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Advancing BIM Adoption in Malaysia's Construction Industry: Overcoming Barriers and Enhancing Operations and Facility Management

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ABSTRACT

Building Information Modeling (BIM) has become a transformative digital methodology within the global construction industry, yet its comprehensive adoption in Malaysia—particularly within the operational and facility management stages—remains limited. This study evaluates the current state of BIM adoption and systematically identifies critical barriers and success factors influencing its implementation. A structured questionnaire survey was administered to 152 construction professionals, encompassing both BIM users and non-users, to capture diverse perspectives on adoption dynamics. The analysis revealed that technological limitations (Relative Importance Index, RII = 0.79), shortage of skilled manpower and low awareness (RII = 0.78 each), and project cost concerns (RII = 0.76) were the predominant barriers to adoption. Conversely, the most significant enablers of successful implementation were found to be strong top management support (RII = 0.83), effective training initiatives (RII = 0.82), robust project management practices (RII = 0.81), and enhanced system interoperability (RII = 0.80). Statistical testing using the Kruskal–Wallis H method indicated no significant difference between the responses of BIM users and non-users ($p > 0.05$), suggesting a unified perception of both challenges and enabling conditions across the industry. These findings underscore that leadership commitment and workforce development are indispensable for advancing BIM implementation. The study contributes practical insights for policymakers and industry leaders by highlighting the necessity of strategic coordination among stakeholders to accelerate BIM integration, not only during design and construction phases but also throughout the operational and facility management lifecycle.

1. INTRODUCTION

Digital construction refers to the use of digital technology to facilitate the operation and completion of buildings. The digital revolution in the construction industry has the potential to completely change the way the industry operates and bring greater success. The digital revolution has a significant impact on the engineering and design sectors. Various approaches can be adopted to leverage the benefits of digital construction, ranging from commonly used tools such as messaging applications that facilitate effective communication to technologies that support process automation, factory optimization, and material management through software-based delivery and process management systems. Additionally, digital construction can be developed into advanced tools such as drones for site inspection, 3D printing, robotics, artificial intelligence (AI), etc. A key component of digital construction is BIM, which operates at multiple levels, i.e., 3D, 4D, and 5D. 5D BIM integrates 3D spatial design with project scheduling and cost estimation, thereby enabling more comprehensive and efficient project management. This approach facilitates improved accuracy and efficiency in construction planning and execution [1]. Technology is now permeating every aspect of construction, from digital blueprints to smartphones during construction, although the adoption rate in Malaysia has been slow, especially when it comes to BIM, with only 13% of respondents from both the public and private sectors using BIM in their companies. This low adoption rate reflects the broader challenge faced by Malaysia in embracing BIM technologies at a national level.

Lack of knowledge regarding shortages, costs, slow adaptation [2], lack of BIM guidance and failure to implement BIM in a timely manner are all important reasons for the slow progress. This information can be used to assess the extent to which stakeholders in the Malaysian construction industry have adopted and are ready to embrace digital tools. The construction industry plays a crucial role in Malaysia's economy, contributing significantly to national growth, public health, and overall quality of life. It impacts virtually all sectors and levels of the economy, making its competitiveness both locally and internationally vital. The industry is closely linked with other sectors and is essential for the country's long-term development, as capital flows through construction directly influence social and economic progress [3]. However, the COVID-19 pandemic disrupted the industry, causing construction activities to halt and industrial production to decline. This impact extended to project budgets, contract agreements, and worker health and safety [4]. Despite these challenges, the pandemic accelerated the adoption of digital technologies in construction, including cloud computing, mobile computing, and BIM [5]. These digital tools have become increasingly important in modernizing the industry, although efforts to bridge the digital divide remain ongoing [6].

In 2020, inspections of over 6,700 construction sites revealed a 19.4% reduction in the final construction budget from RM146.4 billion in 2019 to RM117.9 billion in 2020. The value of work in all sub-sectors of the construction industry decreased, with civil engineering recording the largest drop of 24.0%, followed by residential projects (-17.2%), non-residential projects (-17.1%), private commercial activities (-17.1%) and building trade (-2.1%). This reflects a general decrease in the final construction budget compared to the previous year, with all sub-sectors experiencing declines—particularly in civil engineering and residential projects. Recognizing the potential of BIM to reduce construction costs and design issues early in planning, the Malaysian government has moved to mandate BIM use for both public and private developers [7]. This initiative aligns with broader efforts to address housing shortages, improve infrastructure, and support Malaysia's modernization goals. The government's commitment is reflected in its five-year economic growth plan, which prioritizes public infrastructure as a key funding recipient [2]. Recent data show the construction sector's steady recovery and growth, driven by both private and public investments, underscoring its resilience and central role in Malaysia's economic development. Despite the ongoing efforts made by the Malaysian Infrastructure Development Authority to promote BIM annually, traditional construction methods remain dominant in the industry [8]. This reliance on conventional practices has led to frequent delays, increased costs, poor quality, subpar performance, and low productivity, all of which negatively affect the country's development and international competitiveness [9]. While BIM has seen success during the planning phase of projects, its application during the construction phase has been limited. In most cases, BIM is primarily used for design simulation rather than being fully integrated into construction processes. The varied approaches to BIM implementation have contributed to its slow adoption and limited impact within the industry.

In 2008, the Malaysian government established a committee specifically to promote BIM adoption in construction. However, several challenges continue to hinder effective implementation, including technical, managerial, financial, and legal risks. Failure to properly identify and manage these risks can lead to inconsistent outcomes and increased project uncertainties. Currently, BIM use in Malaysia is mostly confined to complex, high-risk projects, although the government is pushing for wider adoption by mandating BIM requirements for more contractors [10]. The Malaysian construction industry faces mounting social pressure to enhance quality, productivity, and value, driven by its inherent complexity. Issues such as additional production costs, substandard outputs, delays, labor-intensive workflows, and outdated technologies persist [11]. Like many countries, Malaysia's construction sector is multifaceted, involving numerous economic activities, specialized professionals, diverse materials, equipment, organizational structures, and a wide range of products [3]. This complexity, along with the involvement of multiple stakeholders, contributes to communication challenges and inefficiencies.

Information management remains a critical concern, as much of the data exchanged between parties is poorly organized, often relying on paper documents and drawings. This disorganization leads to errors that negatively impact productivity and project outcomes. In recent years, BIM has gained traction as a tool for managing construction information more effectively. By combining geometric and non-geometric data within an object-oriented 3D system, BIM enables comprehensive digital simulations of buildings and provides valuable information to all stakeholders, including architects, engineers, contractors, and subcontractors. BIM fosters improved collaboration by consolidating information into a single source, enhancing documentation related to cost, time, quality, and safety throughout the construction process. Moreover, BIM technology holds the potential to stimulate economic growth within the construction industry. Despite government initiatives to encourage its use, interest in BIM remains limited in Malaysia, indicating a need for further research and efforts to support its broader implementation [11, 12].

Even though there have been efforts to encourage using BIM in Malaysia's construction sector, recent studies show that there are some important gaps in our understanding. For example, not enough research has looked into the real-world challenges of using BIM during the operations and facility management stages. Besides, there's no clear agreement on what factors really help ensure BIM is successfully adopted. This study aims to address these issues by examining key obstacles like costs, workforce skills, technology, and awareness. It also explores what influences successful BIM implementation, such as support from upper management, proper training, and system compatibility. This study addresses the slow adoption of BIM technology within the Malaysian construction industry by investigating the barriers and challenges that hinder its application. Additionally, it seeks to understand the factors driving the adoption of BIM in this sector. The research objectives are twofold: first, to analyze the challenges associated with using BIM in operations and facility management; and second, to explore the reasons behind successful BIM implementation in these areas. To achieve these goals, a quantitative approach was employed, utilizing a questionnaire survey to gather data for statistical analysis concerning BIM application and related issues within the Malaysian construction industry.

2. LITERATURE REVIEW

2.1 Definition of BIM

The fast-growing sector of Architecture, Engineering, and Construction (AEC) is altering BIM [13]. BIM has been defined in various ways throughout its development, and a universally accepted definition has yet to be established [1]. In the early 2000s, BIM was used pre- and post-construction to simulate building components. In the late 2000s, BIM revolutionized the way AEC processes and tasks were conducted, increasing communication, collaboration, and efficiency by reducing the amount of paperwork required. To date, BIM has permeated the entire industry, making it easier to plan, design, produce, and operate facilities more efficiently

[14]. Delivering products via rational 3D virtual models in design is one of the BIM methods [13]. In other words, BIM is digital information that combines all of the information regarding building during every phase of a project's lifespan [15, 16]. BIM is defined as a new approach to managing and improving AEC performance in project completion and management. The current definition of BIM emphasizes its role as an industry paradigm shift which affects every aspect of projects throughout the design and construction cycle [15]. The concept of BIM appeared in the early 1980s, and researchers described its concept and applied it to actual CAD software applications [13]. Until the mid-1990s, BIM was not widely adopted due to technical limitations. Over time, BIM technology evolved from basic 3D modeling to include additional dimensions based on product lifecycle management (PLM), expanding into 4D, 5D, and even 6D capabilities. Today, this enhanced 3D BIM is readily available. On construction sites, however, BIM use remains mostly limited to managers who provide guidance and manage information, as construction activities heavily depend on effective communication [17]. BIM is rarely used on construction sites. Visualization technology can help workers better understand the planned building. Access to BIM models can give workers continuous insight into current planning work [18].

Construction managers play a vital role in the planning and production aspects of the construction industry [17]. A common problem in the construction industry is inadequate or incorrect construction documentation, which construction managers must correct or interpret during the production process, wasting time and money. BIM helps construction companies manage data and maintain graphical elements [19]. BIM affects quantity aspects like cost, schedule, and material inventory, which speed up decision-making, and quality aspects like structure and environment data analysis. From 2014, all United Kingdom (UK) government contracts must include fully collaborative 3D BIM in construction projects, reducing transaction costs and errors. Project management benefits from BIM because it reduces documentation time and improves stakeholder communication [20]. Business interest in BIM is growing due to its ability to promote information exchange and reuse across a project lifecycle [13]. BIM can improve construction efficiency by increasing participant participation, reducing disputes, and eliminating the need for constant correction and adaptation. It is not only beneficial for large projects such as the London 2012 Olympic Stadium but also can be used for smaller projects [20].

BIM is a technology that uses computers and software to simulate building structures virtually, integrating all the information required for construction. The physical characteristics of building components are transformed into a 3D model, which then evolves into a 4D model by incorporating the element of time. When cost information is added, this model becomes 5D, and further dimensions can include aspects such as sustainability, energy performance, and facility management. BIM can be understood as both a process and a technology that involves creating, managing, and sharing detailed data about an asset's physical and functional attributes. This is done within a collaborative digital environment, using simulation models that support the entire lifecycle of a project [21]. This subsection provides an extensive literature review on the definition of BIM and its evolution from the past to the present day, as well as its benefits and importance in the construction sector. The following subsection presents the challenges facing BIM implementation in the construction sector.

2.2 Challenges in BIM implementation

An extensive literature review was conducted to determine the four challenge categories as follows:

• Cost: Several studies show that the initial cost of BIM adoption in Malaysia is very high [22-24]. The comprehensive BIM adoption is thereby based much on the incorporation of all BIM software. The cooperation of all the authoring software demands a high cost to buy for the BIM stakeholders. In addition, Ismail et al. [25] stated that the great investment should be conducted financially by the company to adopt BIM technology. Only large organizations in Malaysia can afford the cost of BIM technology and training programs. Roseli and Mohd [26] indicated that the cost regarding BIM adoption in the construction industry needs a great initial investment in terms of software, hardware, and personnel training. Alterations in workflow and processes are costly when innovative technologies are applied.

• Workforce: BIM adoption faces several obstacles related to the workforce in the construction industry. BIM projects comprise several offices and locations, with staff working in silos and following different goals. Another challenge to BIM execution is that employees and staff resist changing their attitudes. Sometimes staff resist and have a diverse attitude toward sharing data. In addition, BIM adoption in Malaysia is very slow since learning new skills is considered a long procedure for employees and staff [27]. Elhendawi [28] found that the Malaysian construction workforce doesn't have adequate BIM experience, although personnel generally possess enough academic qualifications. Furthermore, the lack of guidance and supervision from BIM experts has hindered effective implementation.

• Technology: Numerous studies show that the lack of interoperable software or inadequate information technology (IT) infrastructure are the main causes behind slow BIM adoption in Malaysia [24, 29]. Ahlam and Abdul Rahim [30] found that the technological barriers to BIM adoption are primarily associated with issues of interoperability, compatibility, and technological complexity, including licensing policies, risks related to data sharing, version control problems, data loss during file exchange, lack of software compatibility, and inadequate information and communication technology (ICT) infrastructure. In addition, the situation of small construction companies was not favorable for adopting new technology, which acted as one of the management barriers to implementing BIM [31].

• Awareness: Al-Ashmori et al. [32] stated that BIM implementation in the Malaysian construction industry is low due to lack of awareness of its benefits. Since 2007, the government has implemented BIM, but industry stakeholders are unaware of its benefits. In Malaysia, there is still a shortage of knowledge about the advantages of using BIM. There is a shortage of workshops, lectures, and conferences aimed at increasing public awareness of BIM. When a firm applies BIM to its daily processes, the level of BIM knowledge and staff awareness tends to enhance; however, teaching or facilitating seminars becomes passive if BIM is not applied [33]. From a technological awareness perspective, there is also a lack of understanding regarding BIM techniques, innovative technologies, and their applications [34]. Waqar [31] found that there is limited awareness of the benefits of BIM adoption in Malaysia, particularly among project staff, which exacerbates challenges in BIM execution. Most of these challenges involve the knowledge, technology, and processes of BIM adoption [35]. Some BIM adoption barriers are easier to overcome than others. Several obstacles have slowed BIM adoption in construction as follows:

• Uncertain BIM benefits with regard to growing techniques.

• The duties and accountability for incorporating data into a model and maintaining it are unclear.

• A lack of understanding of the adoption of BIM.

• A lack of hardware and software resources for using BIM technologies.

• The project's stakeholders are not integrated enough to use the model at various project stages.

• A lack of tools and a proper legal framework for incorporating owners' opinions into design and construction [19].

• The adoption of BIM in the construction industry involves several risks, including technical and software challenges, unsustainable user development, security vulnerabilities, selecting unsuitable development partners, communication issues, and accidental data leaks [30].

A real-world case study examining 32 non-residential buildings in the UK highlighted the limitations encountered when migrating to BIM-based facility management. These risks emphasize the importance of careful planning and risk management to ensure successful BIM implementation and to mitigate potential setbacks during the transition process [36]. The case study findings illustrate how BIM can improve staff and operational efficiency as well as the accuracy of geometric data capture using real-life examples. Interviews with real estate experts in the case study revealed the challenge, i.e., there are significant differences between BIM technology, facility management technology, and the building lifecycle. Therefore, facility management organizations must prepare for different information and data standards in the medium and long term, rather than adapting their business processes to specific technologies.

Kassem et al. [37] selected the construction industry in the United Arab Emirates (UAE) as a case study to examine the barriers hindering the adoption of BIM. The choice of the UAE reflects the diversity of its local AEC sector, which attracts contractors, consultants, and suppliers from around the world. The study revealed a general lack of motivation within the industry to engage with BIM, which significantly slows its adoption. Key challenges identified include resistance to change, insufficient support from senior management, significant differences in workflows, absence of BIM requirements from owners and clients, limited BIM experience, uneven adoption among stakeholders, shortage of skilled BIM personnel, high costs associated with BIM, low interoperability between systems, issues with project procurement, difficulties in BIM model management, and unresolved legal and contractual concerns. These factors collectively contribute to the slow and uneven implementation of BIM across the UAE construction sector.

Re Cecconi et al. [38] investigated the challenges faced by large construction companies in Brazil regarding the full implementation of BIM. The research focused on understanding the difficulties in adopting BIM and enhancing infrastructure projects using 3D and 4D modeling. As a case study, the analysis included company documents and project records, supported by data collected through two questionnaires. The first questionnaire gathered information on BIM applications, while the second explored the understanding of BIM implementation in projects and identified key limitations in using selected 3D and 4D modeling projects. Several major limitations emerged from the case study, including:

• Limited awareness and experience with BIM feasibility among design subcontractors.

• Insufficient information within 3D models, which restricts advancements in other dimensions like 4D and 5D.

• A lack of understanding about how BIM applies to design and its connection to construction processes.

• Tight project timelines driven by Engineering, Procurement, and Construction (EPC) contract requirements, which constrain design development and verification.

• Client reluctance to invest in BIM development due to concerns about increased time and costs.

• Difficulties in optimizing projects when working with international contractors.

• Challenges in sharing common models and databases due to intellectual property concerns.

The AEC industry faces significant challenges in adopting BIM, largely due to its fragmented, project-based nature and varying levels of market readiness across countries [39]. These factors have slowed the pace of BIM implementation. Additional obstacles include the high costs associated with projects, the extensive training required, and resistance from many designers who prefer traditional methods, all of which negatively affect overall productivity [40]. Surveys of AEC academics and practitioners highlight that the high cost of human resources and the lengthy time needed for training are among the main barriers hindering wider BIM use [41]. For large projects, new BIM management roles have been introduced, but managing change during BIM implementation remains difficult [39]. Employees require better training and engagement to adapt to new workflows [20]. Furthermore, after BIM adoption, the specific roles and daily responsibilities of project managers remain unclear. There is also ongoing debate about whether BIM can effectively address the longstanding fragmentation within the construction industry that hinders seamless information sharing throughout a project’s lifecycle [22].

Legal issues related to BIM can be grouped into four main categories: (1) incompatibility between existing procurement systems and BIM processes, (2) increased liability risks such as design errors, data transcription mistakes, data loss, and misuse, (3) questions around model ownership and intellectual property rights, and (4) unclear roles, responsibilities, and obligations among project participants. Since BIM affects the traditional collaboration among project stakeholders, the legal issues mentioned can also have legal consequences for these traditional procurement methods, depending on the existing roles of project stakeholders in the contract structure. When BIM is applied to relational project delivery systems such as project partnerships, project alliances, and Integrated Project Delivery (IPD), procurement system incompatibility is no longer an issue. Accountability issues and unclear roles and responsibilities should not be viewed as obstacles to project operations, as these procurement systems, to varying degrees, incorporate collaborative elements (e.g., early involvement of key parties, transparent finances, shared risks and opportunities, joint decision-making, and collaborative multi-party agreements) into contractual arrangements. However, since formal contracts represent a protection mechanism that ensures transactional security among project participants, those involved in project delivery systems should carefully consider the potential legal implications of BIM use. It is recommended that the cooperation terms for coordinating BIM-related services between the parties be clearly defined within the formal contract to prevent unnecessary disputes [42].

Wong and Gray [43] found that there are many legal barriers to BIM implementation in the Malaysian construction industry, with copyright issues being the biggest legal barrier. In addition, uncertainty in ownership structure poses another barrier. BIM projects lack formal contracts and documentation. The construction industry is reluctant to invest in BIM due to its fragmented nature. Lack of formal documentation also makes it difficult to determine the ownership of BIM data. This subsection reviews all challenges and obstacles that hinder BIM implementation in construction projects and addresses the role of BIM in the construction sector. The following subsection provides an extensive literature review of factors affecting successful BIM implementation in the construction sector.

2.3 Factors affecting successful BIM implementation

The following factors influence the successful implementation of BIM in any organization:

• Top management: Top management plays a crucial role in driving BIM adoption within an organization [44].

• Training and learning: Intensive training and learning can improve workforce competency. Additionally, most novice engineers have theoretical knowledge of BIM application. Therefore, they should be welcomed and make a difference in the organization. Experienced staff can proactively learn new topics and technical skills [45].

• Interoperability and compatibility: Sunil et al. [46] found that competitive pressure strongly influences organizations' BIM adoption. Only a few Malaysian companies use BIM, while most use the traditional method.

• Project management: Project types are also important for BIM implementation in Malaysia's construction industry. Van Tam et al. [45] identified project size, complexity, and requirements as critical considerations affecting the application of BIM in different project types.

2.4 Role of BIM in the construction industry

2.4.1 BIM for facility management

BIM can streamline operations for facility managers. It can provide information to facility managers in the form of electronic copies such as PDF documents, CAD drawings, and as-built BIM models in a BIM-based project environment. With the introduction of BIM in construction projects, there is a growing need for non-geometric information in the form of the Construction Operations Building Information Exchange (COBie) standard [47]. In addition, they have demonstrated the effectiveness of integrating BIM with the Internet of Things (IoT) for smart building management [25, 48, 49], thereby improving the efficiency of long-term asset maintenance. Re [26] identified the requirements of asset managers and asset management practices: (1) space occupancy management; (2) mechanical equipment condition management; (3) qualitative assessment of building conditions; and (4) life assessment of building components and systems according to ISO15686-8.

2.4.2 BIM and sustainable development

BIM as a digital platform has been developed to enhance real-time collaboration and simulate construction processes, making it a valuable tool for boosting efficiency in construction projects [31]. A study focusing on Perak, Malaysia, highlighted BIM's role in promoting sustainable development within building projects. The research aimed to evaluate how BIM influences resource efficiency, energy conservation, waste reduction, and decision-making processes geared toward sustainable construction. The findings revealed a strong positive relationship between BIM adoption and early design optimization, energy performance analysis, material selection, lifecycle assessment, and waste minimization. This evidence supports the integration of BIM in construction practices, demonstrating its potential to improve environmental sustainability and contribute to achieving greener building outcomes. Furthermore, multiple studies have confirmed BIM's critical role in advancing sustainable development by reducing waste, lowering energy consumption, and encouraging adherence to green building standards [50-52]. This complies with Malaysia's goals for sustainable urban development [53, 54].

2.4.3 BIM and Industry 4.0

Information integration for smart industry is an important step towards gaining a deeper understanding of the construction and renovation of existing buildings. While smart sustainability technologies such as BIM and IoT continue to evolve, challenges exist for a single technology and the integration of both technologies is needed to address these evolving challenges. The database created through BIM-IoT integration takes full advantage of application programming interfaces (APIs) and relational data by developing new queries, languages, semantic web technologies, and hybrid technologies [2]. The integration of IoT with BIM can significantly enhance six essential functions within facility management: energy management, operation and maintenance, space management, project management, emergency response, and quality control. By combining these technologies, IoT-BIM offers a practical and effective platform to drive the digital transformation of facility management. This integration helps optimize building performance, improving both the efficiency and effectiveness of facility operations [55]. Furthermore, building a data-driven digital twin framework that brings together BIM, IoT, and data mining for advanced project management can facilitate data communication and exploration, enabling physical construction operations to be better understood, predicted, and optimized [56].

3. METHODOLOGY

3.1 Framework of the conceptual study

This study focuses on exploring the challenges that hinder the adoption of BIM in the Malaysian construction industry, as well as examining the key factors influencing its uptake. To develop a conceptual framework aligned with these research objectives, an extensive review of existing literature was conducted. This review identified four main independent variables impacting BIM adoption: cost, workforce, awareness, and technology. Additionally, the framework incorporates several other important factors that affect BIM implementation, including top management support, training and learning opportunities, interoperability and compatibility of systems, and project management practices. As shown in Figure 1, the conceptual framework brings together these elements to provide a clear structure for understanding how they relate to BIM adoption within the Malaysian construction sector.

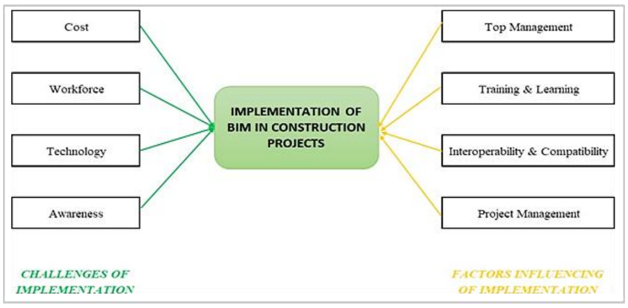

Figure 1. Conceptual framework of this study

The research flowchart in Figure 2 shows the implementation procedures of the research methodology. The flowchart starts with conducting an extensive literature review that covers several aspects regarding challenges of BIM adoption in the construction industry and facility management and the factors affecting BIM adoption in the Malaysian construction industry. Based on the literature review, a survey questionnaire was developed. Then a group of experts evaluated the content validity and provided their opinions and suggestions regarding the questionnaire items to refine the questionnaire and finalize its structure. The questionnaire comprised several sections: demographic information of respondents, challenges of BIM adoption in the Malaysian construction industry according to several categories (awareness - workforce - technology - cost), factors affecting BIM adoption in the construction industry and facility management (top management - training and learning - interoperability and compatibility - project management). A 5-point Likert scale was selected to measure the questionnaire items related to the challenges of BIM adoption and the factors affecting BIM adoption in the Malaysian construction industry, with 5 points representing strong agreement and 1 point representing strong disagreement. Then the questionnaire was distributed to the participants. As for the selected sample size, according to the study by Latif et al. [57], approximately 1.4 million personnel work in the Malaysian construction sector. According to the study by Hair et al. [58], a simple regression analysis requires a minimum sample size of 50, although most research institutions recommend at least 100 samples [58].

Consequently, in this research, the questionnaire targets structural engineers - project managers - facilities engineers - site engineers in order to get a comprehensive view from all stakeholders in the construction industry and accurately investigate all challenges from several perspectives. The questionnaire was distributed electronically via social media channels randomly to achieve at least over 150 respondents. After completing the data collection process and obtaining sufficient responses, the data were extracted and analyzed using the SPSS software. A reliability test was conducted using Cronbach's alpha (Table 1), based on the criteria established by McClave et al. [59]. Finally, the findings of the analysis were discussed and concluded.

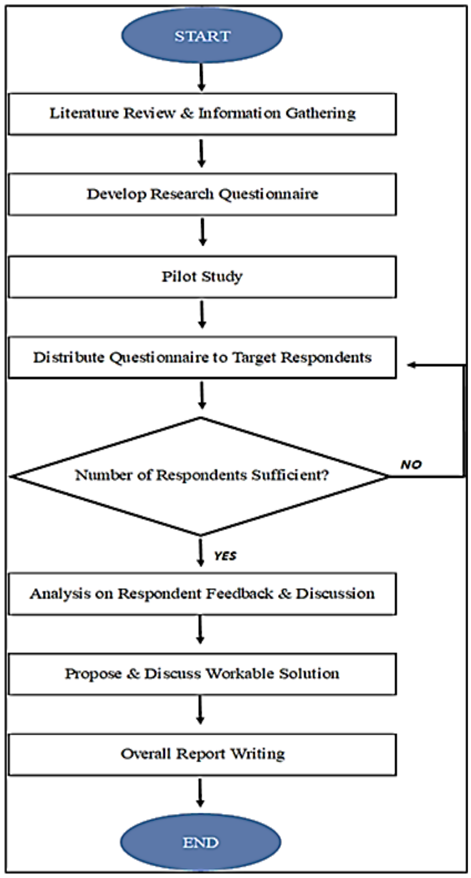

Figure 2. Research flowchart

Table 1. Cronbach's alpha criteria

Criteria	Description
Above 0.9	Excellent
0.8-0.9	Good
0.7-0.8	Acceptable
0.6-0.7	Questionable
0.5-0.6	Poor
Less than 0.5	Unacceptable

This study followed ethical research practices at every step. Before participating in this research, everyone was told what the study was about and what their rights were, and they gave their consent online. The participation was completely voluntary. Participants' privacy was protected, and the data were kept anonymous. No personal information was collected, and all responses were combined together in the analysis to keep participants' identities safe. These steps helped stay true to ethical standards and kept the data collection trustworthy.

3.2 Descriptive statistical analysis

Descriptive statistical analysis was conducted to determine the mean, minimum, maximum, and standard deviation (SD) of both dependent and independent variables, thereby summarizing the results and enabling their generalization to the broader population.

3.2.1 RII

RII helps identify the relative importance of variables or parameters that influence the dependent variable [60]. This tool can contribute to identifying critical factors affecting BIM adoption in the Malaysian construction industry and facility management. Several studies in the field of construction management have used RII to prioritize and rank various factors affecting construction management [61-63] by analyzing the importance level of variables. The value of each item perceived by the participants is represented by RII [64]. This is one of the most commonly used techniques and has a very accurate value in evaluating projects through questionnaires [65]. The RII of element k is calculated as follows:

$$RII = \frac{\sum Si}{S \times N} \tag{1}$$

where, *Si* is the degree given by the participant at point *k* (1 to 5), *S* is the highest degree (5), and *N* is the total number of participants. Increasing RII values can lead to a higher impact on the dependent variable. The RII values were assessed utilizing the criteria assessment illustrated in Table 2 [66].

Table 2. Criteria assessment of RII scores

Likert Score Interval (Mean)	RII Score	Evaluation Criteria
1.00 – 1.79	0.200 – 0.358	Very low level
1.80 – 2.59	0.359 – 0.518	Low level
2.60 – 3.39	0.519 – 0.678	Medium level
3.40 – 4.19	0.679 – 0.838	High level
4.20 – 5.00	0.839 – 1.000	Very high level

RII is a helpful way to rank and prioritize different challenges like cost, workforce, technology, and awareness, and success factors such as support from top management and training when adopting BIM. It's a reliable tool for turning survey answers on a scale into clear, numerical rankings, thus identifying the most significant factors and summarizing them into key priorities.

3.2.2 Kruskal-Wallis H test

One-way analysis of variance (ANOVA) is another name for the Kruskal-Wallis H test. It is a nonparametric rank test. Typically, the Kruskal-Wallis H test is used to determine statistically significant differences between two or more groups of independent variables. This method is used to determine whether challenges and influencing factors differ significantly between different groups of respondents. The Kruskal-Wallis test is applicable in the following situations: (i) three or more variables are compared; (ii) each variable was administered by another group of respondents; (iii) the data do not meet the requirements for parametric tests. The three different groups of respondents in this study were given scores on the rating scale. All scores were evaluated. Respondents with the lowest scores were ranked lowest. Respondents with similar scores were ranked "same." The ranking should be the average of the expected rankings. The H value is calculated using the following formula:

$$H=\frac{12}{[M+(M+1)]} \times \sum_{nc}^{Tc^2} -3(M+1) \tag{2}$$

where, *M* is the total number of respondents (sum of all groups), *Tc* is the sum of rankings for each group, and *nc* is the number of participants in each group. Where applicable, the total number of completed responses should be clearly stated. For instance, instead of writing "two responses were incomplete," it should be explicitly stated that 152 valid responses were obtained. In this study, the Kruskal-Wallis test was used to assess statistical differences across respondent groups like BIM users compared to those who don't use BIM when it came to challenges and success factors in adopting BIM. This test was selected for two reasons. The responses gathered through the Likert-scale questions are ordinal, meaning the numbers indicate order but not exact differences. Because they might not follow a normal distribution, the Kruskal-Wallis test is a good fit since it doesn't require data to be normally spread out or have equal variances. In addition, this test works well when comparing several independent groups. It helps us see if the middle responses of these groups are considerably different, facilitating understanding of different perspectives across various demographics.

4. RESULTS AND DISCUSSION

4.1 Response rate

The questionnaires for this study were distributed to 180 participants working in the construction industry in Malaysia. Of the 180 participants surveyed, only 154 provided feedback. The response rate for this study was 98.70%. The data are shown in Table 3.

Table 3. Response rate of the research

	Frequency	Percentage	Cumulative Frequency
Valid	152	98.70%	152
Incomplete	2	1.30%	154
Total	154	100%	

4.2 Demographic analysis

Section A of the survey focused on gathering demographic information from the participants, covering six different categories. A total of 152 individuals took part in the study. Among them, 78% were male engineers, while females made up 22% of the respondents. In terms of age distribution, most participants (64%) were under 30 years old, followed by 24% aged between 31 and 40, and 11% who were 41 or older. Regarding educational background, the majority of respondents (72%) held postgraduate degrees. Those with bachelor's degrees accounted for 20%, diplomas for 3%, and 5% had other forms of education. In terms of professional experience, 61% had less than five years in the field, 22% had between six and ten years, 10% had 11 to 15 years, and 7% had over 16 years of experience. The survey also explored participants' familiarity with BIM, revealing that 69% had not used BIM before. Overall, the demographic data indicate a diverse group of participants, ranging from junior to senior engineers, with various educational qualifications and levels of experience. These details are summarized in Figure 3 and Table 4.

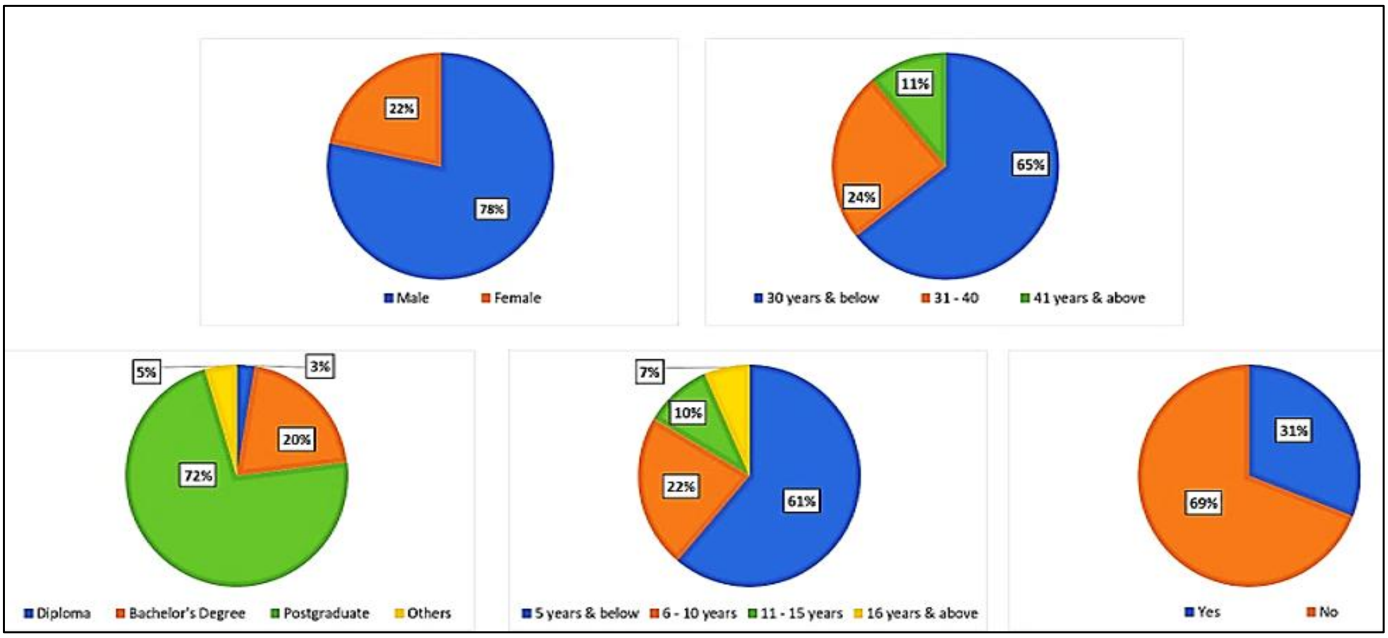

Figure 3. Demographic analysis of respondents

Table 4. Demographic distribution of respondents

	Frequency	%	Cumulative Frequency
Gender			
Meal	199	78%	199
Female	33	22%	152
Total	152		
Age			
30 years and below	98	64%	98
31-40	37	24%	153
41 and above	17	11%	152
Total	152		
Education			
Diploma	4	3%	4
Bachelor's degree	31	20%	35
Postgraduate	110	72%	110
Other	7	5%	117
Total	152		
Years of experience			
5 years and below	93	61%	93
6-10 years	34	22%	127
11-15 years	15	10%	142
16 years and above	10	7%	152
Total	152		
BIM experience			
Yes	47	31%	47
No	105	69%	152
Total	152		

Demographic information such as gender, age, experience and education directly influences respondents' attitudes and opinions of BIM adoption in construction projects. Sometimes, women may be less exposed to advanced technology in some sectors due to under-representation in technical roles, which may affect their attitudes towards BIM. As for age, younger generations are more open to adopting new technologies such as BIM, as they are more exposed to digital technology in education and training. Older groups may face greater challenges in adapting to technological changes, but greater practical experience may contribute to appreciating the benefits of using BIM. Individuals with long experience in the construction sector may be more reluctant to adopt BIM if they have not previously dealt with similar technologies, due to familiarity with traditional working methods. Education level plays an important role in shaping opinions about BIM. Individuals with academic backgrounds in engineering or management are often more familiar with advanced technologies, which facilitates their adoption of BIM [67]. On the other hand, individuals with less formal education or in non-technical disciplines may find it difficult to adopt BIM tools due to lack of technical knowledge. In contrast, individuals with experience in technology-based projects tend to be more welcoming of BIM, as they recognize the benefits of improved efficiency and reduced errors.

4.3 Questionnaire validation

A pilot study was conducted to test the reliability of the questionnaire. The questionnaire was administered to 30 participants, and its reliability was assessed using the Cronbach's alpha test. Sections B and C each have 16 questions. Table 5 shows alpha values of those two sections, and Figure 4 displays data. Section B's alpha is 0.861, which is good; the alpha value of Section C is 0.741, which is acceptable according to the criteria presented in Table 1, as indicated by McClave et al. [59].

Table 5. Reliability test

	No. of Questions	Alpha Value	Judgment
Section B	16	0.861	Good
Section C	15	0.741	Acceptable

4.4 Challenges in implementing BIM

This study examines the challenges of integrating BIM into Malaysia's construction industry. Four criteria were found through a literature review. A Likert scale from 1 to 5 was used to identify the sectors' most common issues. Figure 4 shows the ranking based on RII.

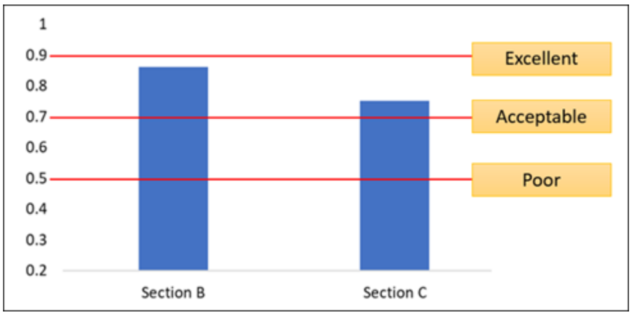

Figure 4. Reliability validation of the research questionnaire

4.4.1 Cost

Table 6 shows the mean and SD for each cost-related question. The mean is 3.82 (out of 5.00) and the SD is 0.94. With a mean of 3.76 (out of 5.00) and an SD of 0.85, the results indicate that the respondents moderately agree that the implementation cost is high (C1). It was found that companies avoid BIM projects due to cost issues (C2). The mean is 3.68 (out of 5.00) and the SD is 1.01. Other costs of BIM were investigated (C3). With a mean of 4.05 (out of 5.00) and an SD of 0.89, the results indicate that respondents agree that other costs of BIM implementation are high. Many project clients reject high-budget projects due to implementation costs. This affects the project budget. However, BIM implementation does not necessarily guarantee a Return on Investment (ROI). The mean is 3.78 (out of 5.00) and the SD is 1.01, indicating a moderate level of agreement.

Table 6. Mean score distribution of cost

	Cost	Mean	SD
C1	High implementation cost	3.76	0.85
C2	Refusal of the company to invest in the project	3.68	1.01
C3	Other costs associated with BIM adoption, such as training and IT, are high.	4.05	0.89
C4	Project budget and project size do not guarantee a good ROI for BIM implementation.	3.78	1.01
	Overall	3.82	0.94

These results are compatible with the results of many studies, i.e., the high costs of BIM are caused by many reasons. Apart from being expensive and having high licensing fees, the BIM-related software requires computers with strong processing units and enormous specifications that further increase the overall cost [68, 69]. In addition, companies also incur great costs to provide training for employees to effectively use BIM software and acquire the necessary expertise [65, 70]. The cost barriers in Malaysia underscore a critical gap between BIM's potential and its perceived affordability. Policymakers could prioritize fiscal incentives and ROI frameworks to align industry expectations with BIM's proven efficiency gains.

4.4.2 Workforce

This part examines workforce competency and BIM adoption as the next challenge. The workforce usually writes the success story for a new system or technology. Worker acceptance is crucial. Respondents moderately agreed that construction workers have BIM capabilities (W1). As shown in Section A, most respondents do not have BIM capabilities, which confirms this problem. The average score was 3.87 with an SD of 0.95. This result is consistent with a question showing that personnel aren't skilled enough in BIM technique. Workers were moderately willing to learn and adapt, according to respondents. An SD of 0.92 and a mean score of 3.85 (out of 5.00) align with the findings of Moshood [70], i.e., workshops are conducted regularly to keep staff adapted to changes in the Malaysian construction industry.

The training needs were also examined. Respondents agreed that BIM's technical complexity makes workforce training time-consuming, which aligns with the findings of Waqar [31]. To make BIM user-friendly, they must train current and new staff. They must also establish a support group for BIM application issues. W3 averages 4.11 out of 5.00 with an SD of 0.98. W4 examines project stakeholder integration. Respondents moderately agreed that project stakeholders must integrate to use the BIM model at different phases. The score averaged 3.96 out of 5.00 with an SD of 0.88. Overall, workforce scores average 3.95 out of 5.00 with an SD of 0.93. The workforce mean score distribution is shown in Table 7.

Table 7. Mean score distribution of workforce

	Workforce	Mean	SD
W1	The current construction team is familiar with BIM.	3.87	0.95
W2	Employees are willing to learn and adapt to new changes.	3.85	0.92
W3	Employee training takes longer.	4.11	0.98
W4	To ensure that the model can be used at all stages of the project, all project stakeholders are involved.	3.96	0.88
	Overall	3.95	0.93

The importance of training lies in enabling workers in the construction sector to acquire the necessary technical skills to deal with the digital tools provided by BIM, which contributes to improving the quality of projects and increasing productivity and efficiency. Training programs also guarantee reducing human errors and improving risk management in construction sites, which reduces the total costs of projects and enhances work safety. Moreover, the development of the workforce helps enhance the understanding of the economic and technical benefits of BIM adoption, such as improving communication between the different parties in the project and achieving integration between the various stages of design, construction and operation. Without appropriate training, developing countries face difficulties in applying this technology as a result of a lack of knowledge, fear of change and high costs, which aligns with the findings of Kineber et al. [71] and Syed Jamaludin et al. [72].

4.4.3 Technology

Technology was identified as the third challenge through the literature review. Technology is a major issue for Chinese construction [34]. Construction companies must evaluate IT resources and technical bottlenecks before implementing BIM. Many general issues were identified and used as sub-issues in this challenge for this study. Table 8 shows that the mean score is 3.95 out of 5.00 with an SD of 1.00. The need for BIM implementation was assessed in T1. A mean score of 4.16 (out of 5.00) and an SD of 0.91 indicate that good hardware is required for BIM implementation according to the respondents. The rapid evolution of technology necessitates BIM software to have technical properties that address associated issues and increase the efficiency of AEC projects. Technical considerations include the functionality of software, interoperability, usability, BIM standards and regulations, data security and privacy, application integration/extension, accessibility, and the handling of large datasets. In addition, respondents moderately agreed that multiple stakeholders can lead to data integrity issues, with a mean score of 3.91 and an SD of 1.05. In addition, respondents generally concurred that BIM software is technically intricate (T3) and that traceability may be impaired because multiple parties can access data simultaneously (T4). As shown in the table, the average score for T3 is 3.93 out of 5.00, with an SD of 0.96, and for T4 it is 3.80 with an SD of 1.08.

Table 8. Mean score distribution of workforce

	Technology	Mean	SD
T1	BIM implementation requires high-quality hardware.	4.16	0.91
T2	Data integrity issues (data ownership and protection)	3.91	1.05
T3	Software complexity	3.93	0.96
T4	Poor traceability (tracking of changes and accountability)	3.80	1.08
	Overall	3.95	1.00

Several studies have mentioned the same technological barriers while others have reported additional barriers. Malaysia, like many developing countries, faces significant technological challenges in adopting BIM technologies. Compared to other developing countries, the technological challenges in Malaysia include several key aspects, including the lack of technical skills, as there is a significant shortage of professionals in Malaysia who specialize in using BIM technology [73]. Adopting BIM requires advanced expertise in software and 3D data management, which a large number of workers in the construction sector lack. This shortage leads to delays in the implementation of the technology and difficulty in realizing its full benefits. In addition, the weakness of the technological infrastructure poses a major challenge, as BIM relies on fast internet connectivity and advanced computing devices. In Malaysia, like many developing countries, the digital infrastructure is still insufficient to support complex applications such as BIM on a large scale. Compared to other developing countries [55], Malaysia faces similar challenges in terms of a lack of government support and awareness of the importance and benefits of BIM. However, the Malaysian government is seeking to promote this technology through strategies aimed at improving skills and providing financial support for companies to adopt BIM [71].

4.4.4 Awareness

One of the key challenges remaining is to raise awareness within the industry about the implementation and practical use of BIM. According to Table 9, the average rating for this aspect is 3.92 out of 5, with an SD of 0.92. Understanding BIM and its benefits is crucial for improving project productivity. Many researchers have highlighted that increasing industry knowledge about how BIM works, along with its advantages and potential drawbacks, is essential to encourage its adoption as a new project delivery method. For example, BIM adoption has been slow in Malaysia largely due to a lack of sufficient knowledge [9]. Successfully adopting BIM involves building confidence in the technology, developing expertise, choosing the right BIM tools, understanding project scope, and managing contracts effectively. Therefore, boosting awareness can help overcome these obstacles and unlock the benefits that BIM offers. Survey respondents generally agreed that experienced workers and managers are familiar with BIM, giving average scores of 3.93 and 3.97 (out of 5), respectively. They also acknowledged the availability of BIM training courses, which received an average score of 4.00 with an SD of 0.83. Additionally, there was strong agreement that university graduates possess knowledge of how to apply BIM in the industry, with an average score of 3.78 and an SD of 1.16.

Table 9. Mean score distribution of awareness

	Awareness	Mean	SD
A1	Experienced staff are familiar with the use of BIM.	3.93	0.82
A2	Management understands the benefits of BIM.	3.97	0.87
A3	There are awareness programs/courses for BIM application.	4.00	0.83
A4	Graduates will learn how to use BIM in practice.	3.78	1.16
	Overall	3.92	0.92

Despite the Malaysian government's efforts and initiatives to promote BIM, awareness of this technology remains relatively low within the industry and this finding corresponds to the study by Al-Ashmori et al. [32] which affirmed that the awareness level of BIM in Malaysia's construction industry is still very low. Several studies have identified key challenges that complicate BIM adoption. One major obstacle is the high cost associated with BIM technology. Implementing BIM requires significant investment in advanced software, powerful hardware and personnel training to use these tools effectively. This financial burden is particularly heavy for small and medium-sized enterprises (SMEs) [71]. Furthermore, the lack of sustained government support acts as a barrier, as indicated by Munianday et al. [74]. Many companies feel that more funding or subsidies are necessary to support training programs and encourage wider BIM adoption [75], which is supported by the results in Table 9 where the awareness for training and courses for BIM is still not very high, with a mean score of only 4. Moreover, the mean values show that the graduates still lack awareness of BIM uses in practice. In addition, unclear guidelines and the absence of standardized policies on how to implement BIM in projects contribute to hesitancy among firms to fully embrace the technology [73]. Addressing these issues is essential to facilitate smoother BIM integration and to realize its potential benefits across Malaysia's construction sector.

Many workers in the construction sector do not have the technical skills necessary to implement BIM effectively, which leads to a reluctance to change the traditional processes they rely on [76]. The findings in Table 9 can prove that there is still a lack of awareness about staff skills in BIM. Ultimately, these technical and cultural challenges add to the resistance to change that exists among many companies, which consider using traditional systems easier and less risky. Awareness of BIM adoption is also linked to demographic groups in Malaysia and other developing countries. Studies have indicated that demographic factors such as age, education level and professional experience play an important role in the level of awareness and understanding of BIM technologies.

Younger individuals, who receive specialized education in technical fields, are more likely to adopt BIM compared to older professionals who may prefer traditional methods [77].

4.4.5 RII ranking of challenges in BIM implementation

BIM implementation challenges in the Malaysian construction industry were identified through RII ranking. Table 10 ranks the challenges, and Figure 5 depicts their levels. Each challenge has an RII value between 0.70 and 0.80, indicating that BIM implementation in Malaysian construction is moderately difficult.

Table 10. RII ranking of challenging factors

Factor	RII Value	RII Ranking
Cost	0.76	4
Workforce	0.78	2
Technology	0.79	1
Awareness	0.78	3

The findings show that technology, workforce, and awareness are the industry's biggest challenges. The fourth challenge is cost. Malaysia's construction industry must overcome many challenges to implement BIM. BIM skills shortages in the building sector are a major workforce issue. Business resistance to BIM is caused by its complexity and high cost. Untrained users could accidentally change data, endangering the project. Fragmented construction projects increase project partners' resistance to BIM adoption. The inability of BIM software to communicate is a major technological issue that hinders collaboration and workflow. BIM implementation and deployment are often criticized as costly. BIM deployment requires a large upfront investment in technology, training and development. BIM has ambiguous legal obligations and processes in policies, standard contracts, data ownership, insurance, risks, and role and duty division. Due to unclear rights and duties, project development is difficult and risky, as shown in Figure 5.

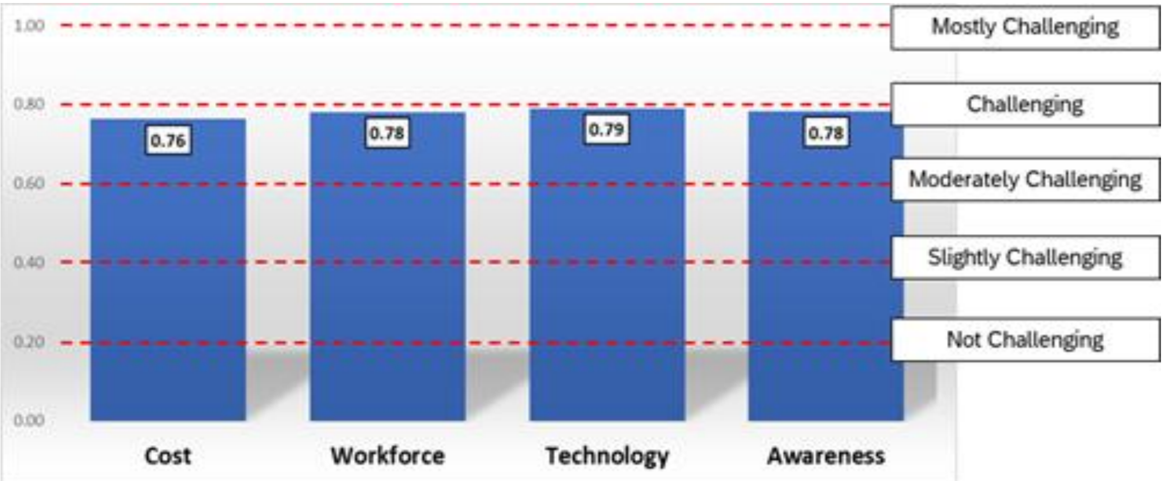

Figure 5. RII ranking of challenges

Organizations must change their operations for BIM. Improved cross-disciplinary communication and cooperation yield a fully integrated BIM model. Assigning duties and conducting design reviews and validation require shared procedures and norms. The Construction Industry Development Board (CIDB) then called for national BIM standards and guidelines to control BIM workflow and adoption. Private company adoption was ignored except for government initiatives. Management and leaders are often unprepared to use BIM in their companies.

It can be noted that the technological challenges related to BIM adoption are of primary importance and reflect the reality of the construction industry in Malaysia, where technological development remains limited. The use of BIM technologies requires strong infrastructure and advanced software, which is difficult to achieve for many Malaysian companies, especially SMEs, who suffer from a lack of investment in technology and training. This can be attributed to the fact that the construction industry in Malaysia relies heavily on traditional methods, making it difficult to adopt modern technologies without fundamental changes in infrastructure and skills. Modern technological developments such as cloud computing and AI technologies can help mitigate these challenges. By using these solutions, companies can bypass the high cost of advanced hardware and increase the efficiency of adoption.

4.5 Factors influencing the successful implementation of BIM

BIM is a combination of technological proficiency and advanced processes that employs IT to facilitate collaboration on construction projects. Many Malaysian infrastructure construction companies consider BIM a new technology because its use remains relatively uncommon. There are several key success factors for BIM adoption and implementation. First, success can be defined and described differently depending on the context. It should be noted that even in the construction industry's production phase, success is hard to measure. The fragmented nature of the AEC industry, along with the uniqueness of each project, makes assessing success challenging. However, several general success factors have been identified in the literature, including altering management perspectives on BIM, integrating project teams, balancing knowledge, and providing employee training [6]. In this study, four factors were considered to influence performance: senior management, training and learning, interoperability and compatibility, and project management. As in Part C, respondents rated each question on a 1 to 5 Likert scale. Successful BIM use depends on the integration of several key factors below: senior management support, training, and project management, as shown in the conceptual framework in Figure 1.

- Senior management support is essential for allocating financial and technical resources and adopting a long-term strategy for BIM adoption. Senior leadership provides the vision and drives necessary to adopt the technology and encourage employees to use it.
- Training ensures the development of technical skills among employees, which helps them deal with the complexities of BIM. Continuous training contributes to reducing errors and increasing efficiency in projects.
- The use of modern project management techniques such as integrated planning and coordination contributes to improving workflow and reducing duplication, which enhances project productivity and accelerates task completion.

This overlap between these aspects contributes to the success of BIM, as each plays a complementary role in achieving the desired goals.

4.5.1 Top management

First, the top management's role in BIM implementation was examined. Table 11 indicates that the average score is 4.17 (out of 5.00) and the SD is 0.86. The top management must explain the benefits of BIM to the team and make it a part of the company's policy. High implementation costs are a concern. The top management must devote funds to the operational expenditures of BIM. Before implementing BIM, top management must understand and address the constraints in the implementation process. The implementation of new technologies fails due to organizational issues. Some companies are concerned that changing business processes can incur costs and jeopardize existing processes due to an inability to accept uncertainty [47]. Some employees in the company are concerned that technology would replace their jobs and are apprehensive about change, especially with new technology, as few of the managers have knowledge of how to adapt to technological advancement. Many organizations consider BIM to be disruptive to their existing business processes, because the implementation of new technology would lead to a restructuring of their business processes, thereby reducing productivity and putting the results of projects and client expectations in jeopardy [44].

Table 11. Mean score distribution of top management

	Top Management	Mean	SD
TM1	Top management must fully communicate the benefits of BIM implementation to team members.	4.121	0.78
TM2	Top management must incorporate BIM implementation into the company policy.	4.27	0.86
TM3	Top management must invest in BIM operational costs.	4.16	0.88
TM4	Top management must understand the constraints in implementation and solve them before introducing BIM to the company.	4.14	0.92
	Overall	4.17	0.86

4.5.2 Training and learning

As discussed in Subsection 4.5, workforce competency is a challenge. Therefore, providing adequate training and learning opportunities can help the Malaysian construction industry implement BIM. The mean score is 4.11 with an SD of 0.91. BIM implementation success is linked to training and learning, according to the respondents. Construction team members need BIM training [78]. BIM should be integrated into engineering curricula so that graduates gain experience before entering the workforce [79]. Companies should fund employee development so that team members can take BIM courses [80]. Team members must be committed to learning new skills and technologies.

It can be noted that inadequate company training increases implementation resistance because a lack of new technology knowledge and expertise can hinder implementation and reduce confidence. Training can accelerate IT adoption. However, it is difficult to ensure that everyone in a company has the appropriate technologies and skills [80]. Therefore, companies can establish a technical support team to address these and future issues. This technical support team could promote a culture of knowledge sharing by demonstrating its value through practice. The new IT implementation also needs support from relevant authorities. Any construction company willing to adopt new IT could receive an interactive package from the authority. Table 12 shows the mean score distribution of training and learning.

When training the adoption of BIM in the construction industry, the training type is significantly influenced by many factors. Researchers have suggested that specialized training directed at specific technical skills in BIM, such as specialized software training, can enhance workers' ability to use the technology effectively in the day-to-day operations of projects. In contrast, managerial and strategic training that focuses on understanding the organizational benefits and integration between different departments contributes to improving BIM adoption at the senior and middle management levels, as it shows them the long-term value of using this technology in improving efficiency and reducing costs [71, 81]. One of the challenges facing BIM training is the lack of awareness about how to effectively integrate this technology into the existing framework, which slows the adoption process, even in countries where training programs are available. Therefore, it is essential that there is a diversity in the training provided to include technical, managerial and strategic aspects alike to ensure that all project workers are fully aware of how to use BIM in an integrated manner [71].

Table 12. Mean score distribution of training and learning

	Training and Learning	Mean	SD
TL1	Team members in the construction industry must receive adequate BIM training.	4.12	0.88
TL2	BIM must be incorporated into the curriculum of engineering so that students can gain experience before entering the profession.	4.17	0.92
TL3	Companies must devote funds to the development of human resources so that team members can participate in BIM-related educational programs.	4.08	0.94
TL4	Members of the team must have the power and desire to learn new abilities and technologies.	4.071	0.881
	Overall	4.111	0.911

In addition, continuous training and constant updating of skills are crucial given the rapid evolution of the technology used in BIM. There are successful experiences in other countries such as the United States and the Netherlands, which have witnessed significant progress in adopting BIM after implementing integrated training strategies at all levels within organizations [71, 81].

4.5.3 Interoperability and compatibility

Interoperability enables ICT systems and business processes to exchange data and knowledge. This definition applies to construction, BIM, and interoperability. For successful BIM implementation, interoperability between departments must be ensured. When selecting BIM software, it is essential that the chosen solution aligns well with the company's existing technologies and available resources. Organizations need to ensure that the software fits within their budget, suits the specific requirements of their projects, and is compatible with their technological infrastructure. Additionally, respondents highlighted the importance of evaluating the software's complexity prior to implementation, ensuring that it can be effectively integrated into business processes without causing unnecessary difficulties. The transfer of BIM data between departments or stakeholders must be simple. From a technical perspective, data accuracy is a concern. The average rating was 4.05 out of 5.00, with an SD of 0.87. Table 13 illustrates the average rating of each question.

Table 13. Mean score distribution of interoperability and compatibility

	Interoperability and Compatibility	Mean	SD
IC1	The compatibility between different departments must be understood.	4.121	0.87
IC2	The chosen BIM software should be compatible with the company's technologies and other resources.	4.051	0.88
IC3	The complexity of the software must be studied and investigated before implementation within the company.	4.03	0.89
IC4	Data transfer between departments/stakeholders through BIM must be seamless and efficient.	4.02	0.85
	Overall	4.05	0.87

Compatibility and interoperability between technology systems, including different BIM software, have a significant impact on collaboration in multidisciplinary projects. When technology systems are incompatible or suffer from operational issues, this can cause barriers that negatively impact the flow of information and communication between different teams, leading to project delays and increased costs. Incompatibility of BIM software with other systems or tools on the project can also lead to difficulties in transferring data between architects, civil engineers, and contractors [71]. Interoperability issues make it difficult for multidisciplinary teams to work smoothly, as design and construction teams rely on accurate and constantly updated models. If data from BIM software are not interoperable with construction management software or engineering systems, this can lead to misunderstandings of designs or unplanned modifications, increasing project complexity and slowing down the completion process [81]. Interoperability can play a crucial role in boosting BIM adoption rates in Malaysia by improving collaboration and system integration between different players in the construction industry. This enables the facilitation of data and model exchange between architects, civil engineers, and contractors. When different BIM tools and software are compatible, it becomes easier for multidisciplinary teams to work together more effectively, reducing errors caused by miscommunication or information loss. This can encourage more companies in Malaysia to adopt BIM, as the direct benefits can be seen in increased efficiency and reduced rework costs [71].

Running BIM on multiple platforms requires strong compatibility between different software, which reduces operational costs for companies that may be wary of investing in new technology infrastructure. By using operational standards such as Industry Foundation Classes (IFC), companies can use their existing software or reduce the costs associated with purchasing new software that better integrates with existing systems. This encourages SMEs in Malaysia to adopt BIM without fear of technology upgrade costs [71, 81]. Interoperability makes the BIM adoption process faster and less complex for companies that may initially find it difficult to transition to this technology. By enabling the seamless flow of data between different design and construction systems, companies can see an improvement in the overall efficiency of projects, which increases their willingness to adopt BIM as a standard. Companies that are able to operate BIM in an integrated manner with other systems are able to innovate more quickly in delivering architectural and engineering solutions. This enables Malaysia to better compete internationally in the construction sector, as companies can deliver more complex and accurate projects, which in turn increases confidence in investing in BIM [71]. Therefore, enhancing interoperability can encourage the widespread adoption of BIM in Malaysia by providing a smoother and more efficient collaborative environment and reducing the costs and challenges associated with transitioning to this technology.

4.5.4 Project management

The final factor examined was the impact of project management on BIM adoption in the Malaysian construction industry. The company should assess project size and needs before consulting with BIM. This helps the company evaluate the application and quote a reasonable price. In addition, the company should investigate how BIM can be integrated into projects of any size or budget to improve customer experience and simplify work. The project management team should highlight BIM-monitored critical factors. The average score was 4.08 with an SD of 0.92. The project management's mean score distribution is shown in Table 14.

Table 14. Mean score distribution of project management

	Project Management	Mean	SD
PM1	The company must first assess the magnitude and complexity of the project before employing BIM.	4.05	0.92
PM2	The company must consider how BIM can be incorporated into projects of any size and budget, regardless of the project's ultimate goal.	3.93	1.03
PM3	The team responsible for project management should discuss the critical components that can be monitored with BIM.	4.26	0.81
	Overall	4.08	0.92

Table 14 shows that project management adopting BIM is essential in the construction industry and should address several points. The results show that the company must first assess the magnitude and complexity of the project before employing BIM, as indicated by Bakhshi et al. [82]. Additionally, the stakeholders have the responsibility to discuss the critical components that can be monitored with BIM. Several studies have highlighted the responsibility of the project management team to hold regular meetings aimed at addressing critical BIM-related issues [83].

4.5.5 RII ranking of factors influencing successful implementation of BIM

The most influential factors were ranked using RII. Table 15 shows that top management has the largest influence, followed by training and learning. Project management is ranked third, and interoperability and compatibility are ranked fourth on the RII scale. The RII value is 0.80 or higher, which indicates that all of the identified factors are involved in BIM implementation in the Malaysian construction industry, as shown in Figure 6.

Table 15. RII ranking of challenging factors

Factor	RII Value	RII Ranking
Top management	0.831	1
Training and learning	0.821	2
Interoperability and compatibility	0.801	4
Project management	0.810	3

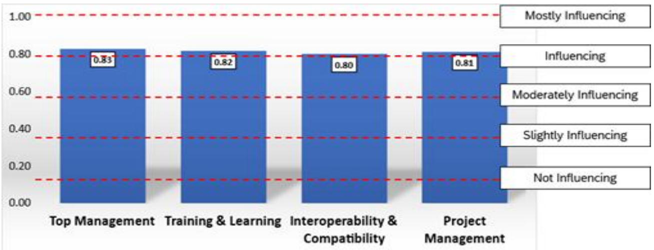

Figure 6. RII ranking of factors influencing BIM implementation

Several studies have affirmed that top management is a significant factor influencing BIM execution [76, 84]. Top management plays an important role in the successful adoption of BIM in the construction industry through an integrated planning methodology between management departments. It is not just a tool, but rather an integrated methodology through planning, setting vision and goals and managing resources in an appropriate manner. Additionally, Abbasnejad et al. [84] emphasized the importance of training and education for learning BIM in both the construction industry and educational curricula [85, 86].

In order to further refine the interpretation of the Kruskal–Wallis H test results, additional clarifications were incorporated to strengthen the analytical rigor of this study. The test was applied to three distinct respondent categories: BIM users, partial users with limited exposure, and non-users. The dependent variables included the perceived challenge scores (cost, workforce, technology, and awareness) as well as the success factor scores (top management support, training and learning, interoperability, and project management). The hypotheses were formulated as follows: the null hypothesis (H_0) assumes no statistically significant difference in the median scores across the three groups, whereas the alternative hypothesis (H_1) posits that at least one group differs significantly. Although the test results reveal no significant differences ($p > 0.05$), the effect size ($\varepsilon^2 = 0.02$) suggests a very small impact. The mean rank analysis indicates that BIM users tend to perceive the challenges as less severe compared to non-users, while partial users occupy an intermediate position. This trend, although not statistically significant, corresponds with theoretical expectations that exposure to BIM reduces the perceived severity of challenges. The results underscore the importance of considering both statistical and practical significance when interpreting findings. Furthermore, the non-significant outcomes highlight the need for future studies with larger and more diverse samples to capture sector-specific variations, such as those in healthcare, infrastructure, or residential construction. Longitudinal research is also recommended to monitor how perceptions evolve as BIM adoption progresses over time.

The Kruskal–Wallis test was used to compare BIM-literate and non-BIM-literate respondents. P-values were calculated for each section and respondent group using SPSS Version 22. Table 16 shows the Kruskal–Wallis p-values for each part.

Table 16. Summary of Kruskal–Wallis H test statistics

	Chi-Square	P-Value	Result
Section B	15.9811	0.1891	No significant difference
Section C	16.4351	0.4291	No significant difference

The Kruskal–Wallis H test demonstrates that the sections don't have a significant difference, because the p-value is greater than 0.05. There is no significant difference in respondents' perceptions of BIM implementation challenges and factors in the Malaysian construction industry. When comparing the responses to BIM challenges and influencing factors in the Malaysian context, the lack of significant differences in the Kruskal–Wallis test could be explained by several possible reasons. For example, the differences in knowledge or experience between educated and uneducated respondents may not be as large as expected. Sometimes, uneducated respondents may have gained practical understanding or knowledge from direct work on projects. In addition, information on BIM challenges and techniques has become widely available through multiple channels, such as the Internet or informal training courses, making the differences between educated and uneducated respondents less pronounced.

5. CONCLUSIONS

This study examines how Malaysia's construction industry uses BIM for operations and facilities management. The study seeks to identify the challenges and factors influencing BIM implementation in the Malaysian construction industry. The objective of identifying the challenges that hinder BIM adoption in the Malaysian construction industry and facility management was achieved. According to the descriptive analysis conducted and RII values, top management engagement is the most influential factor for BIM adoption in the Malaysian construction industry. Before implementing BIM, top management must understand and resolve implementation constraints. The factor of training and learning was the second most influential, followed by project management and interoperability and compatibility. In addition, the Kruskal–Wallis H test was used to compare the responses of BIM users and non-users. Among the respondents in Section A, 31% had BIM experience, while 69% did not. The Kruskal–Wallis H test shows no difference in responses. The differences in knowledge or experience between educated and uneducated respondents may not be as large as expected. Sometimes, uneducated respondents may have gained practical understanding or knowledge from direct work on projects. This study contributes to the development of a theoretical framework for future research aimed at conducting more in-depth investigations into BIM adoption techniques in the Malaysian construction industry. In addition, it provides the Malaysian construction companies that intend to adopt BIM with potential limitations, challenges, and critical factors influencing BIM adoption.

6. RECOMMENDATIONS

The following directions are recommended for future investigations:

First, it is recommended to concentrate on government initiatives that promote the local adoption of BIM in organizations. These initiatives are financially motivated and mandatory and include training, legislation, and policy formation.

Second, it is recommended to conduct collaboration between universities and industry to evaluate the competency gap between graduates and current workers, as well as to develop curricula through the integration of BIM concepts and workforce training programs and workshops.

Third, it is recommended that further research be conducted on BIM adoption in the Malaysian context to study the extent to which the identified challenges and factors influence adoption, using additional statistical testing.

Finally, further research is recommended to examine the extent to which the integration of the identified factors influences BIM adoption in the Malaysian context.

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