RESEARCH IN MANAGEMENT OF TECHNOLOGY AND BUSINESS
e-ISSN: 2773-5044

RMTB

Vol. 5 No. 1 (2024) 1559-1575
https://publisher.uthm.edu.my/periodicals/index.php/rmtb

Potential of Implementing Artificial Intelligence (AI) for Reducing Waste at Construction Site

Tan Wan Yuan[1], Mohd Hilmi Izwan Abd Rahim[1]*

[1] *Department of Construction Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor 86400, MALAYSIA*

*Corresponding Author: hilmiizwan@uthm.edu.my
DOI: https://doi.org/10.30880/rmtb.2024.5.01.103

Article Info

Received: 31 March 2024
Accepted: 30 April 2024
Available online: 30 June 2024

Keywords

Artificial Intelligence (AI), Construction Waste, Construction Site

Abstract

This research presents the potential implementation of Artificial Intelligence (AI) to reduce construction waste in Johor, Malaysia. Most of the construction and demolition wastes in Johor, Malaysia are not recycled but are eventually dumped and landfilled, which may have serious environmental consequences and require the construction of more landfills in the future. Therefore this research focuses on the potential of implementing Artificial Intelligence (AI) to reduce construction waste in the construction industry in Johor, Malaysia. The main objectives of this research are to investigate the current practice of construction waste management in the construction industry, the challenges of implementing Artificial Intelligence (AI) in the construction industry, and the potential of implementing Artificial Intelligence (AI) to reduce construction waste in the construction industry. The respondents of this study are G5, G6, and G7 contractors from the state of Johor. The population of G5, G6, and G7 that registered with the CIDB are total 1618 and the number of responses is 154 which contributed to 9.54%. The quantitative method is used to reach the objective of this research. The data and information was analyzed by using Statistical Package for Social Sciences (SPSS). At the end of the research, there are most of the respondents are agree that implementing AI in the construction industry able to reduce waste generation during the construction process. Besides, most of the respondents also said that there are still many obstacles to the adoption of Artificial Intelligence (AI) in the Malaysian construction industry and that Artificial Intelligence (AI) really can change the current practice in construction waste management. Lastly, this study is very useful for the construction industry development in the future. This research can provide sustainability for the environment.

1. Introduction

This section describes the research background, problem statement, research questions, research objectives, research scope, and significance of the research.

1.1 Research Background

Malaysia's construction industry is growing continues. However, it brings a lot of construction waste and affects the natural ecosystem. Malaysia is at risk of exceeding its capacity for construction waste disposal by 2050 (Nuradzimmah *et al.*, 2023). Up to 30% of all building materials delivered to a normal construction site can be wasted. In 2018, construction and demolition operations generated about 145 million tonnes of garbage in US landfills (BigRentz, 2021). The major waste sources in building construction are classified as design, procurement, material handling, operation, residue, and the remaining six significant sources (Bekr *et al.*, 2014). In Malaysia, artificial intelligence was introduced to improve the quality of project delivery. It is believed that artificial intelligence can help improve project quality in terms of project duration, cost, and design through the latest technology in the construction industry.

1.2 Problem Statement

In Malaysia, the population is increasing rapidly, reaching 32.8 million in 2021, generating a tremendous amount of solid waste, which is estimated to be 38,427 metric tonnes per day in 2021. Solid waste management is a challenge to global economies as the world population increases (Malaysian Investment Development Authority *et al.*, 2021). The increased demand for buildings also generates construction waste every year. All of the waste can cause more serious issues to the environment, society, and economy. Construction waste from construction activities such as demolition, rehabilitation, and renovation will generate 10% - 15% of the materials utilized for the construction of the building (Shambhu *et al.*, 2020). A large amount of construction waste is disposed of, which may raise the landfill's loading and operating pressure. New dumps may be difficult to locate, while current landfills are filled and closed every year. Given these challenges, numerous experts in the construction field have begun to investigate alternative methods of dealing with building and construction waste, such as recycling and reuse (Stella *et al.*, 2011).

1.3 Research Questions

This section should include the research questions of the study.

(i) What is the current practice of construction waste management in Malaysia's construction industry?
(ii) What are the challenges of implementing Artificial Intelligence (AI) in the construction industry.
(iii) What is the potential of Artificial Intelligence (AI) to reduce construction waste in the construction industry?

1.4 Research Objectives

This section should include the research objectives of the study.

(i) To investigate the current practice of construction waste management in the Malaysian construction industry.
(ii) To investigate the challenges of construction of implementing Artificial Intelligence (AI) in the construction industry.
(iii) To investigate the potential of Artificial Intelligence (AI) to reduce construction waste in the construction industry.

1.5 Scope of the Study

According to the centralized information management system (CIMS), there is a total of 128048 companies registered under CIDB as qualified contractors in the construction industry. This research will focus on contractors G5, G6, and G7 in Johor there are a total 1618 of registered with the CIDB. This research focuses on Johor because according to the statistics released by the Ministry of Economy Department of Statistics Malaysia (EMBARGO) Johor had RM3.4 billion in construction projects in the fourth quarter of 2023. It contributes 10.7 % to Malaysia's state. Johor ranked 3rd among the states in west Malaysia. The G5, G6, and G7 contractor was chosen since it is the highest grade in the CIDB Contractor Grad. The G5, G6, and G7 Contractor is a class of contractors that possesses the highest standard in terms of capital, workforces, and facilities that enable them to bid and tender for a limitless project value. The G5, G6, and G7 contractors have the best probability of winning megaprojects and implementing AI in their projects.

1.6 Significance of the Study

The increase of construction projects affects the construction waste also increases rapidly. The quantity of construction waste becomes uncontrollable because of poor waste management. Because construction waste cannot be controlled. therefore, this research is an emphasizes determining the implementation of Artificial Intelligence for reducing waste at the construction site.

2. Literature Review

The literature review section describes all relevant literature related to the research and is critically discussed.

2.1 Current Practices of Waste Management

This part will discuss the current practice of implementing AI in the construction industry. Table 1 shows the research gap for the current practice of implementing AI in the construction industry.

Table 1 *Current Practice of implementing AI in the construction industry*

Author	Summary of study	Study focused on
Salgın *et al*., 2017 Ibrahim *et al*., 2022 Zoghi *et al*., 2021 Ang *et al*., 2022 Andrzejewski, 2023 Uddin, 2021	BIM can also help us reduce C&D waste by enhancing the quality and adapted Internet of Things (IoT) Industrial Building Systems (IBS) in the construction industry also helps to reduce waste generated.	Reduced waste generation
Wong *et al*., 2019 Sofie Bang, 2022 Li *et al*., 2023 Nick, 2021	3R principles is the most popular practice used in construction waste management	Promote 3R Principal Reduce, Recycle, Reuse
Zhang & Atkins, 2015 Bansal *et al*., 2022 Loh *et al*., 2021	The RFID system can assist in determining where the material has been stored and the condition of the material	Radio Frequency Identification Devices (RFID)
Dziuk, 2023 You *et al*., 2020	To verify the location for waste disposal	Global Positioning System (GPS)

2.1.1 AI help to reduce waste generated

BIM allows for the creation of a 3D model that contains comprehensive data about a construction project, allowing for better decision-making, resource optimisation, and project management. Building Information Modelling (BIM) is commonly used during the design and pre-construction phases of a construction project and continues during the construction phase. Before real building work begins, BIM is used to plan, design, and visualise the construction project, which improves project coordination and reduces errors and rework (Salgın *et al*., 2017). Beside, BIM can reduce incorrect design, raw material residues, and unexpected changes in design, procurement, site planning, and material handling (Zoghi *et al*., 2021).

In addition, the collaboration between the Internet of Things (IoT) and Industrial Building Systems (IBS) in the construction industry also helps to reduce waste generated. The potential for IoT to reduce waste and increase resource efficiency is huge, since it may provide significant information and automation in the construction industry (Andrzejewski, 2023). developers may monitor the building process and optimise the supply chain by including IoT devices into the construction process of various building components. This leads to a large minimised of errors, which reduces the generation of waste on site (Uddin, 2021).

2.1.2 AI help to promote 3R Principal - Reduce, Recycle, Reuse

Implement AI in the construction waste management help to promote the 3R principal. The 3R concept focuses on the idea of optimizing resources before they are disposed of. It is considered effective and efficient for construction waste management since it lowers transportation and disposal costs (Sofie Bang, 2022). It as a way of reducing the ecological footprint of construction operations on the environment (Li *et al*., 2023).

2.1.3 Radio Frequency Identification Devices (RFID)

Construction waste is being monitored and managed using digital waste tracking technologies. These systems keep track of the kind, quantity, and location of waste products, ensuring transparency and accountability throughout the waste management process. Radio Frequency Identification (RFID) can be used to track, schedule, and intelligently handle waste movement occurrences in order to avoid fly-tipping and increase management efficiency. RFID has the potential in providing convenient materials tracking to reduce the cost of materials wastage. The materials tracking system can assist in determining where the material has been stored and the condition of the materials. With the technology in place, the placement of materials or waste on-site can be more orderly, freeing up more room on the busy building site (Loh *et al*., 2021)

2.1.4 Global Positioning System (GPS)

The practice of utilizing GPS trackers to verify the location of waste is known as GPS tracking. GPS devices are frequently used to track trash trucks and street sweepers. While GPS is in operation, the user can see where it is in real-time (Dziuk, 2023). The global positioning system (GPS) is a satellite-based real-time positioning and navigation system. The GPS may determine the precise location of the receiver by measuring the distance between a satellite with a known position and the user's receiver and combining data from many satellites. A vehicle tracking scheme based on GPS technology can be constructed due to its high precision and dependability (You *et al*., 2020).

2.2 Challenges of implementing AI in construction waste management

This part will discuss the challenges of implementing AI in construction waste management. Table 2 shows the research gap for the challenges of implementing AI in construction waste management.

Table 2 *Studies about the challenges of implementing AI in construction waste management*

Author	Summary of study	Study focused on
Saadi *et al*., 2016 Ramos *et al*., 2023 Ramos and Martinho, 2022 Menegaki & Damigos, 201 Ramos *et al*., 2023	Lack of knowledge in sustainable construction	Lack of Awareness and Education
Regona *et al*., 2022 Zirar *et al*., 2023	The initial cost for these changes can be high, especially for smaller construction firms	High Initial Cost
Lin *et al*., 2021 Nagapan, 2012	The distance between the project location and the landfill site is far	Limited Space for Waste Disposal
Regona *et al*., 2022 OECD, 1998	It is impossible to switch from tradition and let AI replace it in a short time	Willingness to Change and Career Opportunity
Ramos & Martinho, 2023	Lack of consistent monitoring and enforcement measures	Lack of Regulation

2.2.1 Lack of Awareness in Construction Waste Management

Construction waste is generated as a result of poor building material management in construction projects. Construction waste management is one of the sustainable development approaches to minimize waste and avoid negative impacts on the environment. There is a lack of collaboration among stakeholders. Lack of onsite oversight actions for legal procedures or good practices, compounded by a lack of manpower, resources, and technological experience; and procedural control for legal needs.

2.2.2 High Initial Cost

Implementing AI in construction often requires a significant investment in infrastructure. This includes upgrading hardware, deploying sensors, and establishing a robust IT infrastructure. The initial cost for these changes can be high, especially for smaller construction firms. AI systems require skilled professionals to operate and maintain them (Regona *et al*., 2022). Training existing employees or hiring new ones with the necessary skills can be expensive. Construction companies may need to invest in training programs to ensure their workforce can effectively use AI technologies (Zirar *et al*., 2023).

2.2.3 Limited Space for Waste Disposal

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Malaysia's growing urbanization and limited land availability make it difficult to identify adequate trash disposal sites. As a result, unlawful dumping of building waste occurs, causing pollution and health risks. The SW Crop has identified a total of 42 illegal waste hotspots in 2022 from which 29 of the hotspots involved construction waste. The number of hotspots last year increased to 42 compared to only 32 in 2021. The overall amount of unlawful waste discharged last year was 333.3 tons, indicating that construction waste accounts for 94.6 percent of all illegal rubbish in Kuala Lumpur (Lin *et al.*, 2021).

2.2.4 Willingness to Change and Career Opportunity

The construction sector is noted for its conventional methods and resistance to change. Many professionals and organisations may be hesitant to use AI because they are concerned about upsetting current processes. It needs to transform a traditional hierarchy into a digital and more autonomous one (Regona *et al.*, 2022). Traditional methods are prioritised over untrustworthy technologies. The building industry's fragmented nature makes reform difficult. To successfully transition from traditional to future models, compatible design, management, labour practices, and site operation practices are required (OECD, 1998).

2.2.5 Lack of Regulation

While Malaysia has regulations and guidelines in place to manage construction waste, enforcement can be a challenge. There may be a lack of consistent monitoring and enforcement measures, allowing some construction companies to bypass waste management regulations. Construction waste management can be seen from both a legal and an enforcement standpoint. A proper legal structure is required to provide a framework for building sector participants. To ensure that the system is in place, enforcement must be used to provide a deterrent to those who do not follow the laws. While waste management through incentive policies and regulations would be an effective method from a short-term perspective, the reduction of waste through recycling would make it possible to decrease waste generation and achieve a circular economy(Ramos & Martinho, 2023).

2.3 Potential of Implementing AI to reduce construction waste in the construction industry

This part will discuss the potential of implementing AI for construction waste management. Table 3 shows the potential of implementing AI to reduce construction waste in the construction industry.

Table 3 *Potential of Implementing AI to reduce construction waste in the construction industry*

Author	Summary of study	Study focused on
Krakauer *et al.*, 2017 Fang *et al.*, 2023 Zhou *et al.*, 2023 Koskinopoulou *et al.*, 2021	Artificial intelligence can be used to automate the identification and sorting of many forms of building waste materials	Sorting and identifying waste
Sivaprakasam *et al.*, 2020 Joshi *et al.*, 2022 Pardini *et al.*, 2020 Javaid *et al.*, 2021	Artificial intelligence-powered sensors and monitoring systems can be placed on building sites to track trash output in real time.	Efficient Monitoring and Alerting
Frąckiewicz, 2023 Ali *et al.*, 2019 Sarker, 2022 Andeobu *et al.*, 2022 Elshaboury *et al.*, 2022	AI systems can continuously improve their accuracy and performance by learning from historical data and user feedback	Continuous Learning and Improvement in Construction Waste Management
Abdallah *et al.*, 2020 Rubab *et al.*, 2022 Fang *et al.*, 2023 Bhattacharjee *et al.*, 2022	AI can offer decision-making aids for waste management planning	As A Decision Support

2.3.1 Sorting and Identifying Waste

Artificial intelligence can be used to automate the identification and sorting of many forms of building waste materials. Computer vision algorithms can identify and categorise diverse waste products by analysing photographs or video footage from building sites. This improves segregation and recycling efficiency, eliminating the need for human sorting (Krakauer *et al*., 2017). Additionally, AI have the potential to considerably improve waste management efficiency, reduce labour costs, and improve refuse classification precision. AI focuses on improving the accuracy and efficiency of waste classification robots, which requires the development of better sensors and cameras to recognise different forms of waste, as well as improved artificial intelligence algorithms for waste categorization (Koskinopoulou *et al*., 2021).

2.3.2 Efficient Monitoring and Alerting Systems

Artificial intelligence-powered sensors and monitoring systems can be placed on building sites to track trash output in real time. When garbage bins exceed capacity or when specific waste types demand special care, these devices can detect and alarm (Joshi *et al*., 2022). Besides that, AI can forecast the need for the maintenance of waste management equipment and infrastructure. AI algorithms can identify possible equipment faults or maintenance needs by analyzing past data and taking into account factors such as consumption trends. This enables preventive maintenance, decreases downtime, and ensures waste management systems operate continuously (Javaid *et al*., 2021).

2.3.3 Continuous Learning and Improvement in Construction Waste Management

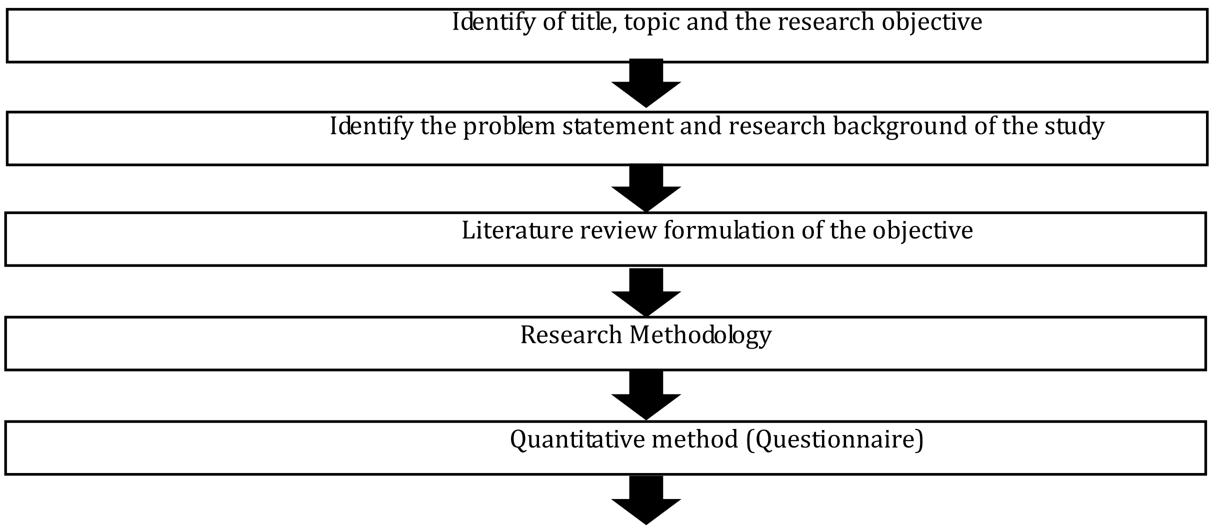
AI systems can continuously improve their accuracy and performance by learning from historical data and user feedback. AI algorithms can develop their models and offer more precise and context-specific alerts over time by analyzing previous alarms and the following actions performed (Frąckiewicz, 2023). Historical data on construction waste allows AI models to determine the most appropriate way to allocate waste management resources. For example, AI can predict the quantity and size of waste containers needed at construction sites, the frequency of waste collection, and the best transportation routes to disposal facilities based on prior data (Elshaboury *et al*., 2022)

2.3.4 As A Decision Support

AI can offer decision-making aids for waste management planning. AI algorithms can recommend optimised waste management solutions, such as recycling choices, waste reduction techniques, and efficient transportation routes, by analysing project data, construction schedules, and waste management regulations (Abdallah *et al*., 2020). AI assists in the monitoring of current waste management systems. AI assists in locating the waste dumping ground/landfill site. it is identifying the exact position of waste bins using GPS or surveys and demarcating on a base map. AI speeds up the process because human labour can sort 30 to 40 items per minute, whereas AI-powered machines can sort 160 items per minute (Bhattacharjee *et al*., 2022).

3. Research Methodology

The research methodology section describes all the necessary information that is required to obtain the results of the study. Figure 1 below illustrates the process of the research methodology.



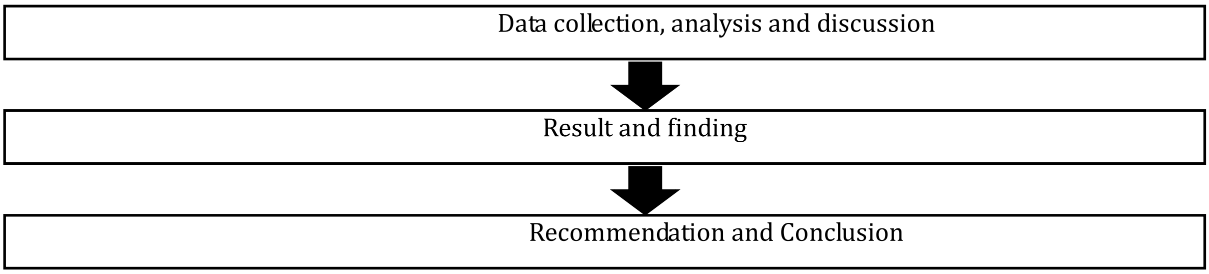


Fig. 1 *Flowchart of methodology research*

3.1 Research tools

The questionnaire relies on Google Forms to get information from contractors G5, G6, and G7. The question has been passed to the respondent through the link. After all the respondents have completed the questionnaire, the result will be recorded and analyzed by the researcher. The questionnaire survey will be composed of 4 sections. The first section will be related to the information of the respondent. The respondent asked by using five Likert scales to state their agreement. The five-point scale for the Likert scale is set out in the table below.

Table 4 *Likert scale*

Scale	Level of agreeing
1	Strongly disagree
2	Disagree
3	Neutral
4	Agree
5	Strongly agree

Table 5 *Section of Questionnaire*

Section A	The respondent will be asked about the individual information. This includes gender, age, race, position, and work experience.
Section B	The respondent will be asked the question related to first objective, which is about the current practice of construction waste management in Malaysia's construction industry by using the Likert scale.
Section C	The data will be collected to achieve the second objective, which is the challenges of construction waste management in Malaysia's construction industry by using the Likert scale.
Section D	The data will be collected to achieve the third objective, which is the potential of Artificial Intelligence (AI) for construction waste management by using the Likert scale.

3.1.1 Population

According to the centralized information management system (CIMS), there is a total of 128048 companies registered under CIDB as qualified contractors in the construction industry. This research there will focus on contractor G5, G6, and G7 there are a total of 1618 G5, G6, and G7 contractors in Malaysia. The G5, G6, and G7 contractor was chosen since it is the highest grade in the CIDB Contractor Grad. The G5, G6, and G7 Contractor is a class of contractors that possesses the highest standard in terms of capital, workforces, and facilities that enable them to bid and tender for a limitless project value. The G5, G6, and G7 contractors have the best probability of winning megaprojects and implementing AI in their projects.

Table 6 *The number of G5, G6, and G7 contractors in Johor that register under CIDB (Source: Construction Industry Development Board, 2023)*

Grade	Number of contractors	Total
G5	731	
G6	136	1618
G7	751	

3.1.2 Sample Size

The sample size is the percentage of a population required to ensure that there is enough information to make valid conclusions (Memon *et al*., 2020). The sampling method allows the researcher to select the contractor in G5, G6, and G7 in a Johor state in Malaysia. This is because the G5, G6, and G7 contractors are aware of construction waste management practices to reduce the amount of construction waste. There are a total number of 1618 G5, G6, and G7 contractors in Johor who are qualified to involve in this research. The sample size 310 of respondents is determined using the Krejcie and Morgan sampling table method. A response rate of 20% is regarded as an excellent response rate for an online survey, while a response rate of 30% is considered good. Therefore, a total of 93 respondent from the G5, G6, and G7 bring choose randomly among the contractors.

3.2 Pilot study

A pilot study is the initial phase in the research procedure and is typically a smaller-sized study that aids in the planning and adjustment of the major study. It entails testing the research processes and instruments on a small scale before deploying them on a bigger scale (In, 2017). Pilot testing aids in finding errors, inconsistencies, or ambiguities in the research strategy, methodology, or instruments. It enables researchers to uncover potential issues such as confusing instructions, biased questions, or technical challenges before the real data gathering phase begins.

3.3 Data Collection

In the research, the data and information been collected from primary data and secondary data. The primary data is collected through the literature review. The literature review helps the research to get information about construction waste management and AI. All of the information is collected from journal articles, conference papers, previous theses, books, and other websites. The secondary data is conducted by using a questionnaire survey. The purpose of the survey is to gain more opinions from the respondent that involve in the construction industry.

Table 7 *Data Collection by Each Research Objective*

Research Objectives	Data Collection	Data Analysis
To investigate the current practice of construction waste management in the Malaysian construction industry.	Literature Review Quatitative	Statistical Package for Social Sciences (SPSS)
To investigate the challenges of construction waste management in the Malaysia construction industry.	Literature Review Quatitative	Statistical Package for Social Sciences (SPSS)
To investigate the potential of Artificial Intelligence (AI) for construction waste management.	Literature Review Quatitative	Statistical Package for Social Sciences (SPSS)

3.4 Data Analysis

The Statistical Package for Social Sciences (SPSS) is a software that helps to analyze the data collected from the respondent. The SPSS has been used to record the data collected from the respondent in the research. After that, Microsoft Excel will be used to form the graphs, table, and chart to present the mean, medium, and standard deviation of the data. The reliability analysis has been used in this research by using SPSS to test the questionnaire before giving to the respondent. The result of a reliability analysis of more than 0.7 is still acceptable.

4.0 Results and discussion

This section presents the results of the data analysis and reveals the findings of the study. A total of 154 sets of questionnaires have been collected through online survey forms. The respondent rate required for this study is 93 respondents which is 30% out of 310 respondents from the sample size of this study. After the collection of the questionnaire survey, there are 154 respondents are valid for this study for further analysis. However, the data were sorted and evaluated by using a Social Science Statistical Package (SPSS) and calculated using formulas and equations to meet the objectives of this research.

4.1 Reliability for Pilot Study and Actual Study

Table 4.0 displays the value of Cronbach's Alpha where the alpha value of the collected responses was found to be more than 0.6, the minimum acceptable value for a test of reliability. In conclusion, the collected feedback data is trustworthy and suitable for analysis.

4.2 Data Analysis

From this study, the grade 5, 6 & 7 (G5, G6 & G7) contractors involved in the construction industry in Johor were surveyed via a digital questionnaire. In addition to a high Cronbach's Alpha value, the majority of respondents are experienced and knowledgeable in the construction industry, making the collected data accurate and trustworthy. This questionnaire contains four major sections: Section A, Section B, Section C, and Section D.

4.2.1 Data Analysis for section A : Demographic of respondents

From the Table 8 shown, the most respondents are male contractor, The frequency of male's respondent is 117 with the percentage of 76%. Most of the respondents are from the age of 51 – 60 years old. The frequency of the respondents from the age of 51 -60 years old is 69 with a percentage of 44.8%. There are a total of 56 respondents have the bachelor's degree with a percentage of 36.4%. Most of the respondents have more than 15 years of working experience in the construction field. There are a total number of 117 respondents who have more than 15 years of working experience with a percentage of 76%. There is total 84 respondents with a percentage of 54.5% are G7.

Table 8 *Summary of Data Analysis for Section A*

No.	Respondent Background	Frequency	Percentage(%)
1	Gender		
	Male	117	76%
	Female	37	24%
2	Age		
	20 - 30 years old	0	0%
	31 - 40 years old	22	14.3%
	41 - 50 years old	45	29.2%
	51 – 60 years old	69	44.8%
	>61 years old	18	11.7%
3	Education Level		
	SPM	3	1.9%
	STPM	4	2.6%
	Diploma	24	15.6%
	Bachelor Degree	56	36.4%
	Master	36	23.4%
	PhD	26	16.9%
	Other	5	3.2%
4	Working experience		
	Less than 5 years	1	0.6%
	5 – 10 years	8	5.2%
	11 – 15 years	28	18.2%
	More than 15 years	117	76%

5	Grade		
	G5	35	22.7%
	G6	35	22.7%
	G7	84	54.5%

4.2.2 Data Analysis for Section B: The Current Practice of Implementing AI in Construction Waste Management

Table 9 *Mean Score and Ranked for Section B*

No	Item	Mean	Standard Deviation	Level of agreement	Rank
B1	3Rs Integrated With BIM - Reduce, Recycle, Reuse				
B1a	Optimizing materials before disposal	4.66	0.857	High	3
B1b	Sorting recyclable waste at construction sites	4.71	0.855	High	2
B1c	Reducing waste generation during construction activities	4.75	0.755	High	1
	The average mean	4.71			
	The average level of agreement	High			
B2	Practicing Industrialized Building Systems (IBS) In Projects				
B2a	Can generate less waste	3.99	1.493	Medium High	3
B2b	Minimize waste during construction activities	4.13	1.317	High	2
B2c	Reduce waste production on-site	4.16	1.398	High	1
	The average mean	4.09			
	The average level of agreement	High			
B3	Radio Frequency Identification Devices (RFID)				
B3a	Track and assist construction waste	4.71	0.863	High	1
B3b	Overcome human error	4.60	0.881	High	3
B3c	Provides easy material tracking to reduce the cost of material waste	4.63	0.928	High	2
	The average mean	4.65			
	The average level of agreement	High			
B4	Global Positioning System (GPS)				
B4a	Trace and verify the location of the waste	4.60	0.967	High	2
B4b	Determining the exact location using satellites	4.63	0.914	High	1
	The average mean	4.62			
	The average level of agreement	High			

Based on the Table 9. The statement B1 which is 3Rs Integrated with BIM – Reduce, Recycle, Reuse ranked 1 in section B with the average mean 4.71. Followed by Radio Frequency Identification Devices (RFID) Rank 2 with the average mean 4.65 and Global Positioning System (GPS) rank 3 with the average mean 4.62. The last is Practicing Industrialized Building Systems (IBS) in projects, it rank 4 and have the lower average mean which is 4.09.

From the Table 9 shown most of the respondent are strongly agree with the BIM assist with AI can achieve 3R principles- Reduce, Recycle, Reuse. It is because AI algorithms integrated with BIM can analyse these models and optimise the design for resource efficiency and waste reduction. This entails choosing materials and construction processes that generate as little waste as possible. Besides, the AI algorithms integrated with BIM can use historical data and project-specific information to forecast the volume and kind of waste created during construction projects and BIM also can offer the required data for the forecasts, such as the quantity and the specification of project materials needed. BIM data can help these systems identify and categorize materials more efficiently. BIM can also assist in tracking recycled materials, ensuring they meet quality standards and are reintegrated into the construction process. The fundamental digital representation is provided by BIM, while AI adds predictive and analytical capabilities to optimise operations and decision-making throughout the construction lifecycle.

Additionally, the statement practicing IBS in construction project have the low rate if compare with another 3 statement in section B. It is because, IBS is a construction technique not an AI element to improve the efficiency and quality of the construction process. But there are most of the respondents also strongly agree with the IBS is entering the stage of integration with AI. Integrating IBS with AI in construction waste management can further enhance the sustainability and effectiveness of the overall construction process.

Table 10 *Others opinion on current practice of construction waste management from respondents*

Opinion
Implement green technology
Use the mobile apps
Construction robotic
Augmented reality (AR)
Virtual reality (VR)
Sensor
Conventional segregation method
Landfilled disposal
Waste to energy
Use the cloud server

Table 10 shows the opinion from the respondent. There are several current practices that related with the artificial intelligence (AI). Some of the respondents said they used the sensor, mobile apps and computer vision technology can monitor construction sites to identify inefficiencies and potential sources of waste. This can include tracking materials movement and identifying areas with high waste generation. Besides, the Augmented reality (AR) and Virtual reality (VR) are used developed to educate construction workers and site personnel about proper waste management practices and AR can be used to create interactive dashboards that provide real-time data on waste generation, recycling rates, and other key metrics.

4.2.3 Data Analysis for Section C: The Challenges of Implementing (AI) in the Construction Waste Management

Table 11 *Mean Score and Ranked for section C*

No	Item	Mean	Standard Deviation	Level off agreement	Rank
C1	Lack of awareness				
C1a	Lack of understanding about construction waste management	4.81	0.627	High	3
C1b	Lack of knowledge about sustainability	4.88	0.503	High	1
C1c	Lack of on-site surveillance actions for legal procedures	4.82	0.584	High	2
	The overall mean	4.84			
	The overall level of agreement	High			
C2	High Cost And Limited Space For Waste Disposal				
C2a	Limited land availability for waste disposal	4.88	0.433	High	1
C2b	The distance between the site and the landfill location is long	4.84	0.513	High	3
C2c	Fees for transportation to landfills are high	4.87	0.467	High	2
	The overall mean	4.86			
	The overall level of agreement	High			
C3	Legal Weaknesses				
C3a	Lack of monitoring and enforcement regulations	4.09	1.359	High	1
C3b	There is no appropriate and strong law for the disposal of construction waste	3.88	1.430	Medium high	2
	The overall mean	3.99			
	The overall level of agreement	Medium high			

Based on Table 11, The statement C2 which is high cost and limited space for waste disposal are rank 1 in the section C. Followed by Lack of awareness are rank 2 with the average 4.84 and the statement C3 legal weakness are rank 3 with the average 3.99. From the table above shown most of the respondent are strongly agree with the high cost and limited space for waste disposal are the biggest challenges in implement AI in the field. Implementing artificial intelligence (AI) technologies for building waste management may necessitate a considerable initial investment. This includes the costs of procuring and installing sensors, IoT devices, AI algorithms, and other relevant technology. Therefore, initial expenses of integrating artificial intelligence (AI) technologies may be regarded as a barrier for construction enterprises operating on limited budgets, even though the long-term benefits in terms of waste reduction and efficiency may outweigh these initial charges. Besides, the expense and logistics of handling waste can be particularly difficult in urban areas or regions with limited available acreage for waste disposal. Traditional disposal options, such as landfilling, may be limited by space constraints and environmental requirement.

Additionally, the legal weakness have the lower average mean compare with others. But most of the respondents also strongly agree with legal weaknesses also as an challenges to implement the AI in construction waste management. It is because, for training and decision-making, AI systems rely on massive volumes of data. Determining ownership of this data and establishing accountability in the event of AI system failures or mishaps can be legally challenging. Clear legal frameworks are required to identify data ownership, usage rights, and duties, particularly when dealing with sensitive waste management information.

Table 12 *Others opinion on the challenges of implementing (AI) in the construction waste management from respondents*

Opinion
Resistance to Change
Lack of attention from relevant authorities
High Volume and Diversity of Waste
Efficacy and Safety
Change Management
Ethics and Privacy Issues
Facing a shortage of skilled professionals
Lack of support from the government
The attitude of employees who do not follow instructions
The problem of sorting waste by category

Based on Table 12, there are the opinion from the respondents about the challenges of implementing (AI) in the construction waste management. Some the respondents said the resistance to change is the main challenges because some of construction companies may have established cultures that resist change. If the organizational culture does not encourage innovation and adaptability, employees may be resistant to the introduction of new technologies like AI. Implementing AI requires a workforce with specific skills to operate and manage the technology. Therefore, the employees may resist change if they feel they lack the necessary skills or if the training provided is insufficient.

4.2.4 Data Analysis for Section D: The Potential of Artificial Intelligence (AI) to Reduce Construction Waste in the Construction Industry

Table 13 *Mean Score and Ranked for section D*

No	Item	Mean	Standard Deviation	Level off agreement	Rank
D1	Identify waste by category				
D1a	Automatically identify and separate construction waste by category	4.72	0.852	High	2
D1b	Reduce labor costs to improve the accuracy of construction waste disposal.	4.84	0.652	High	1
D1c	Optimize operations and simplify waste processing	4.68	0.899	High	3
	The overall mean	4.75			
	Overall level of agreement	High			
D2	Site Condition Monitoring And Notification				
D2a	Real-time tracking and monitoring of waste	4.75	0.670	High	3

D2b	Collect real data in real time	4.80	0.609	High	1
D2c	Analyze data in the past	4.78	0.716	High	2
	The overall mean	4.78			
	Overall level of agreement	High			
D3	Continuous Improvement of Construction Waste Management System				
D3a	Learn from historical data and user feedback to improve performance	4.75	0.697	High	1
D3b	Data transfer from before to get a fast start	4.71	0.800	High	3
D3c	Recommend appropriate recycling processes	4.73	0.769	High	2
	The overall mean	4.73			
	Overall level of agreement	High			
D4	As A Support To Make Decisions				
D4a	Recommends optimized waste management	4.81	0.724	High	1
D4b	Choosing the best waste disposal solution	4.71	0.781	High	3
D4c	Determine the appropriate waste disposal location	4.73	0.778	High	2
	The overall mean	4.75			
	Overall level of agreement	High			

Based on Table 13. The statement D2 which is site condition monitoring and notification are rank 1 with the average mean 4.78. There are 2 statement have the same average mean which is statement D1 is identify waste by category and D4 is as a support to make decisions, the average mean is 4.75. Last, the statement D3 are rank 3, which is continuous improvement of construction waste management system with the average mean 4.73.

From the table above shown most of the respondent are strongly agree with the AI is potential for site condition monitoring and notification. AI, in conjunction with sensors and IoT devices, can provide real-time monitoring of construction sites. This includes tracking the usage of materials, equipment, and energy. By continuously assessing the site conditions. AI can help with precise material tracking throughout the construction process. This includes keeping track of material delivery, use, and disposal. AI helps minimise overordering and waste associated with surplus resources by maintaining a precise inventory and guaranteeing correct material handling. Besides, based on established criteria or deviations from expected conditions, AI can generate warnings and messages. For example, if there is an excessive use of materials, a delay in the construction schedule, or a violation of environmental standards, AI can send messages to the appropriate parties, allowing for quick corrective action.

Additionally, the potential of AI help to continuous improvement of construction waste management system in the industry. The AI can be used to instruct construction workers on best waste management methods. Virtual simulations and AI-driven training modules can help construction teams develop their abilities and foster a culture of continual improvement in waste reduction.

Table 14 *Others opinion on the potential of Artificial Intelligence (AI) to reduce construction waste in the construction industry from respondents*

Opinion
Manage inventory of building materials
AI can replace humans in the industry
Can speed up the construction process
Reduce the duration of the project
Forecasting Waste Generation
Reduce the human error
Enhanced safety
Less documentation
Quality of the project can be control
Continuous sustainability in the future

Based on Table 14, there are the opinion from the respondents. Some of the respondents said the potential of implement AI help to reduce construction waste is the AI can replace human in the construction and help to minimize the human error. It is because the AI can use predictive analytics to estimate the amount and types of waste that will be generated during different phases of a construction project. This allows for proactive waste management strategies and resource planning and the AI can automate the documentation and reporting of waste management activities. This helps maintain accurate records of waste generation, recycling rates, and disposal methods, ensuring transparency and compliance with regulations. Additionally, AI technologies also can contribute to improved safety on construction sites. By monitoring and analyzing data related to safety practices, AI can help identify potential hazards and minimize the occurrence of accidents that may result in additional waste generation.

5.0 Conclusion and recommendation

5.1 Objective summary

The findings of this study have demonstrated that the objectives of this study have been successfully accomplished through the utilization of the outcomes of the data analysis obtained from questionnaires that have been returned. Achievement of objectives is crucial to ensure the success of the study. Based on the synthesis of the literature review and the data collected from the survey, the integrated with BIM is the most commendable practice that implement in the construction industry. The results show that most of the respondent are strongly agree all statement and they also can understand the current practice that implement in the construction waste management or the needs of the questions that comply with the first objective. Based on the data collected, the current practice of construction waste management is still temporarily remain at the conventional method. But there are most of the private company are begin to adopt or implement AI in their project.

For the second objective, The challenges is the cost for implement AI is too high and there are lack of awareness. Based on the data collected, the high implementation cost is indeed common barrieis to the adoption of AI. It is because the initial investment is too high. Integrating AI with existing systems and technologies may require additional investments. Legacy systems may need updates or replacements to be compatible with AI technology. Therefore, the upfront costs associated with implementing AI technologies can be substantially, and the expenses is included in hardware, software, training, and possibly restructuring existing workflows.

For the third objective, it found out there are a lot of potential of AI help to reduce construction waste. Most of respondents are strongly agree with the AI can help to monitoring the condition at the site and give the notification. The installation of smart sensors and Internet of Things (IoT) devices and implement AI on construction sites allows for the collection of data on material usage, energy consumption, and machine operation. Besides, the data can be analysed by AI to find inefficiencies and areas for waste reduction.

5.2 Recommendation

The utilisation of technology in Malaysia's building industry has been continuously rising, but the progress of development has not been as expected and has slowed down. There are Several factors can contribute to slower-than-expected progress in the development of the construction industry. Political insecurity or changes in government can create uncertainty and impede the completion of construction projects. Policy, regulatory framework, or government priority changes may have an impact on the viability of ongoing initiatives. The economic uncertainties and downturns can have a significant impact on construction projects. Reduced investments, tighter budgets, and financial constraints may lead to delays or cancellations of construction initiatives.

(a) Government

Governments play an important role in supporting and encouraging the use of artificial intelligence (AI) in the construction industry. Their activities can impact legislation, give assistance, and foster a climate conducive to AI technology adoption. Governments can provide cash or grants to promote AI research and development activities in the construction industry. Offering tax breaks to company that invest in AI technologies can help to increase adoption. Tax benefits or credits for enterprises who use AI in construction projects can help to lower financial barriers.

Besides, the governments can launch public awareness campaigns to educate construction experts, businesses, and the general public on the benefits and possibilities of artificial intelligence (AI) in the construction industry and the initiatives serve as practical examples and encourage other companies to adopt similar technologies. This can aid in overcoming reluctance to change and instilling confidence in the adoption of new technologies.

(b) Construction players

The contractors, developers, engineers, and other industry stakeholders, must play a crucial role in promoting and encouraging the implementation of artificial intelligence (AI) in the construction industry because they are the professional that have a lot of knowledge on the sector and they provide the confident for the user. The construction players must engage with industry associations, forums, and conferences focused on AI in construction. Sharing experiences, challenges, and best practices with peers can contribute to the collective advancement of the industry. After sharing experiences, can share the knowledge to the team team through training program. The construction firms should have the training program to ensure their workforce has the necessary skills to operate and manage AI systems. This includes providing ongoing education about the benefits and applications of AI in construction.

Acknowledgement

The author would like to thank the Faculty of Technology Management and Business and Universiti Tun Hussein Onn Malaysia for their support.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Tan Wan Yuan, Mohd Hilmi Izwan Bin Abd Rahim;* ***data collection:*** *Tan Wan Yuan;* ***analysis and interpretation of results:*** *Tan Wan Yuan;* ***draft manuscript preparation:*** *Tan Wan Yuan, Mohd Hilmi Izwan Bin Abd Rahim. All authors reviewed the results and approved the final version of the manuscript.*

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