POTENTIAL APPLICATIONS OF ARTIFICIAL INTELLIGENCE (AI) FOR MALAYSIAN CONSTRUCTION INDUSTRY

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ABSTRACT. Artificial intelligence has revolutionized potential benefits in transforming the technology landscape of the Malaysian construction industry. The adoption of AI in the construction industry has been relatively low. Besides, the construction sector is currently dealing with a skilled labour shortage, frequent project delays and cost overruns, all of which are reducing overall efficiency and production. To solve these serious concerns, the use of artificial intelligence (AI) has been recommended as a transformative solution. AI technologies provide novel approaches to improving project management, enhancing safety measures, and streamlining construction operations. In addition, the application of Artificial Intelligence (AI) in construction industry has also gradually increased globally as it promises a lot of advantages. Therefore, this research paper aims to establish the potential application areas of Artificial Intelligence (AI) in Malaysian construction industry. By utilizing a questionnaire, the data was collected from the industry professionals to gain their perceptions for AI adoption. Out of 70 targeted respondents to whom the questionnaire was distributed, only 45 responded. The collected data was then analyzed with Statistical Package for the Social Sciences (SPSS) to identify the barriers and drivers associated with AI implementation. The potential application areas were also established throughout the study. From the research, it can be concluded that risk management with project management has the biggest anticipation for AI application areas in Malaysian construction industry.

Keywords: Artificial Intelligence, AI, Construction Management, Construction Industry

1.0 Introduction

The construction sector is a significant contributor to Malaysia's economic growth, it is expected to reach over 13.5% in 2030 according to Oxford Economics. It includes a wide range of activities, from residential and commercial buildings to large-scale infrastructure projects like roads, bridges, and railways. However, construction industry is also known as the industry that has complex projects, common project delays, high cost and low production (Egwim et al., 2023). Some of the reported construction industry challenges are shortage of skilled workers, lagging in technology adoption, health and safety challenges and lack of collaboration and communication (Alsharef et al., 2024). As the industry contributed a lot of the country's economic, an enhanced product performance is required for effective construction performance (Pan & Zhang, 2021). According to Construction Industry Development Board (CIDB), the industry has not yet adapt to the digitalization of new technologies. In the past several years, Industry 4.0 is having a surge of rapid pace that the construction industry is finding it challenging to keep up with the latest advancement (Egwim et al., 2023). In light of the sluggish performance growth, companies are now turning to artificial intelligence (AI) to optimize processes and boost productivity (Regona et al., 2022). Hence, Artificial Intelligence (AI) is present in construction industry to aids the development. AI in Industry 4.0 refers to the integration of artificial intelligence technologies within the context of the fourth industrial revolution. AI is an expert system designed to identify intelligent entities and streamline decision-making processes, resulting in quicker and more effective outcomes (Pattanshetti & Mali, 2023). A research conducted by Mrosla and Von Both (2019) indicates that AI technology is increasingly being adopted throughout the construction sector, encompassing all aspects of architectural and engineering design as well as building services. Abioye et al. (2021) also conducted a comprehensive study of AI in construction, highlighting the technology's major contributions to resource and waste optimisation, supply chain management, health and safety analytics, estimating and scheduling, and job creation. In the fields of construction and engineering, innovation plays a crucial role in significantly enhancingproductivity and saving substantial amounts of time during the construction process (Silverio

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Fernández, et al., 2021). Furthermore, AI is projected to decrease the number of phases needed to bring infrast[1]ructure designs to operational status (Egwim et al., 2023). Although generative AI applicationsare currently at a developmental phase in the construction business, there are a few research on their utilisation in the construction field (Zheng & Fischer, 2023). Generative AI is a subfield of AI that attempts to produce innovative and realistic data or content, such as words, pictures, video, audio, or code, based on some input or past knowledge (Taiwo et al., 2024). Generative AI can also be viewed as a type of creative AI, striving to generate data or content that is not just realistic but also unique and expressive (Gozalo-Brizuela & Garrido-Merchán, 2023).

The construction industry currently faces major challenges despite being a critical driver of economic growth and development, including a lack of skilled labor, disruptions in supply chains leading to volatility in material and labor costs, particularly exacerbated post-COVID-19 pandemic the slow adoption for early-stage development of new technologies like 3D printing and virtual/augmented reality (Alsharef et al., 2024). Given the slow pace of performance improvement in recent years, there is a pressing need for advanced technological solutions to address these issues. However, the adoptionof AI in Malaysia's construction industry remains limited and there is a scarcity of construction personnel experienced in utilizing AI-based software and applications within this sector (Mohamed et al., 2021). Therefore, a comprehensive exploration of Artificial Intelligence capabilities, barriers and implementation is essential to unlock its full potential and drive the construction industry towards a more effective and innovative future.

2.0 The Definition of Artificial Intelligence (AI)

Numerous definitions of artificial intelligence (AI) have been proposed by scholars, each highlighting the technology's capability to process data, derive insights from historical information and navigate future uncertainties. Emeritus Stanford Professor John McCarthy first used the term artificial intelligence (AI) in 1955, and he defined it as "the science and engineering of making intelligent machines." Artificial intelligence algorithms are capable of learning, perceiving, solving problems, comprehending language, and/or applying logic (Saleh., 2019). Shi et al. (2020) stated that the primary objective of artificial intelligence (AI) is to address issues that are challenging to define but that individuals can generally solve with ease utilising their innate intuition.

2.1 Artificial Intelligence (AI) in Construction Industry

In order to overcome the issues and challenges in construction industry, AI technologies were integrated to address various challenges and obstacles along the projects development. In addition, the construction industry has also started utilising technology in recent years as businesses have realised its advantages (Regona et al., 2023). With AI, the sector is still being shaped by new trends anddevelopments in AI technology, which spur additional innovation and productivity increases. The seven AI technologies that were used in the construction section were generally addressed in the articles thatwere reviewed by Egwim et al. (2023) in which the most frequently mentioned ones were supervised learning, deep learning, robots, knowledge-based systems and natural processing.

2.2 Artificial Intelligence and Construction Industry – Bibliometric Analysis

Figure 1 below shows the visualization from the keyword co-occurrence networks that were generated from the publications that have been filtered. The links are referring to the connections or relationships between variables in a dataset such as documents, authors and keywords. Each link represents an individual item and its size typically corresponds to a certain metric associated with that item. From the network visualization, it can be identified that the terms “artificial intelligence”, “machine learning” and “deep learning” are interconnected with each other. Apart from that, it also illustrated that “construction industry”, ‘internet of things”, “decision making’, “big data” and “project management”have similar network.

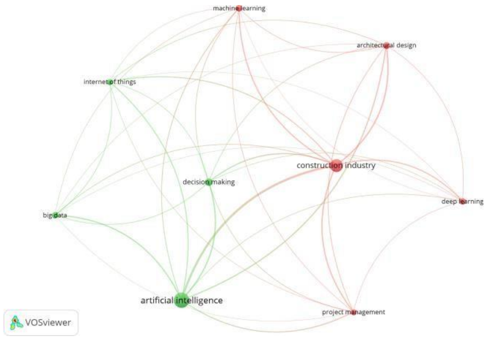

Figure 1 Keywords co-occurrence

2.2.1 Chronological Publication Trend

Over the last few years, the chronological publishing trend for AI in the construction industry has showed a substantial increase based on Scopus. Initially, the number of publications was low, with only a few research articles appearing in the early 2000s. This time represented the early stages of incorporating AI technology into building, with a concentration on theoretical frameworks and prototype initiatives. However, as the potential of AI became more apparent, the mid-2010s saw a significant surge in research activities. This rise aligns with developments in AI technology. Based on Figure 2, it shows that there are a gradual increase of the papers starting from the year of 2019 until 2023.

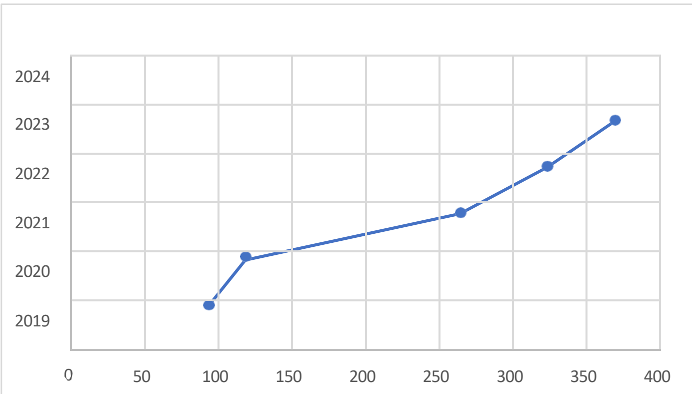

Figure 2 Publications number by year

2.2.2 Geographic Distribution

The bar chart titled "Documents Published by Countries" illustrates the number of documents published on AI in the construction industry by various countries from the year 2019 until 2023. There are a total number of 76 countries with the theme of Artificial Intelligence in Construction Industry published in Scopus. The findings show a large discrepancy in research output across the countries indicated. Based on Figure 3, it illustrated the top 15 countries with the stated theme on the platform. China has the highest number of papers published with 315 papers followed by United States with 117 papers. Saudi Arabia, Poland and Malaysia have the equivalent amount of 18 published papers which indicates the low stages of research activity in AI within their construction industries.

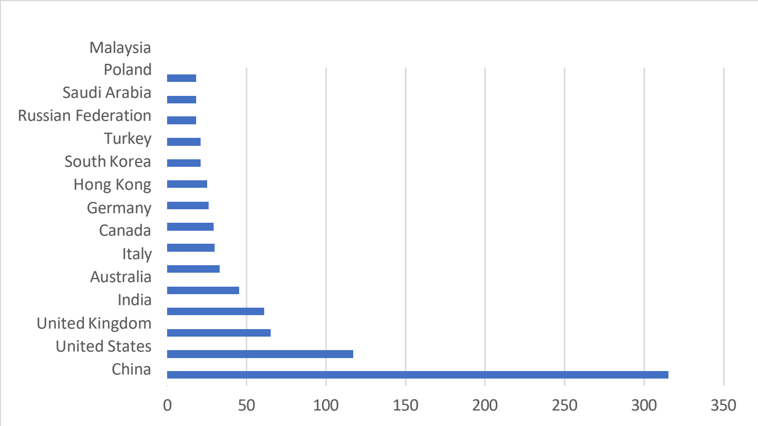

Figure 3 Documents Published by Countries

2.3 Barriers of Artificial Intelligence (AI) in Construction Industry

As the construction industry is known for its traditional methodologies, the transformative revolution driven by Artificial Intelligence (AI) is slowly progressing. Even though there are a significant advantage of the enhancement in the industry, its integration into the construction sector is fraught with consequential barriers. The barriers of the applications are categorized into three which are technical barriers, economic barriers and managerial and organisational barriers.

In technical barriers, Osuizugbo and Alabi (2021) stated that a lack of understanding and acceptability has been cited as a significant hurdle, with awareness being critical in the adoption of AI. Furthermore, data quality issue is also one of the technical barriers as it produces inaccurate data, outdated data, insufficient data and influence of the degree of data being input (Zammari & Ayob, 2023). Rampini et al. (2022) stated thatthe lack of studies and standards contributed to the barriers as better interoperability are required for AI implementation. Lack of real-world capability is one of the challenges for AI application in construction industry (Egwim et al., 2023).

While for economic barriers the AI application refers to the financial challenges and constraints the adoption and implementation of AI technologies. Abioye et al. (2021) stated that the high initial cost of AI is the barrier as the maintenance requirements of these solutions may be prohibitively expensive for the majority of subcontractors and small firms that constitute the bulk of the construction industry. The implementation of AI in construction industry will have an additional cost as it requires AI expert involvement for the technology (Regona et al., 2022). Meanwhile, Omar (2022) suggested that the deployment cost of AI implementation is higher than other barriers for the application. Managerial and organisational barriers are the problems and constraints within management practices and organisational structures that will affect the successful adoption of AI. construction industry. Employees fear they may lose their jobs as monotonous repetitive chores aregradually replaced by AI (Ivanov et al., 2020). In addition, Abioye et al., (2021) expressed that building and sustaining public trust in AI technologies relies on inclusive, transparent, and responsible governance practices. Due to insufficient government funding, the adoption of AI in the industry is delayed, resulting in small and medium-sized construction companies continuing to rely on traditionalmethods (Omar et al., 2022).

2.4 Drivers of Artificial Intelligence application in construction industry

The utilisation of Artificial Intelligence (AI) in the construction sector is motivated by various compelling elements that hold the potential to transform conventional methods and improve overall effectiveness. It addresses the complexity of construction industry while fundamentally reshaping the industry's landscape. Comprehending and utilising these factors is crucial to remain competitive, enhancing safety and promoting sustainable development in the construction industry.

2.4.1 Project Management

The integration of AI in project management within the construction industry offers substantial benefits. The advantages of adopting AI in the AEC business include boosting efficiency and enhancing productivity safety (Senjak et al., 2023). Efficiency and productivity are paramount in project management within the construction industry as it will determine the quality of the projects. Hatoum et al., (2023) stated that Artificial Intelligence speeds up the decision making in project management, but it also should be adhere to social and ethical principles in the process.

2.4.2 Design Optimization

Design optimisation in the construction sector through the use of Artificial Intelligence (AI) entailed algorithms and data analytics to develop building designs that are more efficient, cost-effective and sustainable. Another driver of design optimization by using AI in the industry is automated drafting that compute a variation of design techniques to be produced according to the project requirements and constraints. Apart from that, generative design through AI is also the drivers of AI application in the industry. For an instance, there are potential applications for image-text utilisation encompass land survey data extraction, specification of 3D models and digitization of blueprints (Taiwo et al., 2024).

2.4.3 Finance

A study that was conducted by Abioye et al., (2024) suggested that with the effective and efficient resources management, there will be a reduction of cost and waste. It analyzes the building materials and supply chains hence leading to cost saving and environmental benefits. Additionally, AI-powered towards predictive maintenance has the potential to alter the construction sector by ensuring dependability and cost-effectiveness (Rohith et al., 2023).

2.4.4 Quality Delivery

The higher the quality of the construction project's output, the greater the client's confidence in the constructor. The availability of defect detection procedures in the construction sector has been significantly improved, leading to enhanced building maintenance and improved structural integrity (Mariniuc et al., 2024). Artificial intelligence systems enable the continuous monitoring of building sites and workers, facilitating the fast detection of any dangers and triggering proactive actions to prevent accidents (Rabbi et al., 2024). A significant amount of photos, videos, and other forms of data are produced on construction sites through real-time monitoring. These data are predominantly unstructured and provide valuable insights for management purposes (Abioye et al., 2024).

2.4.5 Governance

Effective governance of AI in the construction industry is important to prove its potential while mitigating risks. Employees need to possess incentive programmes in fields such as information and digital technology and data analytics due to AI's involvement in automation, the advancement of interconnected networks of smart devices and materials and the fusion of physical and virtual environments (Khan, 2023).

2.5 Potential Application Areas of Artificial Intelligence in Construction Industry

The integration of Artificial Intelligence (AI) in the construction industry heralds a transformative era as it does seamlessly contribute to the industry's growth. AI technologies are also being integrated into various facets of construction from design and planning stage to execution and maintenance stage. In addition, the usage of Machine Learning (ML) and Deep Learning (DL) in between of the AI incorporation allows for advanced data analysis and pattern recognition, enabling more precise predictions and automations within the construction industry. During Pre-construction Phase, a study conducted by Elmousalami (2020) by analyzing past cost modelling suggested that artificial intelligence (AI) and machine learning have the capabilities to execute cost estimation accurately. According to the Hasan and Mohmed (2024). Artificial intelligence (AI) is also used during the design and planning scale for the optimization techniques in the sector of architectural and constructions. In addition, the project scheduling processes can be enhanced with the integration of AI technologies (Bahuguna, 2019).

During Construction Phase, a high quality control can be achieved through AI as it can estimate the quality of a construction project with precision that can avoid costly rework as it follows the standards that have been provided (Liu, 2024). Real-time monitoring can also be carried out by using computer vision AI for the purpose of monitoring the construction project (Korke et al., 2023). Additionally, efficient resource allocation during the construction period which included manpower, materials and machinery can be augmented (S Abishek et al., 2023). With the integration of AI and site safety culture, AI opens up groundbreaking opportunities through safety inspection monitoring as it provides high precision and efficiency (Tamoor et al., 2024). As for Post-Construction Phase an AI will not displace workers on construction sites but will bring about substantial changes in office workflows, including documentation and reporting with information retrieval (Giyasov et al., 2024). Through an assessment by Scaife (2023), artificial intelligence can be applied in conjunction with predictive maintenance to lower the operational and maintenance expenses of a facility. By the utilization of artificial intelligence (AI), it can address numerous challenges and enhance the efficiency of security and surveillance on construction sites by accurately identifying security threats.

3.0 Methodology

This study adopted mixed research method (i) literature review (ii) quantitively data collection analysis for the topic. The integration of a literature review and quantitative data methods is essential for establishing a robust foundation and providing empirical evidence to support the study's objectives. This approach is to ensure a well-supported and comprehensive of the potential application areas of Artificial Intelligence (AI) in the Malaysian construction industry.

4.0 RESULTS AND DISCUSSION

4.1 Introduction

The findings from the study through the statistical analysis and key results from the questionnaire data collected from the construction industry professionals. It included data collection and response rate, demographic information, barriers and drivers of Artificial Intelligence (AI) application in construction industry. The potential application of Artificial Intelligence (AI) is also established through the questionnaire survey. A Google form that consisted of 5 sections was distributed to the industry professionals during the study. The participants for this study were meticulously chosen to exclusively include persons who are currently involved in Malaysia's construction sector. This group consisted of academicians who contribute to the area through research and teaching, contractors who are directly engaged in the implementation and administration of construction projects and consultants who offer expert guidance and specialised services in different parts of construction with 45 responses.

Table 1 General Information of Respondents

General Information	Categories	Frequency	Percentage (%)
Age	26-30	15	33.3
	31-35	13	28.9
	36-40	12	26.7
	41-45	2	4.4
	46 and above	3	6.7
Individual’s background	Academician	12	26.7
	Consultant	15	33.3
	Contractor	18	40.0
Current academic qualification	Bachelor's degree	30	66.7
	Master	14	31.1
	Registered Professional Engineer	1	2.2
Number of years involved in construction industry	1-5	1	2.2
	6-10	16	35.6
	11-15	13	28.9
	16-20	11	24.4
	21-25	3	6.7
	26 and above	1	2.2

4.2 Barriers of Artificial Intelligence (AI) Application in Construction Industry

Objective 1 is to identify the barriers of Artificial Intelligence (AI) application in construction industry. Through the benchmarking that has been reviewed in Literature Review, the expected barriers were listed out in the Google Form questionnaire to collect the perspectives of the industry professionals. To ensure that the collected data is ideal, KMO test will be conducted to identify the strength of the partial correlation between the variables. The higher the KMO proportions and closer to 1.0, the ideal it is. However, if the KMO value is less than 0.5, then the variables are considered unacceptable. Additionally, the Bartlett's Sphericity test is used to prove that the hypothesis of null is an identity matrix. A significant value that is less than 0.05 represents that the matrix is not an identity matrix.

Based on the Table 2 below, the barriers of AI application in construction industry have a value of 0.872 for KMO which exceed the minimum of 0.5, hence the variables can be used for factor analysis. The Bartlett Sphericity Test analysis conducted have an approximate chi-square value of 3566 and the significance value of 0.000. which has proven that the variables are not identity matrix. Hence, factor analysis can be done as the requirement have been achieved.

Table 2 Descriptive Statistics (Barriers)

Barriers	**N**	**Mean**	**Std. Deviation**
Technical Barriers			
Resistance to change and lack of awareness and understanding of AI technology	45	3.67	0.603
Data quality and management issues, including data privacy and security concerns	45	3.96	0.878
Lack of IT infrastructure or resources to implement AI and maintain AI solutions	45	3.98	0.892
Difficulty in integrating AI with existing processes and workflows	45	3.93	0.330
Legal and regulatory challenges, such as intellectual property rights and liability issues]	45	3.84	0.475
Dependence on third party AI providers	45	4.2	0.815
Lack of studies or standards	45	4.13	1.014
The need for reliable power, telecommunications and internet connectivity	45	4.38	0.936
Lack of real-world capability	45	3.33	0.769
Economic Barriers			
High initial investment costs and ROI uncertainty	45	3.96	0.562
Lack of financial incentives by government and funding agencies	45	4.42	0.812
High cost of operation and maintenance	45	4.22	0.765
Additional cost due to requirement of AI expert	45	4.49	0.787
Managerial and Organisational Barriers			
Ethical concerns regarding AI's impact on jobs and human decision making	45	4.09	0.848
Training the workers	45	3.51	0.589
Technologies are not easily available	45	4.36	0.883
Conservatism by construction managers	45	3.38	0.650
Unique nature of construction environments	45	4.22	0.670
Fear of unemployment	45	4.76	0.743
Required change of management	45	3.96	0.298
Maintaining the public trust	45	3.64	1.048
Government Policy	45	4.36	1.004
Cultural difference	45	4.22	0.560
Multi-point responsibility between stakeholders	45	4.29	0.549

Table 3 Descriptive Statistics (Drivers)

Drivers	**N**	**Mean**	**Std. Deviation**
Project Management			
Increased efficiency and productivity	45	3.73	0.654
Improved decision-making and accuracy	45	4.31	0.701
Greater visibility and transparency in the supplychain	45	3.64	0.570
Optimization of inventory and logistics	45	3.93	0.986
Ability to quickly adapt to changing customer demands and market trends	45	3.96	0.999
Improves planning stage	45	4.44	0.813
Improves communication between stakeholders	45	3.91	0.557
Helps with on-the-job training of employees	45	3.40	0.539
Possibility for big data analytics	45	4.33	0.564
Innovation by bringing new technology	45	4.89	0.438
Extracts data from complex document and categorize them based on patterns easily	45	4.24	0.645
Design Optimization			
Automated drafting	45	4.13	0.625
Clash detection	45	3.53	0.968
Generative design (Model generalization and transferability)	45	3.89	0.532
Finance			
Reduction in costs and waste	45	3.93	0.393
Predictive maintenance of construction equipment	45	4.29	0.589
Opportunities for innovation and competitive advantage	45	3.73	1.009
Quality assurance	45	3.89	1.009
Effective and efficient resources management	45	4.51	0.815
Quality Delivery			
Defect detection	45	4.47	0.661
Hazard monitoring	45	4.16	0.976
Real-time monitoring	45	3.42	0.621
Enhanced risk mitigation	45	3.91	0.514
Governance			
Incentives programs	45	4.18	0.777
Increase of labour wage	45	3.78	0.927
Increases R&D investment	45	4.51	0.927
Workforce training	45	4.31	0.927
Valid N (listwise)	45		

4.3 Potential Application Areas of Artificial Intelligence (AI) in Construction Industry

The 3rd objective in this research study is to establish the potential application areas of Artificial Intelligence (AI) in Malaysian construction industry. This objective aims to explore on how AI technologies can be implemented to various aspects of construction processes starting from the pre-construction phase until the post-construction phase. This is the most important stage in this research study to shorten the gap within the previous studies. Based on the data in Table 4.6.1, the potential application areas in the construction industry demonstrate a Kaiser-Meyer-Olkin (KMO) measure of 0.873, surpassing the minimum threshold of 0.5. This indicates the suitability of the variables for factor analysis. Additionally, the Bartlett's test of sphericity yielded an approximate chi-square value of 2487 with a significance level of 0.000, confirming that the variables are not perfectly correlated (identity matrix). Therefore, all prerequisites for conducting factor analysis have been met.

Table 4 Descriptive Statistics (Potential Application Areas)

Potential Application Areas	N	Mean	Std. Deviation
Pre-construction Phase			
Budgeting and cost estimation	45	3.91	0.514
Design and planning	45	4.00	0.853
Feasibility study	45	4.00	0.929
Project scheduling	45	4.16	0.737
Construction Phase			
Quality control	45	3.91	0.514
Real-time monitoring	45	3.04	0.367
Resource allocation	45	3.91	0.288
Safety monitoring	45	3.96	0.424
Post-construction Phase			
Building maintenance and operations	45	4.07	0.809
Documentation and reporting	45	4.24	0.679
Predictive maintenance	45	4.24	1.026
Revenue management	45	4.13	0.588
Security and surveillance	45	4.14	0.632
Risk Management			
Technical risks (reliability and compatibility)	45	4.50	0.731
Operational risks (data management and maintenance)	45	4.48	0.731
Regulatory risks (data privacy and standards)	45	4.16	0.731
Risk assessment	45	3.25	0.576
Risk mitigation	45	3.98	0.792
Risk monitoring	45	4.27	0.544

4.4 Weightage Factor Between the Barriers, Drivers and Potential Application of AI in Construction Industry

Factor scoring assigned weightage factors to barriers, drivers and potential application areas of AI in the construction industry to facilitate the analysis of their interrelationships. For the weightage factor for barriers of AI application in construction industry (Table 2), the highest factor scoring belongs to managerial and organizational barriers which has the value of 38.611 with the average mean of 4.072. Based on the data obtained for the drivers of AI application in construction industry (Table 3), the highest factor scoring belongs to project management which has the value of 35.777 with the average mean of 4.138. Meanwhile, the highest factor scoring for the potential application areas of AI application in Malaysian construction industry (Table 4) is during risk management which has the factor scoring of 18.815 with the average mean of 4.278.

5.0 Conclusion

From the study conducted, it becomes evident that the Malaysian construction industry is gradually acknowledging the transformative potential of Artificial Intelligence (AI). The first objective which is barriers of Artificial Intelligence (AI) has been identified in which the need for reliable power, telecommunications and internet connectivity. Technologies are not easily available and the unique nature of construction environment are also the concerns of the industry's professionals that need to be considered for AI application in the industry. The second objective is the drivers of Artificial Intelligence (AI) application in the construction industry has been determined in which it is the finance aspect of reduction of cost and waste. Additionally, the generative design from AI applications contributes to the growth and development of the industry. The third objective of the research is to establish the potential application of AI in Malaysian construction industry and the technical and operational risks from risk management have the highest consideration.

Based on the data analysis, it can be concluded that risk management emerges as the most promising area for implementation within the Malaysian construction industry. Specifically within the context of risk management for AI applications, several critical components are included which are technical risks, operational risks, regulatory risks, risk mitigation strategies and risk monitoring processes. There is relationship between project management as the drivers of AI application with risk management as the area of potential application in the construction industry. These elements collectively form a foundation of framework that can be aimed at effectively managing and mitigating potential risks associated with the integration of AI technologies in construction projects in Malaysia.

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