is a matter of how to promote, how you

encourage, how you get them to change. Of course, the curriculum of the university also has a part to play"

"I think in any implementation, in government policymakers, its always a push and pull factor. Either you give enough incentives to pull people into this area ort you just don't give chance and just tell everybody it has to be implemented"

Table 4.38 summarises the interview findings for the theme of integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)

Table 4. 38: Summary of Findings for the Theme of Integration of BIM and AI

Theme	Sub Theme	Interviewee A	Interviewee B	Interviewee C
Integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)	Personal Views	Willing to try	Interested to learn more	Many benefits
	Future Views	Adoption may take 30 to 40 years in the Malaysian construction industry	Might not bring impact in the coming few years in the Malaysian construction industry	Might be the catalyst for digital construction
	Benefits	Potential to reduce cost, time and errors More projects can be handled simultaneously	Potential to save cost Potential to shorten the project time frame Smoothen project progress	Potential to reduce cost and time
	Expectations	Visualisation of details in reinforcement works to ease quantity measurement Software to scan and convert 2D drawings into 3D models	Software to scan and convert 2D drawings into 3D models	Prediction of the life span of building components Automatic design of precast components based on BIM models
	Current practice	Not adopting	Not adopting	Not adopting
	Coming practice	No plans to adopt	No plans to adopt	No plans to adopt
	Barriers	Cost considerations	Cost considerations	Cost considerations

	Resistance to change as perceiving the traditional approach is effective Training is needed Unfamiliar with software	Resistance to change as perceiving the traditional approach is effective Considerations on authority and client requirements Issues in BIM implementation BIM potential not fully realised Benefits have to exceed the cost	Resistance to change Lack of skilled labour Lack of motivation to change Lack of good people to lead Reliance on cheap labour Many features in software make it complicated Consideration in internal capacity Benefits have to exceed the cost
Suggestions	Incentives for software	Increase awareness of BIM trend	Government incentives A mandatory requirement by the government Promotion from the Malaysian Construction Industry Development Board (CIDB) Update curriculum of universities

4.7 Discussion on Interview Findings

This section will discuss the outcomes from the semi structured interviews. Generally, all interviewees have perceived that Building Information Modelling (BIM) is helpful in their daily work operations. Three of them have emphasised that the clash detection feature in current BIM software is useful during the design process for the mechanical and electrical systems which minimises errors and cost and time implications due to rework. Thus, it can be observed that construction practitioners who adopted BIM have begun to realise the convenience of BIM as compared to the conventional approach. However, the level of BIM achieved by the interviewees' companies remains low. Interviewee B and C's companies can be defined as BIM Level 1. BIM Level 1 is defined as the combination of 2D and 3D information with the use of a Common Data Environment provided by a collaboration tool (Mordue, 2019). Correspondingly, the questionnaire findings in Section 4.4.3(a) and (b) revealed that only less than a quarter of respondents are using Autodesk Revit and Sketch Up in their projects. In addition, only specific projects are required to use BIM as BIM usage depends on client preference and the complexity of the project. As for Interviewee A's company, the Level of BIM is achieved is perceived as BIM Level 0 as information is being shared in conventional 2D CAD drawings or PDF files with separate sources of information involving fundamental assets information (Mordue, 2019). The interviewees have also pointed out the shortcomings of current BIM implementation which include unfamiliarity of the features in the BIM software, the non-user friendly of BIM software and the inaccuracy of quantity estimates generated by the BIM software due to human mistakes. Interviewee A and C which are civil engineers also pointed out that contractors and consultants are not actively involved in using BIM which is supported by the findings in Section 4.4.3 (a). This phenomenon can be observed in the current practice by Interviewee C who is a quantity surveyor working at a contractor firm. In short, engineers have a higher practice of BIM as compared to quantity surveyors and contractors and the achievement of BIM Level 3 might be slow based on the level of current practice.

As for Artificial Intelligence (AI), the interviewees perceive this technology as new and advanced technology. They have yet to adopt any technologies powered by AI and they foresee that AI will not be adopted in the coming few years. This is because BIM is not being widely adopted in the construction industry yet as highlighted by Interviewee A and B and AI is perceived as more advanced technology. Nonetheless, all the interviewees look forward to the potential of AI in increasing the accuracy of work, minimising workload and assisting in decision making. Besides, they have also expressed their concerns on the possible impact AI may bring in reducing job opportunities for blue collar workers who perform repetitive work. Nonetheless, Interviewee A highlighted that this impact may be beneficial to reduce the amount of foreign labour in the industry. In brief, the implementation of AI in construction is still in the infancy stage and construction practitioners have both optimistic and adverse views towards AI in construction.

As for the proposal for the integration of BIM and AI, three interviewees have expressed their interest in this integration and are willing to learn more about this integration to know if it can reduce their workload which is aligned with the findings in Section 4.42 (a). Similarly, to AI, the interviewees perceive that this integration will not have a major impact on the construction industry in the coming few years. This may be due to the fact that construction practitioners are only starting to adapt to use BIM and some are still unfamiliar with the features in the software as mentioned by Interviewee A. Similarly, Section 4.4.3 (a) revealed that less than half of the respondents are moderately familiar with BIM software and only architects have higher familiarity with the Sketch Up software. Moreover, Interviewee C also pointed out that more features may make the software more complicated for users. Since the BIM is adopted along with 2D CAD, Interviewee A and B both stated that they prefer software that can scan existing 2D drawings into 3D models to abolish the chance of performing repetitive work. For example, Interviewee A is required to recreate the 3D model in the Cubitcost software based on the AutoCAD drawings while Interviewee B needs to redraw the identical structural design in both AutoCAD and Autodesk Revit as the contractors are unable to access the Autodesk Revit files at the construction site. This feature may become a reality through the integration of BIM and AI. For instance, Rho, Lee and Park (2020) proposed a framework for the automatic production of a BIM model based on 2D drawings using machine learning for drawing recognition which generated accurate results. Besides, Interviewee C stated that the accuracy of the quantity estimates computed in BIM software is prone to errors which leads to the need for automated cost estimation to elevate the accuracy of estimates.

Several barriers for this integration have been discussed by the interviewees with the primary barrier being the initial and maintenance cost for the software and tools. They emphasised that this integration will only be adopted if the benefits exceed the cost. Similarly, Darko et al. (2020) highlighted that while cost may be a significant obstacle in AI implementation, applications can still be developed if the advantages are clear and well understood. Section 4.4.6 of the questionnaire findings also identified the high initial cost and cost for training workers as the top roadblocks. Additionally, the interviewees mentioned that the resistance to change by construction practitioners is another big challenge to overcome. Interviewee A also mentioned that the unfamiliarity with the features in the software is a major problem. In the same way, Section 4.4.5 (c) in the questionnaire findings has proved that familiarity with the software has a direct relationship with the adoption of software. The lack of detailed information in BIM models is also a top barrier indicated in Section 4.4.6. This may be because BIM is only used for specific projects and mostly in the designing stage which leads to companies not being able to secure sufficient data in the BIM models. Hence, each interviewee further provided suggestions to overcome these barriers that include government incentives and promotion by relevant authorities for example the Malaysian Construction Industry Development Board (CIDB). Interviewee C highlighted an alternative solution is for the government to mandate the use of these technologies by all parties in the construction environment.

4.8 Proposed Framework for Building Information Modelling (BIM) and Artificial Intelligence (AI) Integration

After the analysis from both questionnaire and interview, the framework for BIM and AI integration is proposed to help companies to start with the BIM and AI integration in projects. Figure 4.1 illustrates the framework for the integration of BIM and AI in construction. It outlines the development of the integrated BIM intelligent system and the applications of this system throughout the project lifecycle. It is highlighted that the proposal is not a "one size fit all" framework and is subjected to fine tuning due to the different company plan, policies, availability of tools and experts.

4.8.1 Creating a Database from BIM Models

The manually created BIM models from completed projects and the BIM models produced with the assistance of the intelligent BIM systems are the two main sources of data collected to produce a database. The database will act as training data for the AI models.

4.8.2 Automated Classification of BIM Data

The data in the database is then sorted by AI into more structured data to facilitate the training of the AI models. Two AI approaches have been found to automatically classify the data in the BIM models. First, Lomio, et al. (2018) suggested that there is a need to automate the classification of structure types from a BIM representation. A classifier eliminates the need to manually classify each of the many existing models with no metadata such as building types. The knowledge in the main features of the building supplemented with historical data may aid in the development of automatically designing structures. This study trained modern machine learning approaches such as pre-trained Convolutional Neural Networks (CNN) to classify buildings designs into three categories which are apartment buildings, industrial building and others which generated highly accurate results.

Besides, Koo, Jung and Yu (2021) studied the use of deep learning models such as PointNet and Multi-view Convolutional Neural Networks (MVCNN) and to automatically categorise BIM elements such as doors and walls. MVCNN creates 3D shaped classifiers from its 2D image renderings and PointNets is a deep neural network capturing point clouds as inputs to categorise and separate 3D objects. Both of these deep learning models achieved high accuracy results with MVCNN having the highest classification performance for both door and wall element subtypes.

4.8.3 Development of Intelligent BIM Systems

The trained AI models are then integrated with the existing BIM features to be developed into an integrated intelligent BIM system. As an illustration, Hall (2013) explained the idea of utilising the data needed for thermal, structural, fire, lighting and acoustic simulations provided in BIM models with AI and expert systems to create an intelligent design assistant which can access the recognised BIM database or the international internet database for BIM objects, material and component specification data. The system could offer design suggestions or modify the design itself to minimise cost. Besides, the comfort and fire safety of the simulation of the virtual building could be tested by virtual users through interaction. Moreover, Zhang (2020) proposed an intelligent building planning system using BIM and an AI algorithm called functional module algorithm to improve design quality by improving efficiency such as automatic detection and adjustment of pipeline collisions and accurately determining the quantity of material and data support for project cost.

4.8.4 Practical Applications of the Intelligent BIM Systems

The intelligent BIM systems may be developed to provide applications such as generative design, construction simulation and 3D coordination to aid designers to plan and produce better conceptual designs at the early project stage and introduce automation in the production of the as planned BIM models. After the as planned BIM model is created, the quantity surveyor can utilise the automated cost estimating feature to compute cost estimates with greater accuracy during the pre-construction stage. Furthermore, automated site progress monitoring can enable the automatic production of as built BIM models in real time during the construction stage. The as planned models and as built models can then be compared to identify any missing elements and variances between the planned and actual design to facilitate progress monitoring.

In the post construction stage, both completed as planned and as built models can be added into the BIM model database to act as training data for AI models as the more training data is provided to AI, the higher accuracy of the output generated by AI.

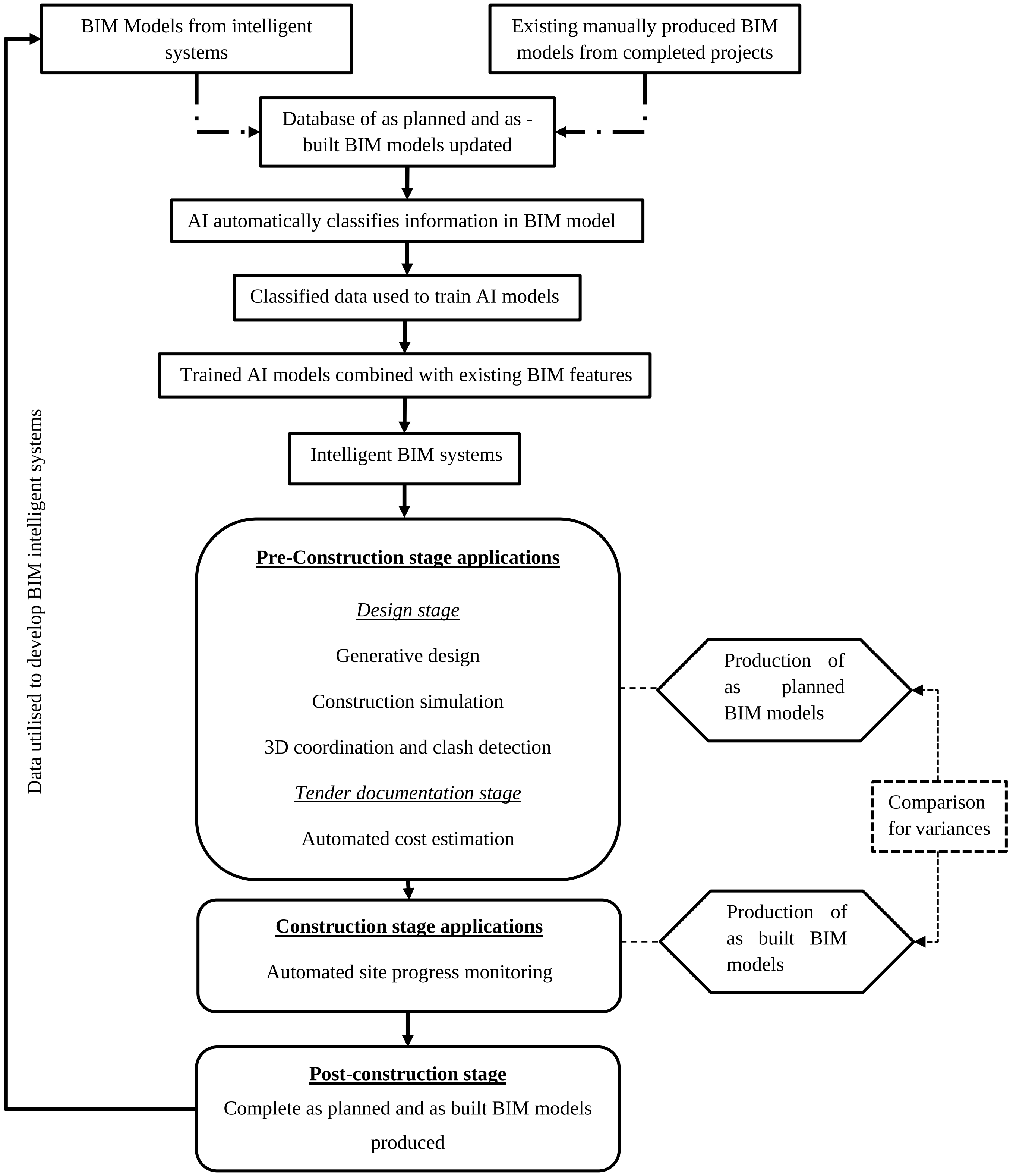

Figure 4. 1: Proposed Framework for BIM and AI Integration

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The research findings and achievement of the research objectives will be outlined in Section 5.2. Section 5.3 will then discuss the contributions of this study and the research limitations and recommendations for future work will be described in Section 5.4.

5.2 Accomplishment of Research Objectives

A literature review was performed to study present studies on Building Information Modelling (BIM) and Artificial Intelligence (AI). A total of 145 questionnaire responses from construction professionals were then analysed using hypothesis testing and three construction professionals were interviewed. The theoretical framework presented in Figure 2.5 describes the development of the study to reach the three research objectives.

The first objective which is to identify the applications of integrating AI with BIM in construction projects is achieved through the literature review. Section 2.6 in the literature review highlighted the existing and developing applications integrating BIM and AI which include generative design, construction simulation, 3D coordination and clash detection, automated cost estimation and automated site progress monitoring. These applications are further ranked by construction practitioners based on the importance to the industry. Automated cost estimating was perceived as the most important and 3D coordination and clash detection being the least important. Nevertheless, findings from the interviews suggest that clash detection is a major benefit provided by existing BIM software.

The second objective is to determine the barriers to adopting AI and BIM in construction projects. This objective is fulfilled from both literature review and data analysis. The general barriers of adopting AI and BIM are outlined in Section 2.8 of the literature review and additional barriers are discovered from the data collection. The high initial cost of the software and hardware for integrating BIM and AI is founded to be the primary barrier based on the findings from both questionnaire and interviews. The interviewees highlighted that the benefits of this integration have to surpass the cost of investment for this integration to be adopted. Besides, construction practitioners are unfamiliar with the user interfaces and AI features in the BIM software and some still prefer traditional methods. The insufficient information in BIM models is also a critical barrier for this integration as data in BIM is a fundamental element for this integration.

The third objective is to profile the perception of the construction industry towards the integration of AI and BIM in construction projects. The indicators of perception include personal views, future views, current practice, problems, benefits, expectations and suggestions. As for personal views, construction practitioners have expressed their high interest in this integration. On the other hand, construction practitioners also perceive that this integration may not be achieved in the coming few years. This is because the construction industry is still adapting to BIM implementation. For instance, only BIM Level 0 and 1 is achieved based on the interview findings and BIM adoption is relatively small among quantity surveyors and contractors. However, practical integration and implementation may only be achieved once BIM Level 2 and 3 is achieved to obtain sufficient data in the BIM database to facilitate the development of this integration. Besides, problems of current BIM software might be tackled through BIM and AI integration. As an illustration, interviewees have stated that the accuracy of the quantity estimates provided by the current BIM software is prone to errors that can be resolved by automated cost estimation. Construction practitioners are also starting to realise the benefits of BIM such as clash detection in existing BIM software. As for suggestions, government incentives and promotion have been suggested by interviewees to facilitate this integration. Figure 5.1 illustrates the theoretical framework with the main findings of the study.

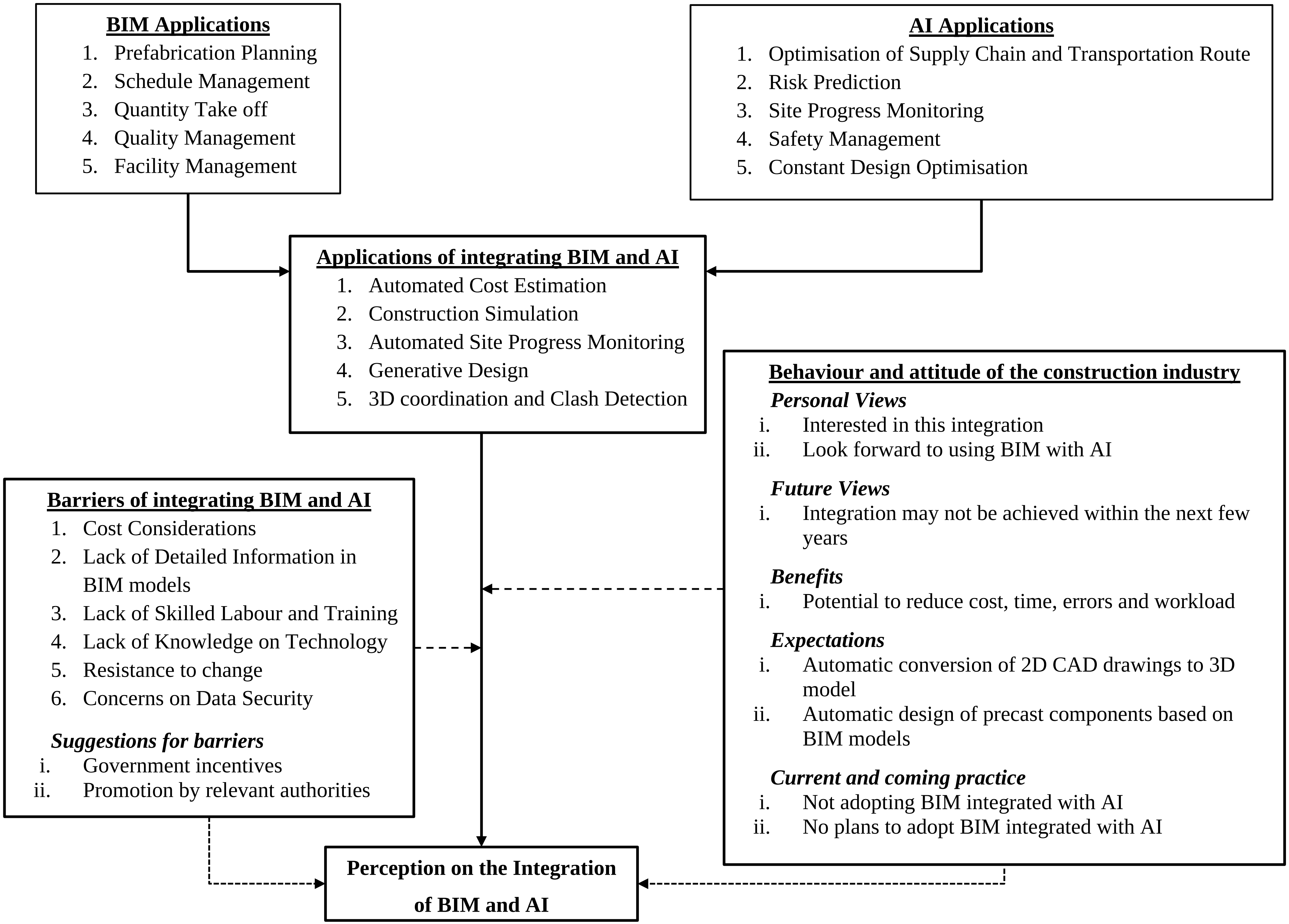
BIM Applications
1. Prefabrication Planning
2. Schedule Management
3. Quantity Take off
4. Quality Management
5. Facility Management
AI Applications
1. Optimisation of Supply Chain and Transportation Route
2. Risk Prediction
3. Site Progress Monitoring
4. Safety Management
5. Constant Design Optimisation
Applications of integrating BIM and AI
1. Automated Cost Estimation
2. Construction Simulation
3. Automated Site Progress Monitoring
4. Generative Design
5. 3D coordination and Clash Detection
Behaviour and attitude of the construction industry
Personal Views
i. Interested in this integration
ii. Look forward to using BIM with AI
Future Views
i. Integration may not be achieved within the next few years
Benefits
i. Potential to reduce cost, time, errors and workload
Expectations
i. Automatic conversion of 2D CAD drawings to 3D model
ii. Automatic design of precast components based on BIM models
Current and coming practice
i. Not adopting BIM integrated with AI
ii. No plans to adopt BIM integrated with AI
Barriers of integrating BIM and AI
1. Cost Considerations
2. Lack of Detailed Information in BIM models
3. Lack of Skilled Labour and Training
4. Lack of Knowledge on Technology
5. Resistance to change
6. Concerns on Data Security
Suggestions for barriers
i. Government incentives
ii. Promotion by relevant authorities
Perception on the Integration of BIM and AI

Figure 5. 1: Theoretical Framework with the Main Findings of the Study

5.3 Research Implications

This study can let construction practitioners have a glimpse of the opportunities of integrating AI with BIM and realise the positive outcomes if adopted in an early stage. Construction practitioners may have a greater interest in using BIM with AI as this study has revealed the benefits of this integration and how AI can mitigate the shortcomings of BIM.

In addition, finding out the perceptions of construction players can provide a guideline for the future development of AI and BIM software. For instance, software developers can pay attention to the expectations of construction practitioners identified in this study to develop software integrating BIM and AI that caters to the needs of the construction industry. This study also contributes to the research gap of identifying the existing and developing collaborations between BIM and AI and the potential applications of this integration for the construction industry. It also furthers research on the automation of BIM. The prevailing applications of this integration are summarised and overviewed which provides fundamental knowledge for researchers which intend to further study BIM and AI integration.

Besides, universities can use this study to act as a guide for the improvement of subjects that have syllabus related to digital construction and the development of short courses related to the automation of BIM. This allows the familiarity on this integration and BIM automation to be elevated among new blood entering the construction industry. University courses regarding BIM automation can be enhanced to aid students to be better prepared for upcoming digital transformation in the construction industry.

Policymakers can also utilise this study as assistance in the drafting of motivational schemes for incorporating AI and BIM together in future practices. For instance, policymakers can introduce initiatives to tackle the barriers identified such as the provision of incentives to overcome the barrier of cost considerations among construction companies. The findings on the behaviour and attitude of the construction industry can also assist policymakers in formulating customised motivational policies for groups with dissimilar professions and working experiences. For instance, additional seminars and training on BIM and AI can be organised for engineers and quantity surveyors as these professions have a lower understanding of BIM as compared to architects.

5.4 Research Limitations and Future Research

The first limitation of this study is that only the behaviours and attitudes from consultants such as quantity surveyors, architects and engineers were studied. The opinions of the contractors and employers were not taken into account in this study. Besides, the development of integrating BIM and AI is still ongoing and the questionnaire may not have covered all the latest breakthroughs of this integration. Moreover, data saturation may not have been achieved for the semi structured interviews as only three construction practitioners were interviewed. The interviewees have minor experiences with BIM and have low familiarity with AI technologies in construction. Also, only the applications applicable during the pre construction and construction stage were studied in detail.

It is recommended for those who seek to continue this study to develop a detailed prototype for the integration of BIM and AI based on the proposed framework in Section 4.8. In addition, future studies can include a larger sample of interviewees and target construction practitioners with pertinent and practical experiences with BIM or AI and include contractors and employers as respondents. It is also suggested to study the applications of this integration during the post construction stage for the building operation management such as prediction of building energy consumption and life span of buildings.

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APPENDICES

APPENDIX A: Questionnaire

Examine the Perception on the Integration of Building Information Modelling and Artificial Intelligence in Construction Projects.

Dear Sir/Madam,

Good day, my name is Lee Jie Anne and I'm a final year student studying at Universiti Tunku Abdul Rahman currently undertaking Bachelor of Science (Hons.) Quantity Surveying under Lee Kong Chian Faculty of Engineering and Science. I am undertaking a final year project titled "Examine the Perception on the Integration of Building Information Modelling and Artificial Intelligence in Construction Projects." This research aims to determine the perception of the construction industry towards the integration of Artificial Intelligence (AI) and Building Information Modelling (BIM) in construction projects.

The three objectives of this research are:

i) To identify the applications of integrating Artificial Intelligence (AI) with Building Information Modelling (BIM) in construction projects.
ii) To determine the barriers of adopting Artificial Intelligence (AI) with Building Information Modelling (BIM) in construction projects.
iii) To profile the perception of the construction industry towards the integration of Artificial Intelligence (AI) and Building Information Modelling (BIM) in construction projects.

This questionnaire includes four sections and I deeply appreciate it if you can spare 10 minutes to contribute your valuable knowledge to this questionnaire. Please be informed that all information collected from this questionnaire will remain private and confidential, and will be only used for academic purposes.

If you have any questions regarding this research, feel free to contact me at jieannehere@1utar.my.

Thank you for your help and stay safe!

Lee Jie Anne
Department of Surveying
Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

Section A: Respondent's Attributes

1. What is your group of age?
    - 18 - 30 years old
    - 31 - 40 years old
    - 41 - 50 years old
    - Above 50 years old

2. Which of the following best describes your role in the construction industry?
    - Architect
    - Engineer
    - Quantity Surveyor
    - Contractor
    - Developer
    - Other:

3. How many years have you been working in the construction industry?
    - 0 - 2 years
    - 3 - 5 years
    - 6 - 10 years
    - 11 - 19 years
    - Above 20 years

Section B - Perception of construction practitioners towards the integration of AI and BIM

1. Please rate the following statements regarding your opinion on the adoption of Building Information Modelling (BIM) and Artificial Intelligence (AI) in construction projects.

	Strongly Agree	Disagree	Neutral	Agree	Strongly Agree
I am interested in learning more knowledge on BIM or AI	0	0	0	0	0
I believe that learning more knowledge of BIM or AI can aid my future career	0	0	0	0	0
I look forward to using BIM or AI in future construction processes	0	0	0	0	0
I take initiatives to propose BIM or AI approaches to my company	0	0	0	0	0
I think that BIM can be used only for illustration purpose	0	0	0	0	0
I prefer to use AI to only aid in decision making and make the final decision on my own	0	0	0	0	0
I believe that AI will only assist in human intelligence and not replace it	0	0	0	0	0

I am interested in learning more knowledge on the integration of BIM and AI	0	0	0	0	0
I look forward to using BIM with AI features in future construction processes	0	0	0	0	0
I believe that integrating BIM and AI will reduce the shortcomings of BIM	0	0	0	0	0
I believe that integrating BIM and AI will improve the performance of AI	0	0	0	0	0
I believe that BIM and AI can complement each other through integration	0	0	0	0	0

2. To what extent you agree that the following scenarios will happen.

	Strongly Agree	Disagree	Neutral	Agree	Strongly Agree
The adoption of BIM might become common within the next 10 years	0	0	0	0	0
The adoption of AI might become common within the next 10 years	0	0	0	0	0
AI might lead to a major change in the operation of the construction industry	0	0	0	0	0
AI might reduce job opportunities for construction practitioners	0	0	0	0	0

There might be a shift in the job scope of construction practitioners due to AI	0	0	0	0	0

3. Please rate the importance of the following applications of Building Information Modelling (BIM) and Artificial Intelligence (AI) in construction projects.

	Not at all important	Slightly Important	Moderately Important	Very Important	Extremely Important
BIM assists in schedule management	0	0	0	0	0
BIM assists in taking off quantities	0	0	0	0	0
BIM assists in prefabrication planning	0	0	0	0	0
BIM assists in quality management	0	0	0	0	0
BIM assists in facility management	0	0	0	0	0
AI enables the risk prediction on quality issues	0	0	0	0	0
AI enables the risk prediction on delay	0	0	0	0	0

AI enables constant design optimisation	0	0	0	0	0
AI assists in safety management	0	0	0	0	0
AI assists in site progress monitoring	0	0	0	0	0
AI enables transportation route optimisation	0	0	0	0	0
AI enables the optimisation of supply chain management	0	0	0	0	0
Generative design to provide alternative design options	0	0	0	0	0
Construction simulation to predict unforeseen circumstances	0	0	0	0	0
Construction simulation to enable project schedule optimisation	0	0	0	0	0
3D coordination and clash	0	0	0	0	0

detection to identify errors in the BIM model					
3D coordination and clash detection to assists in constructability issues prediction	0	0	0	0	0
Automated cost estimation to provide more accurate initial estimates	0	0	0	0	0
Automated Site Progress Monitoring to facilitate progress reporting	0	0	0	0	0
Automated site progress monitoring assists the as-built model production	0	0	0	0	0

Section C - Current practice in adopting BIM and AI in construction projects

1. Please rate your familiarity with the following software.

	Not at all familiar	Slightly familiar	Moderately familiar	Very familiar	Extremely familiar
Sketch Up	0	0	0	0	0
Autodesk Revit (versions before 2021)	0	0	0	0	0
Archicad	0	0	0	0	0
Vectorworks	0	0	0	0	0
Allplan	0	0	0	0	0
Smartvid.io	0	0	0	0	0
Easyflow CV	0	0	0	0	0
BIM 360	0	0	0	0	0
Site AI	0	0	0	0	0
Doxel AI	0	0	0	0	0
Disperse	0	0	0	0	0
Autodesk Revit (version 2021)	0	0	0	0	0
Vico Office	0	0	0	0	0
ALICE	0	0	0	0	0
GenMEP	0	0	0	0	0
Kreo Plan	0	0	0	0	0
HoloBIM	0	0	0	0	0
ReCap Pro	0	0	0	0	0
Scan to BIM	0	0	0	0	0
Visual Command Center	0	0	0	0	0

Other equivalent software	0	0	0	0	0

2. To what extent you apply the following software in your projects.

	Not at all	Slight	Quite	Usual	All the while
Sketch Up	0	0	0	0	0
Autodesk Revit (versions before 2021)	0	0	0	0	0
Archicad	0	0	0	0	0
Vectorworks	0	0	0	0	0
Allplan	0	0	0	0	0
Smartvid.io	0	0	0	0	0
Easyflow CV	0	0	0	0	0
BIM 360	0	0	0	0	0
Site AI	0	0	0	0	0
Doxel AI	0	0	0	0	0
Disperse	0	0	0	0	0
Autodesk Revit (version 2021)	0	0	0	0	0
Vico Office	0	0	0	0	0
ALICE	0	0	0	0	0
GenMEP	0	0	0	0	0
Kreo Plan	0	0	0	0	0
HoloBIM	0	0	0	0	0
ReCap Pro	0	0	0	0	0
Scan to BIM	0	0	0	0	0
Visual Command Center	0	0	0	0	0
Other equivalent software	0	0	0	0	0

Section D - Barriers hindering the integration of BIM and AI in construction projects

1. Please rate the following reasons for not adopting Building Information Modelling (BIM) and Artificial Intelligence (AI) in construction projects.

	Strongly Agree	Disagree	Neutral	Agree	Strongly Agree
I have encountered a bad experience in using BIM or AI	0	0	0	0	0
I am comfortable with traditional practices	0	0	0	0	0
I am uncertain of the output of using BIM or AI	0	0	0	0	0
I predict my workload will increase if I need to learn a new BIM software or AI approach	0	0	0	0	0
I am concerned that AI will change my future job scope	0	0	0	0	0
I am comfortable with using BIM software with no AI features	0	0	0	0	0
I am unfamiliar with the AI features provided in the BIM software	0	0	0	0	0
I am unfamiliar with the user interface of BIM software with AI features	0	0	0	0	0
I am not aware of any good software integrating BIM and AI	0	0	0	0	0

The high initial cost for software and hardware	0	0	0	0	0
The high cost in altering work progress	0	0	0	0	0
The additional cost for training workers	0	0	0	0	0
My company is concerned with data security issues in using BIM or AI	0	0	0	0	0
My company has a lack of trained staff with BIM or AI expertise	0	0	0	0	0
My company has poor ICT infrastructure	0	0	0	0	0
My company has a lack of internal technical support	0	0	0	0	0
The scale of the projects by my company do not require BIM or AI	0	0	0	0	0
My company has insufficient information in existing BIM software to support AI features	0	0	0	0	0

APPENDIX B: Interviewee Attributes

Interviewee's Attributes

1	Profession	
2	Job Title	
3	Years with the company	
4	Nature of Business	

APPENDIX C: Interview Guidelines

INTERVIEW GUIDELINE ON "EXAMINE THE PERCEPTION ON THE INTEGRATION OF BUILDING INFORMATION MODELLING AND ARTIFICIAL INTELLIGENCE IN CONSTRUCTION PROJECTS"

SECTION A: Perception

1. **Personal view towards the adoption and integration of AI and BIM in construction**
   a. What is your view on the adoption of Building Information Modelling (BIM) in construction projects?
   b. What is your view on the adoption of Artificial Intelligence (AI) in construction projects?
   c. What is your view on the integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)?

2. **Future view towards the integration of AI and BIM in construction**
   a. In your opinion, what will be the impact of Artificial Intelligence (AI) on the construction industry?
   b. Do you think that the integration of Building Information Modelling (BIM) and Artificial Intelligence (AI) will accelerate the digitalisation of the construction industry?

3. **Expectations in features/applications from the integration of AI and BIM**
   a. What are the features/applications that you anticipate from the integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)?
   b. Do you think that the implementation of Building Information Modelling (BIM) will increase if AI features are involved in BIM software?

SECTION B: Practice

1. **Current practice in adopting BIM or AI in construction processes**
   a. What are the Building Information Modelling (BIM) or Artificial Intelligence (AI) technology used by your company?
   b. Is there any Building Information Modelling (BIM) software with Artificial Intelligence (AI) features used by your company?
   c. What is the level of adoption of BIM by your company?

2. **Benefits gained from using BIM or AI in construction processes**
   a. If your company is using any Building Information Modelling (BIM) or Artificial Intelligence (AI) technology, what are the main benefits that the company has gained from these approaches in terms of time, cost and quality?

3. **Problems faced in the adoption of BIM or AI technologies**
   a. What are the issues faced when using Building Information Modelling (BIM) or Artificial Intelligence (AI) used by your company?

4. **Coming practice or strategies in adopting BIM and AI**
   a. Are there any plans to adopt any Building Information Modelling (BIM) or Artificial Intelligence (AI) approaches by your company?
   b. If your company has these plans, which technology will be implemented first?
   c. Are there any strategies proposed by your company to facilitate the use of Building Information Modelling (BIM) or Artificial Intelligence (AI) in your projects?
   d. Which strategies does your company find more effective in implementing the use of Building Information Modelling (BIM) or Artificial Intelligence (AI) in your projects?

SECTION C: Barriers

1. **Barriers hindering the integration of BIM and AI in construction projects**
    a. Why is Building Information Modelling (BIM) not adopted in construction projects?
    b. Why is Artificial Intelligence (AI) not adopted in construction projects?
    c. In your opinion, what are the challenges in integrating Building Information Modelling (BIM) and Artificial Intelligence (AI)?

APPENDIX D: Interview Transcript Sample

SECTION A: Perception

Q: What is your view on the adoption of Building Information Modelling (BIM) in construction projects?

A: *I have a positive view of BIM adoption. As a civil and structural engineer, our major job scope is designing the structural systems based on architectural drawings. In some projects not using BIM, there will be issues such as many clashes between the design from the architect and mechanical and electrical systems. However, for projects using BIM, we can just insert everything in the model and it will automatically detect the clashes.*

Q: What is your view on the adoption of Artificial Intelligence (AI) in construction projects?

A: *I think that AI can aid in decision making, but the final decision still has to be decided by the engineer. This is because in the construction industry each project is unique and not all buildings or structures are the same. Each project will have some special circumstances. I'm not sure about the abilities of AI. Thus, I think that many decisions made still require the engineer's expertise. Sometimes we also need to take account of the authority and client requirements.*

Q: What is your view on the integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)?

A: *I am quite interested in this integration and would like to learn more about it. I am interested to know if this technology can reduce our workload.*

Q: In your opinion, what will be the impact of Artificial Intelligence (AI) to the construction industry?

A: *I think the impacts are quite broad. I think that the negative side is that some construction practitioners might be replaced by AI technology. For example, I noticed that some software can automatically calculate the quantity of materials for reinforcement and concrete after the design is completed in the* *software. On the other hand, the bright side is that AI might help to save cost, shorten the project timeframe and help the project progress smoothly.*

Q: Do you think that the integration of Building Information Modelling (BIM) and Artificial Intelligence (AI) will accelerate the digitalisation of the construction industry?

A: *I think that in the coming few years, these technologies might not bring a major impact or change to the Malaysian construction industry. For example, we have a code named as Eurocode in engineering, this code can be considered as a new standard, but the Malaysian construction industry has yet to adopt this code. The original Eurocode from Europe has developed a long time ago, but Malaysia only published some Malaysia Standard that made some amendment or localization for the adoption of Eurocode in Malaysia in the begin in 2010 only. This code has been introduced in Malaysia for more than 10 years but most of us are still using the existing code.*

Thus, as I observed that even an important code has not yet been widely adopted, the BIM in the Malaysia construction might take a longer time to be implemented, not to mention AI technologies.

Q: What are the features/applications that you anticipate from the integration of Building Information Modelling (BIM) and Artificial Intelligence (AI)?

A: *I think that if AI has the ability to learn all information about the past projects, it can produce more accurate predictions to help construction practitioners.*

Q: Do you think that the implementation of Building Information Modelling (BIM) will increase if AI features are involved in BIM software?

A: *I think that the implementation of BIM will increase if the benefits of using this kind of technology exceed the cost of investing in these kinds of technologies. As in the construction industry, the cost is the primary concern.*

SECTION B: Practice

Q: What are the Building Information Modelling (BIM) or Artificial Intelligence (AI) technology used by your company?

A: *Currently, the BIM software used by our company is Autodesk Revit 2020. The architectural BIM model and the structural BIM model will then be combined in the software to become a single model. However, the use of BIM depends on the project. If the client of the project request for BIM services, the architect will provide BIM model Revit files to engineers. For example, in one of my previous projects using BIM, the Revit file for each model will be provided to us. For projects not adopting BIM, AutoCAD files are prepared by the architect showing the front, rear, left and right view of the project building. For me, I think that using BIM is more convenient as compared to using 2D Cad software. Another software used is Civil3D which is used for infrastructure design, water reticulation, sewerage, drainage, earthwork those etc. This software can aid in clash detection of infrastructure system*

Q: Is there any Building Information Modelling (BIM) software with Artificial Intelligence (AI) features used by your company?

A: *Currently, we are using only Autodesk Revit 2020, AutoCAD and Civil 3D.*

Q: What is the level of adoption of BIM by your company?

A: *Normally, the architectural, structural and mechanical & electrical services model will be prepared separately and uploaded to a cloud computing software. The models will then be combined into a single model. We can use BIM during the designing stage, but during the execution of works, physical 2D drawings and AutoCAD files are used by contractors as it is difficult to access the 3D models at the construction site. The contractor will normally remain traditional practice and use 2D drawings when consulting with engineers. So far there is not much involvement of the contractors and quantity surveyors in BIM. Thus, there are still issues in the implementation of BIM in the construction processes as it's potential cannot be fully realised.*

Q: If your company is using any Building Information Modelling (BIM) or Artificial Intelligence (AI) technology, what are the main benefits that the company has gained from these approaches in terms of time, cost and quality?

A: *Cost and time are can be reduced. Sometimes when tendering for large company projects, the adoption of BIM is one of the minimum requirements for participating in the tender.*

Q: What are the issues faced when using Building Information Modelling (BIM) or Artificial Intelligence (AI) used by your company?

A: *One of the problems is that we are doing repetitive tasks. For current practice, we are doing repetitive work as we need to draw the design in AutoCAD and then redraw in the Revit software again. Thus, I think that the current software available is not that user friendly. It would be great if there is a feature in BIM which allows us to import the AutoCAD drawings into the BIM model, and convert those AutoCAD or 2D files in the drawings. Also, the adoption of BIM is just like an additional service provided when the client is willing to pay more for BIM usage.*

Q: Are there any plans to adopt any Building Information Modelling (BIM) or Artificial Intelligence (AI) approaches by your company?

A: *Currently, the BIM used is sufficient for our current practice. Our company has no plans for adopting AI technologies.*

Q: If your company has these plans, which technology will be implemented first?

A: *BIM already implemented first in our company. I think that AI technologies can only be implemented after BIM becomes widely used and familiar among construction practitioners in the industry. But if there are AI technologies which can perform alone without the need for BIM, such as safety management software, we might be interested* to implement this AI technology first.

Q: Are there any strategies proposed by your company to facilitate the use of Building Information Modelling (BIM) or Artificial Intelligence (AI) in your projects?

A: *So far no strategies are proposed.*

Q: Which strategies does your company find more effective in implementing the use of Building Information Modelling (BIM) or artificial intelligence (AI) in your projects?

A: *I think that we need to increase the awareness of construction practitioners that BIM is the coming trend to facilitate its implementation. Normally only clients from large companies will request BIM to be adopted in their projects.*

SECTION C: Barriers

Q: Why is Building Information Modelling (BIM) not adopted in construction projects?

A: *The cost is the major barrier. For example, the cost for the application of the licence of the software. BIM is normally implemented when clients request for it and willing to pay the extra charges included for the use of BIM in a project. Some construction practitioners which have been working in the industry for a long time are also reluctant to accept these technologies.*

Q: Why is Artificial Intelligence (AI) not adopted in construction projects?

A: *Resistant to change is one of the reasons. Some practitioners will think that humans are better and perceive that the traditional way is the best because it is effective and it works.*

Q: In your opinion, what are the challenges in integrating Building Information Modelling (BIM) and Artificial Intelligence (AI)?

A: *I think that since BIM is not adopted widely, AI might take longer time to be adopted as it is perceived as more advanced technology.*