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CHALLENGES IN BUILDING INFORMATION MODELLING AND ROBOTICS INTEGRATION IN MALAYSIA'S FUTURE CONSTRUCTION INDUSTRY

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ABSTRACT:

The construction industry is undergoing a significant transformation driven by advancements in Building Information Modelling (BIM) and robotics, which are key elements of the Fourth and Fifth Industrial Revolutions. While BIM facilitates collaborative information management throughout a building's lifecycle, robotics introduces automation and precision in construction tasks. The integration of BIM-robotics has the potential to enhance safety, productivity and efficiency in construction. However, the adoption of BIM-robotics remains underexplored in Malaysia. This study aims to evaluate the challenges of implementing BIM robotics in the Malaysian construction industry. A total of 22 secondary data sources were collected from a comprehensive literature review. A questionnaire survey was adopted for primary data collection. For data analysis, four statistical tests were conducted which are exploratory factor analysis (EFA), descriptive analysis, reliability analysis and correlation analysis. The main findings identified four key factors from the EFA, such as technological, organisational, environmental and financial. Descriptive analysis revealed the critical challenge within each factor, while reliability analysis confirmed strong internal consistency. All identified challenges were found to be positively correlated. By identifying the challenges to BIM-robotics adoption, this study provides valuable insights for policymakers, industry practitioners and researchers to create plans for overcoming these challenges. Ultimately, this study contributes to advancing the construction industry's readiness for technological integration, aligning with national goals for Construction 4.0 and beyond.

1. INTRODUCTION

In line with the fifth industrial revolution (IR 5.0), the construction sector is undergoing a radical change as emerging technologies like robotics and artificial intelligence become indispensable tools. At the same time, building information modelling (BIM) has become a cornerstone of the fourth industrial revolution (IR 4.0). BIM provides a collaborative platform for storing, sharing, exchanging and managing multidisciplinary information throughout the entire building project lifecycle (Eastman, 2011). Construction robotics is defined as sophisticated machinery that can carry out autonomous or teleoperated tasks (Zhang et al., 2022). It has gained attention for its ability to execute time-consuming construction processes with efficiency. For example, Kumar et al. (2016) estimated the use of robots for certain construction tasks can reduce the time needed by up to 50% when compared to traditional methods. It can be said that BIM and robotics represent the major elements of two industrial revolutions and their integration has the potential to revolutionise the construction industry. Through thorough task planning and virtual environment simulation, the integration of BIM and robotics has introduced new opportunities in different construction tasks. The applications include facility inspection (Chen et al., 2023), visual installation progress monitoring (Zhao et al., 2023), bricks assembly (Ding et al., 2020) and façade installation (Ali et al., 2021). Despite the potential of BIM-robotics, they remain one of the least researched and adopted technologies in the construction industry (Wang et al., 2020). This limitation is evident in Malaysia, where the Construction 4.0 Strategic Plan (CSP) 2021-2025 and the National Construction Policy (NCP) 2030 emphasise that to achieve IR 4.0, it requires twelve emerging technologies, including BIM and robotics.

Recently, robotics adoption is still uncommon and restricted in Malaysia, where BIM implementation has been required for projects costing more than RM100 million (Othman et al., 2021). The primary reason could be the low maturity level of BIM in Malaysia, which is still at BIM level 1 (Othman et al., 2021). Recent studies have observed that BIM maturity in Malaysia is still transitioning from level 1 to level 2 (Omar and Fateh, 2023). It is challenging and unsupported to integrate with cutting-edge technologies like robotics. However, this does not imply that Malaysia is unaware of it. According to CSP, robotics could have a major impact on labour cost reduction, while NCP asserted that

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robots could handle heavy lifting, and autonomous cranes and excavators will be operated by humanoid robots by 2050.

However, achieving this mission requires overcoming challenges, the fundamental challenges of BIM-robotics integration have not been sufficiently covered in any of the previous studies (Kim et al., 2021). While BIM adoption is progressing in Malaysia, the integration of BIM and robotics in construction remains underexplored. Therefore, this study aims to investigate the challenges of implementing BIM-robotics integration in the Malaysian construction industry.

2. LITERATURE REVIEW

2.1 Previous Studies on BIM-robotics

To evaluate the integration of BIM and robotic systems in construction, the selection of the previous studies was based on several key criteria. Firstly, the keywords "BIM & robotics & construction" were used in the search process. Secondly, only studies published within the last five years from 2020 to 2025 were considered to ensure the articles have the most recent insights. Thirdly, priority was given to studies that use a case study methodology due to their practical insights into the real-world application of BIM-robotics integration. Based on the search results, six articles were selected as suitable, as shown in Table 1. The integration challenges for each article are also recorded in the table as one of the secondary data sources in this study.

References	**Brinkhoff and Kolani (2024)**	**Oyediran et al. (2024)**	**Amani and Akhavian (2024)**	**Cao et al. (2024)**	**Huang et al. (2023)**	**Liang et al. (2020)**
Research objective	Translating IFC-based BIM data to robotic task planning (bricklaying)	4D BIM integration for context-aware task and motion planning (wall frames)	Semantic navigation for task-optimised and collision-free pathfinding	BIM-guided task planning for optimal sequencing of rebar binding tasks	BIM-guided semantic/geometry-based robot progress monitoring	Real-time synchronisation of BIM and physical robots using digital twins
Methodology	IFC-BIM to ROS workflow; visualised using MoveIt and Rviz	4D BIM model extended to support robot simulations	MHA* (multi-heuristic algorithm) + NLP models for pathfinding	Genetic algorithm for task optimisation and robot workspace adjustments	SLAM-based framework incorporating BIM for autonomous initialisation	Digital twin linking robots with BIM using ROS + Gazebo for bi-directional control
Data exchange standards	IFC-BIM, ROS	IFC-BIM	IFC-BIM	BIM	IFC-BIM	ROS, IFC-BIM
Robotic applications	Bricklaying	Indoor wall frame assembly	Navigation in dynamic sites	Rebar binding task optimisation	Progress monitoring	Collaborative robots on-site
Robot types	Robotic arm (bricklayer)	Robotic arm (manipulator)	Mobile robots	Wheeled-legged robot	Mobile robots	Collaborative mobile robots (co-robots)
Hardware/ sensors	None	None	RGB-D cameras for object proximity	None	RGB-D cameras, LiDAR	KUKA KR120 robotic arm, Gazebo-based simulation software
BIM utilisation	IFC data used for autonomous task planning and execution	4D BIM extended with robot modelling	BIM semantics drive navigation adjustments via algorithms	BIM position data is used to decompose task zones	BIM geometry/ semantics generate detailed environments	Provides task descriptions, motion plans
Validation	Experimentation with robotic simulation software (MoveIt)	Simulation and case study	Dynamic site testing to validate safety and time efficiency	Simulations and real-world validation with wheeled robots	Real-world progress monitoring tests	System validated with a digital fabrication case
Results	Visualised robot task execution; not field-tested	Sequence of task simulations	Robot pathfinding improved by	Efficiency of rebar binding	Robot successfully initialised and	Effective task synchronisation between BIM

		for interior assembly indicated feasibility	80%; collision probability reduced	tasks increased by 97%; reduces manual labour	navigated for inspection tasks	and robots demonstrated
Integration challenges	Lack of high-detail BIM-to-robotics conversion protocols	Difficulty in incorporating robot knowledge into construction planning	High computational cost for collision avoidance in real-time environments	Dynamic site environment increases task complexity	Dynamic site adjustment remains challenging for robots	Limited scalability of Gazebo and ROS-based systems to complex sites
Emerging trends	IFC-to-ROS with MoveIt visualisation	Combining 4D BIM and robot knowledge models	NLP-based task re-planning via BIM semantics	Genetic algorithm + workspace adjustments for robotic arms	Autonomous mapping without pre-exploration using BIM-based initialisation	Digital twins for online robot synchronisation

Table 1. Benchmarking table

2.2 Use of BIM-robotics in Construction

BIM can potentially be used together with robotic autonomy due to its ability to store extensive data on the built environment. However, due to sensor limitations and programming errors, the 3D models are always not perfect. Although robots can collect data to create a 3D building model, it is often inaccurate (Ibrahim et al., 2019). It is not a good choice to create 3D modelling using robots, but their value can be demonstrated in various construction stages.

Many on-site tasks during construction, such as material handling and bridge inspection are dangerous for human workers. For some dangerous jobs like bricklaying, inspection, and cleaning, numerous researchers are trying to replace manual labour with robotic technologies (Saidi et al., 2016). In real-world scenarios, studies have shown that integrating BIM with robotics is feasible. For instance, Ding et al. (2020) proposed a task-level planning technique for robotic bricklaying based on BIM and a vision-based 3D model.

For prefabricated components, the integration of BIM-robotics allowed for quick surveying and calibration. They can provide positioning data for automated or semiautomated assembly (Cai et al., 2020). However, this technology is not yet popular in Malaysia, but it has gained traction in countries like China, where the government has actively launched it (Cai et al., 2020).

Many studies have concentrated on planning and monitoring robotic tasks on construction sites. Kim et al. (2021) developed a BIM-integrated planning and simulation system for construction robotic tasks and proved that using BIM for autonomous robotic operations is feasible. Karimi et al. (2021) proposed a comprehensive system that uses BIM to guide robots on construction sites. Park et al. (2016) used mobile robot navigation systems with ultra-wideband technology to track indoors in construction environments.

With the advent of 4D BIM, the use of robotics in construction has grown even more. 4D BIM added the construction schedule into a 3D BIM model for construction progress monitoring. Ibrahim et al. (2019) developed a 4D BIM-driven pipeline to define robotic waypoints for data collection. Kim et al. (2021) emphasised that future studies could use 4D BIM in robotic task planning to simulate construction progress through IFC files, which can continuously update schedules based on the tasks completed by robots.

Furthermore, robotics has been explored for multi-agent systems in construction. Asadi et al. (2020) developed a system in which aerial and ground vehicles work together to collect 3D maps for tracking construction progress. This system consists of a BIM interface and a robot operating system. A brief workflow of robot integration with the BIM interface is depicted in Figure 1.

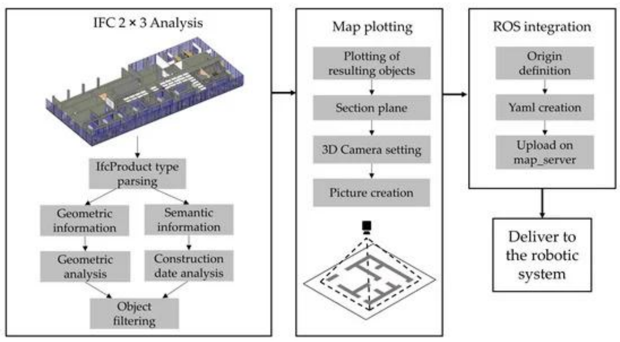

Figure 1. The workflow of the BIM interface integrates with robots (Follini et al., 2021)

2.3 Challenges of implementing BIM-robotics

In the construction sector, there are numerous chances to increase productivity, accuracy and efficiency through the integration of BIM and robotics. However, there are several challenges to its implementation, which can be grouped into technical limitations, workforce development and training gaps, research and knowledge deficiencies, legal and security issues, policy and government support deficiencies, and financial and economic constraints. Table 2 summarises the challenges within each category, along with the corresponding references.

Code	Challenges	References
Technical		
CH1	Interoperability issues between BIM and robotic platforms	(Zhang et al., 2022)
CH2	Insufficient task planning systems to generate detailed robotic motions (e.g. grasping, turning, positioning) based on BIM and construction schedules	(Kim et al., 2021)
CH3	Limited capabilities for realistic interaction between virtual objects and robots	(Matsas and Vosniakos, 2017)
CH4	The maturity level of BIM technology and robotic systems remains low	(Cai et al., 2020)
CH5	Complex construction environments that hinder the flexibility of robotic systems	(Follini et al., 2021)
CH6	Supply chains of construction materials are not configured to support robotic tasks (e.g. bricklaying)	(Dindorf and Wos, 2024)
Workforce development and training		
CH7	Insufficient workforce training to operate BIM-robotic systems	(Ohueri et al., 2024)
CH8	Limited adaptability of training scenarios to meet trainee needs	(Balogun et al., 2024)
CH9	Need for enhanced user education on BIM-robotics applications	(Dindorf and Wos, 2024)
CH10	Resistance of the entire construction sector to adopt new technologies	(Marinelli, 2023)
Research and knowledge gaps		
CH11	Lack of comprehensive data and analysis on user needs and preferences	(Cai et al., 2020)
CH12	Lack of attention to technological advancements in construction	(Liao et al., 2017)
Legal and security issues		
CH13	Intellectual property rights are not adequately protected	(Zhang et al., 2022)
CH14	Cybersecurity risks are increasing	(Zhang et al., 2022)
Policy and government support deficiencies		
CH15	Lack of standardised methods, contractual languages and frameworks for BIM-robotics integration	(Zhang et al., 2022)
CH16	Insufficient government support for implementing BIM and robotics in construction practices	(Cai et al., 2020)
CH17	Lack of government support for academic research on BIM and robotics	(Cai et al., 2020)
Financial and economic constraints		
CH18	High unit costs of robotic stations	(Dindorf and Wos, 2024)
CH19	High initial investment costs	(Dindorf and Wos, 2024)
CH20	High maintenance costs (regular repairs and inspections)	(Dindorf and Wos, 2024)
CH21	Uncertainty of economic benefits and returns	(Cai et al., 2020)
CH22	Low research and development budgets in the construction industry	(Davila Delgado et al., 2019)

Table 2. List of challenges

3. RESEARCH METHODOLOGY

In this study, a quantitative research design was employed to evaluate the challenges of BIM-robotics integration in the Malaysian construction industry. A structured questionnaire survey was selected as the primary data collection. The questionnaire included closed-ended questions and used a five-point Likert scale for responses, where 1 = Strongly disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree and 5 = Strongly agree. A pre-test was conducted involving three developers and three BIM experts to ensure the clarity of the questionnaire. Based on their feedback, necessary refinements were made to improve readability and ensure the adequacy of the questions in addressing the research objectives. Following these revisions, the finalised version of the questionnaire was prepared for distribution.

A purposive sampling strategy was adopted to target respondents who are directly involved in BIM and robotics implementation within the construction industry. The questionnaire was distributed to the Real Estate & Housing Developers' Association (REHDA) Malaysia for registered developers, the Association of Consulting Engineers (ACE) for registered consultant engineers and the CIDB information system for registered contractors in Malaysia.

For data analysis, the collected data were analysed using the Statistical Package for the Social Sciences (SPSS). There are multiple statistical tests involved which are exploratory factor analysis (EFA), descriptive analysis, reliability analysis and correlation analysis. For exploratory factor analysis, principal component analysis with varimax rotation was applied to identify underlying factors contributing to the challenges of BIM-robotics implementation. For descriptive analysis, the challenges were ranked based on their mean scores and standard deviations. Following EFA, Cronbach's alpha was computed to assess the internal consistency of the factors that were found. It was found to be acceptable within the range of 0.70 and 0.95 (Alsolami, 2022). Before the correlation analysis, the normality of the data was tested. Pearson's correlation was used if the data had a normal distribution, otherwise, Spearman's correlation was applied to determine the relationships between the identified challenges.

4. RESULTS AND DISCUSSION

4.1 Demographic Profile

A total of 160 responses were collected, and no missing values were found. The demographic data was effectively visualised using the treemap in Figure 2. According to the findings, the majority of respondents were BIM specialists (55), followed by project managers (39) and contractors (28). There were smaller groups including developers (23) and engineers (15). Most respondents have between 2 and 5 years of experience (70), followed by those with less than 2 years of experience (49). This indicates that BIM and robotics technologies are attracting a younger or newer workforce. The largest organisation types were government agencies (55), followed by BIM companies (56). In terms of BIM usage level, most respondents have low-level usage, where they used it for design purposes. A significant majority were aware of robotics in construction and expressed support for the integration of BIM and robotics in future construction. The high level of awareness gave a view that the industry is becoming more receptive to automation technologies.

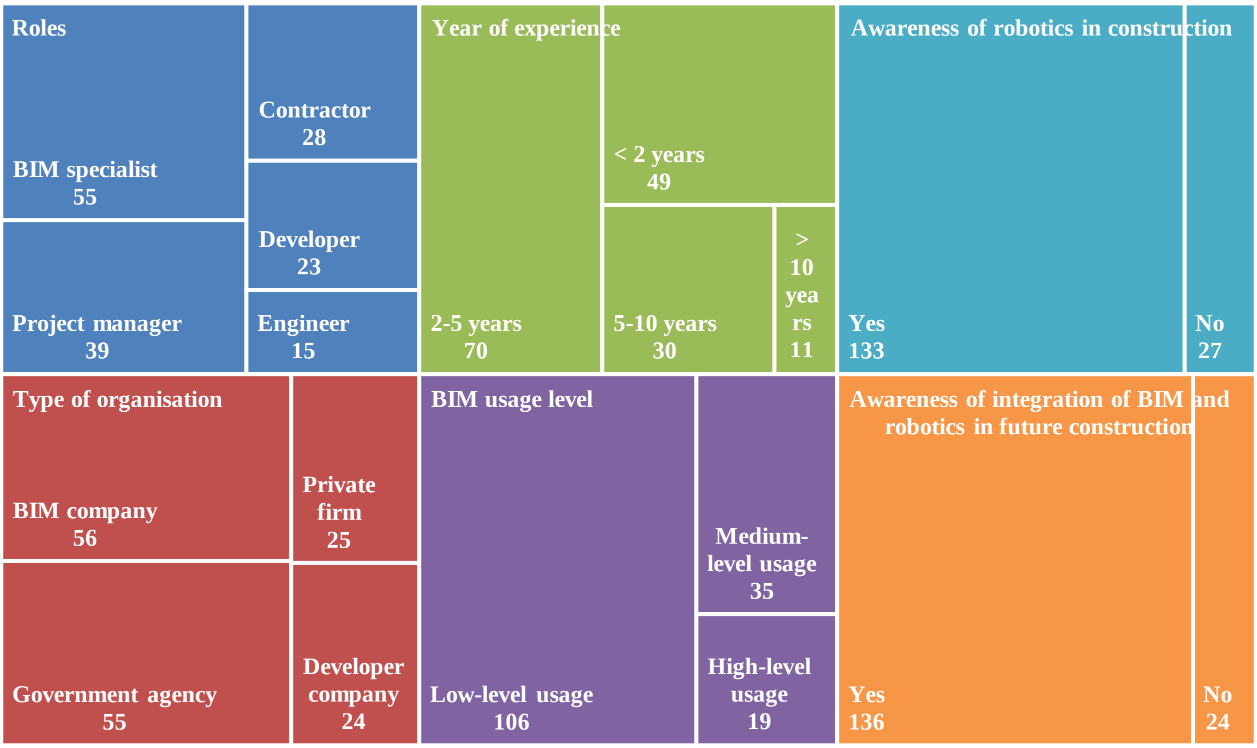

Figure 2. Treemap of the demographic profile of respondents

4.2 Application of BIM-Robotics

Figure 3 displays a radar chart representing the relationship between BIM-robotics applications and respondent roles. It was observed that BIM specialists are most active in the domain of automated site layout and surveying, it is likely due to their heir proficiency in digital tools and modelling. They also dominate in most other areas, except for adaptive path planning and navigation. Project managers had appeared more focus on that use. However, the chart highlights the low scores for bricklaying automation and prefabricated building construction across all respondents' roles. These findings emphasise the need for further exploration into the opportunities for broader adoption of BIM-robotics in these areas.

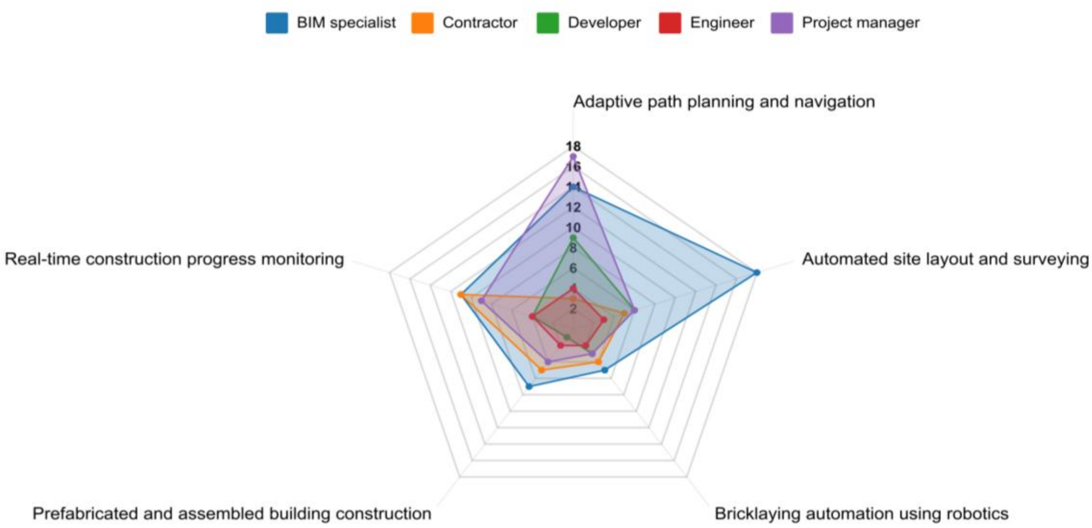

Figure 3. Radar chart showing role-specific applications of BIM-robotics in construction

4.3 Exploratory Factor Analysis (EFA)

Before conducting EFA, the ratio of the sample size to the number of variables was calculated to ensure the adequacy of the sample for this analysis. Gorsuch (2014) recommended a minimum ratio of 5. In this study, the ratio value was 160/22 = 7.27, which surpassed the minimum ratio and indicated that the sample size is sufficient for EFA. The Kaiser-Meyer-Olkin (KMO) test and Bartlett's Test of Sphericity were conducted to determine whether the data was suitable for factor analysis.

The KMO value obtained in this study was 0.866, which was well above the 0.6 threshold recommended by Netemeyer (2003). Bartlett's test reported a Chi-square value of 4446, $p < 0.001$, indicating that there are sufficiently large correlations between the variables to justify continuing with factor analysis. Principal component analysis (PCA) with varimax rotation was conducted because it has been used in previous BIM studies (Davila Delgado et al., 2019; Sinoh et al., 2020; Tan and Gumusburun Ayalp, 2022). The minimum factor loading was 0.5. PCA revealed four factors with eigenvalues greater than 1. Based on Table 3, they have achieved 77.12% of the total variance which exceeds the 60% recommended by Rajabi et al. (2022). A scree plot as shown in Figure 4 also supports the four factors solution, with a clear elbow after the fourth component. Three variables (CH6, CH11 and CH22) have been removed from PCA due to lower factor loading than 0.5.

4.4 Reliability Analysis

The Cronbach's alpha for four factors was greater than 0.7, which surpassed the recommended value by Taber (2018). It indicates that the data are reliable and internal consistency is satisfactory.

Factors	Code	Exploratory factor analysis				Descriptive analysis			Reliability
		Factor loadings	Eigenvalue	Variance	Total variance	Mean	Standard deviation	Ranking	Cronbach's alpha
Technological	CH2	0.793	8.596	22.681	22.681	3.71	1.348	1	0.874
	CH4	0.775				3.67	1.435	2	
	CH3	0.831				3.52	1.213	3	
	CH13	0.745				3.50	1.218	4	
	CH1	0.741				3.45	1.292	5	
	CH14	0.839				3.40	1.314	6	
Organisational	CH10	0.786	2.884	21.669	44.350	4.35	1.427	1	0.781
	CH9	0.807				3.71	0.981	2	
	CH8	0.787				3.41	0.980	3	
	CH7	0.751				3.32	0.819	4	
Environmental	CH15	0.847	1.809	16.913	61.263	3.48	1.046	1	0.816
	CH5	0.785				3.44	0.943	2	
	CH16	0.832				3.39	1.064	3	
	CH12	0.755				3.36	0.987	4	
Financial	CH17	0.853	1.364	15.858	77.121	3.71	1.006	1	0.837
	CH18	0.766				3.65	1.041	2	
	CH19	0.872				3.61	1.082	3	
	CH20	0.735				3.59	1.048	4	
	CH21	0.879				3.59	1.083	5	

Table 3. Results of EFA, descriptive and reliability analyses

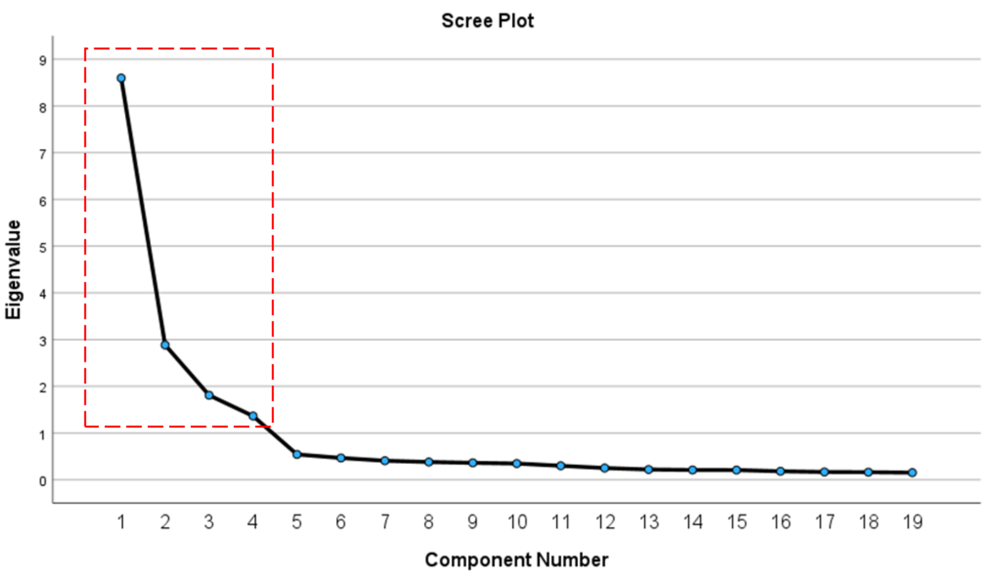

Figure 4. Scree plot for principal component analysis with varimax rotation

4.5 Descriptive Analysis

The most significant challenge among the technological factors was CH2 (*Insufficient task planning systems to generate detailed robotic motions based on BIM and construction schedules*). This finding was aligned with the research by Zaeem (2024), who discovered that the major challenge in adopting robots in construction is the need for task planning systems that can give accurate inputs for manipulating robot motions. To create comprehensive robot task plans, the authors developed a prototype that integrates BIM with the robot operating system.

In the organisational factors, CH10 (*Resistance of the entire construction sector to adopt new technologies*) emerged as a critical challenge. As reported by Van Tam et al. (2024), contractors in the construction sector are often reluctant to embrace digital technologies because of concerns about the complexity and potential disruption that these innovations could bring. To educate them, specific efforts were required.

From the environmental factors, CH15 (*Lack of standardised methods, contractual languages and frameworks for BIM-robotics integration*) was identified as a critical challenge. A lack of standardised frameworks could make it more difficult for teams and technologies to collaborate. Technical complexity would arise in the projects if the roles, responsibilities and project scopes were not well defined. The adoption of BIM in the construction sector may benefit from a well-defined framework (Saad Alotaibi et al., 2024), as well as from the integration of BIM and robotics in construction projects.

Regarding financial factors, CH17 (*High initial investment costs*) was the critical challenge identified in this study. This is consistent with the findings of Davila Delgado et al. (2019), who highlighted that one of the biggest obstacles is still the high upfront costs of training staff, integrating new technologies into current workflows, upgrading infrastructure and buying robotic systems. The high initial costs would be a burden for small and medium-sized enterprises and subcontractors, which make up a significant part of the construction industry (Abioye et al., 2021).

4.6 Correlation Analysis

Spearman's rho correlation analysis was used because the data did not follow a normal distribution. This was confirmed by the Kolmogorov-Smirnov test, where the p-values for all variables were less than 0.001. A correlation heatmap was developed (as shown in Figure 5) to visualise the relationships between the variables. It was obvious to observe that financial factors (C17, C18, C19, C20 and C21) demonstrated very strong relationships with one another. The Spearman's rho value between CH18 and CH10 was the lowest at 0.08, which represents a very weak correlation. This indicates that there is little to no association between these two variables, suggesting that CH18 (*High unit costs of robotic stations*) and CH10 (*Resistance of the entire construction sector to adopt new technologies*) are largely independent in this dataset. Overall, there were positive correlations between all of the challenges, ranging from weak to strong relationships. Since no negative correlations were found, it can be concluded that the difficulties this study identified tend to complement rather than contradict each other.

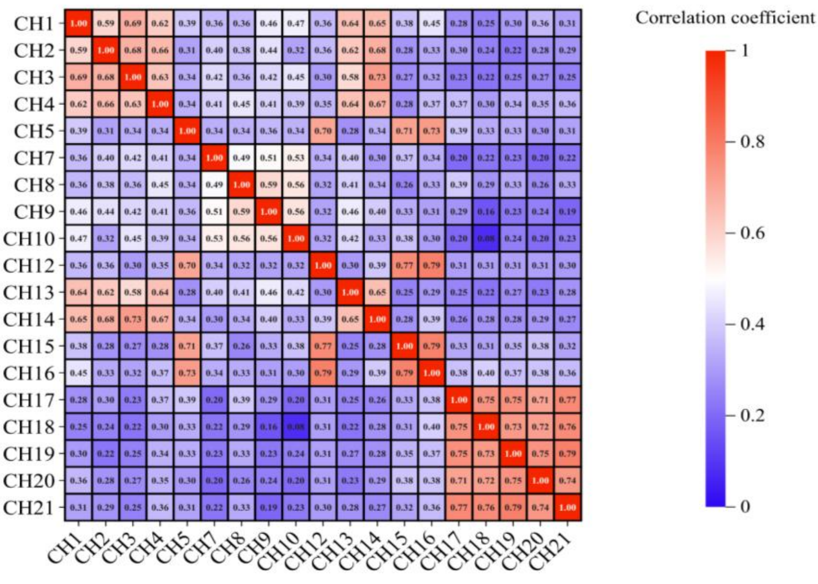

Figure 5. Correlation heatmap

5. CONCLUSIONS

This study successfully achieved its objectives by evaluating the challenges of BIM-robotics integration in the Malaysian construction industry. Through exploratory factor analysis (EFA), four factors with eigenvalues greater than one were identified. These factors were grouped into technological, organisational, environmental and financial. Based on the mean and standard deviation of the descriptive analysis, the critical challenges within each category were determined. From a technological perspective, the lack of task planning systems to generate detailed robotic motions based on BIM and construction schedules emerged as the biggest challenge. Organisationally, resistance to change was the primary challenge, while environmentally, lack of standardised methods, contractual languages and frameworks for BIM-robotics integration posed a major challenge. The biggest financial challenge proved to be the high initial investment costs. Based on correlation analysis, the study found that financial factors have very strong relationships with each other.

When Malaysia begins the implementation, these difficulties should be resolved, but it is conceivable that similar problems could arise when the BIM-robotics system is updated or integrated with new technologies. The interaction of robotic hardware and BIM software will create new data problems and require software and hardware manufacturers to work together to rethink their solutions. To encourage the use, Malaysia needs to take targeted measures like increased government funding, training programs, collaborative research initiatives and incentives for technology adoption. In this way, Malaysia can be supported on its journey towards realising its visions of Construction 4.0 and Industry 5.0. However, it is important to acknowledge that applying BIM robotics is a long-term journey that requires consistent work and commitment.

There are three recommendations for this study. First, future studies could extend the current findings through confirmatory factor analysis using structural equation modelling to validate the results. Second, using a mixed-method with qualitative discussion will help gather deeper insights into the challenges. Third, exploring strategies to overcome these challenges would provide actionable solutions to accelerate the adoption of BIM-robotics in the Malaysian construction industry.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study. The research was funded, but the funding body had no role in the study design, data collection, analysis, interpretation, or decision to publish the findings. The views and conclusions expressed in this study are solely those of the authors and do not necessarily reflect the views of the funding agency.

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