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The Impact of Building Information Modelling (BIM) on Labor Productivity

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Abstract

Globally, the construction sector suffers from low productivity levels due to a large proportion of the workforce consisting of low-skilled laborers. In order to integrate design and construction workflows with the objective of enhancing productivity, there is a considerable need to move from traditional methods to advanced techniques such as Building Information Modeling (BIM). Clear and convincing benefits are key to ensuring the viability of the BIM implementation process, especially for small to medium enterprises (SMEs) that need encouragement to transition to BIM. While the architectural, engineering, and construction (AEC) industry has recently embraced BIM, its adoption has been slow for decades, primarily due to the substantial financial risk, particularly for local SMEs. These SMEs must identify clear and obvious benefits to justify the high initial transition cost from traditional construction approaches to BIM-based methods. The high initial cost of implementing BIM systems in SME businesses limits its implementation among construction professionals. However, one appealing benefit that encourages the implementation and acceptance of BIM in the construction sector is its potential to improve labor productivity. Despite the development of methods to investigate the benefits of BIM in terms of labor productivity, empirical quantification of labor productivity remains challenging and complex due to BIM's innovations, project complexity, and the lack of standard, unified productivity measurements. This study aims to provide guidelines for construction players to understand how BIM is used in projects and apply best practices to prevent project delays and cost overruns while improving communication among project participants and enhancing labor productivity.

Keywords: Building Information Modelling (BIM), Labor Productivity, Construction Productivity, Construction Project Performance

Introduction

The architectural, engineering, and construction (AEC) industry in Malaysia currently utilizes Building Information Modeling (BIM) (Wong, Rashidi, & Arashpour, 2020). Its implementation was initiated in 2007 by the Director of the Public Works Department (PWD) with the aim of reducing construction costs and minimizing design issues. BIM in construction facilitates clash analysis during the design stage, improves project scheduling efficiency, reduces costs, ensures high project quality, and enables effective communication among construction stakeholders.

BIM is a widely used term in the construction industry, representing IT solutions that address current challenges. It is an integrated approach that allows stakeholders to digitally examine a project's physical and functional aspects before construction begins. BIM involves collaboration among different participants throughout a facility's life cycle to input, extract, update, or modify information in the model, aligning with their respective responsibilities. The application of BIM can benefit planning, design, and construction project quality.

The advantages of BIM for construction players encompass the design process, budget management, communication, documentation, and scheduling. The ultimate goal of promoting BIM adoption in construction projects is to enhance the quality of construction projects in Malaysia. BIM has proven to be a valuable tool in preventing project delays, cost overruns, and improving communication among project participants. Understanding how BIM was utilized in projects can provide valuable insights and lessons for improving project quality.

Literature Review

Introduction to Building Information Modeling

BIM, developed over the past two decades, is an effective instrument in response to the competitive nature of the construction industry (Olawumi & Chan, 2019). It has been recognized as one of the most influential new technologies in the AEC sector, enabling increased collaboration, coordination, and a reduction in industry challenges (Azhar, 2011). Architects, engineers, and consultants have been advocating for the use of BIM tools, leading to increased adoption and improved productivity in construction.

The evolution of BIM technology has advanced design capabilities, allowing for more sophisticated modeling. It supports not only 3D models but also construction management, planning, cost control, evaluation, safety education, and sustainability in developed countries (Chan & Olawumi, 2018). A BIM model represents the geometry, spatial linkages, geographic information, quantities, attributes of architectural elements, cost estimates, material inventories, and project schedules. This comprehensive representation enables effective collaboration among project stakeholders, ensuring accuracy and efficiency throughout the project's lifespan. BIM consolidates all aspects, disciplines, and systems of a facility into a single virtual model, facilitating improved collaboration compared to traditional processes (Azhar, 2011). The model is continuously updated to reflect project specifications and design modifications, ensuring its accuracy before physical construction begins (Carmona & Irwin, 2007). The primary motivation for BIM adoption is to maintain a balance within the project management triangle of scope, cost, and time (Chan & Olawumi, 2018).

By incorporating BIM into construction projects, stakeholders can optimize time, cost, and quality (Wong et al., 2009). Achieving a balance between these three criteria is challenging due to the multitude of ideas and solutions required. Innovation, including the adoption of

BIM, can help strike the right balance, offering numerous benefits such as improved project performance and enhanced quality (Mohammed, Sher, & Succar, 2009).

Definition of Building Information Modeling (BIM)

BIM is not a proprietary application or product; rather, it is an integrated process based on consistent and reliable project data. It benefits not only architects but also civil engineers and various other professionals involved in construction projects (Boukara, Naamane & France, 2015). BIM encompasses more than just a three-dimensional model; it enables engineers to estimate project performance, respond effectively to design changes, improve building visualization, and extract valuable data for faster decision-making and implementation of cost-effective projects (A. Borrmann et al., 2015). The building information model represents the structure and its internal features in a three-dimensional computerized format, incorporating intelligent building components with data properties and parametric rules. The model ensures consistent and coordinated representations, providing reliable data for decision-making throughout the object's life cycle (S. L. Fan et al., 2014). The national BIM standard defines the building information model as a digital representation of the object's physical and functional characteristics, serving as a reliable knowledge resource from concept to demolition.

Importance of Building Information Modeling

Researchers have explored the advantages of BIM, highlighting its ability to provide a realistic portrayal of buildings within an informative context (Ahmad et al., 2012). BIM enhances design processes by enabling designers to simulate and evaluate models quickly, leading to improved environmental design and the exploration of various architectural scenarios (Azhar, 2011; Schade et al., 2011). Additionally, BIM facilitates the easy extraction of building plans, details, and sections without the need for manual sketching (Hergunsel, 2011).

The 4D BIM model proves beneficial in both the design and construction stages. During design, it allows owners to visualize construction sequences and develop phasing strategies, while contractors can assess the buildability and viability of the design. The 4D BIM model provides a more accurate depiction of planned construction operations compared to the physical model, enabling contractors to arrange the site and coordinate crew mobility accordingly (Abanda et al., 2015).

Definition of Productivity

Productivity is the ratio of output measures to input measures, directly influencing project costs and timelines. Monitoring and anticipating performance allows project managers to effectively track and project project time and expenses from start to finish. Assessing the team's performance is an integral part of project management, enabling the detection of potential problems and the development of innovative solutions to overcome delays and overheads. Failing to address productivity issues can lead to project failure and subsequent accountability for the contractor (Sauermann, 2016).

Impact of Building Information Modeling (BIM) on Labor Productivity

Despite evidence of BIM's success and benefits in construction projects, small and medium-sized construction companies have been hesitant to adopt BIM due to a lack of empirical justification. However, recent studies have attempted to quantify BIM's impact on construction productivity. Monitoring and regulating building progress have proven effective in collecting productivity data, with 3D BIM modeling and quantity take-off aiding in productivity evaluation (Smith et al., 2022). Recent research has focused on measuring the influence of BIM on worker productivity, evaluating key performance metrics such as quality control, on-time completion, cost, safety, units per man-hour, and dollars per unit performed (Bryde et al., 2013). Various studies have identified quality control, on-time completion, and units per man-hour as significant indicators of project performance. Worker productivity data has been utilized to monitor project development and establish productivity data collection methodologies, with quantity take-off and conflict detection identified as key factors in increasing worker productivity (Memon et al., 2014).

Methodology

This section describes the examination convictions and research methodologies used in this study, including inspection procedures, data collection methodology, and respondent selection. This study used literature review and primary research approaches, such as distributing online survey questionnaires, to collect all relevant information. Questionnaires were produced, and respondents answered questions divided into four sections. The first component of the survey inquired about the respondents' demographic profile, including their gender, job title, and work experience. The second section inquired about factors affecting construction labor productivity. The third section inquired about major BIM-related factors affecting construction project performance, and the last section inquired about the potential use of the BIM method at construction sites. The data was analyzed and interpreted using Statistical Package for the Social Sciences (SPSS) Analysis.

A literature review is a component of a research paper that identifies, evaluates, and synthesizes relevant literature that is related to the research topic (Introduction To Literature Review, 2020). It also provides an overview of current knowledge, as well as pertinent theories, methodologies, and research gaps (McCombes, 2021). A literature review is a research method that examines books, journals, and other relevant sources in relation to a specific issue, research topic, or hypothesis. As a result, it provides further information, a description, a summary, and a critical evaluation of the study issue. Furthermore, it aids in the development of knowledge by assisting in the comprehension of previous research and studies that are relevant to the study's specific focus.

The information on construction consequences from the previous study is crucial since it provides evidence to justify the study's conduct and archival goal. A clear understanding of the study's scope will result in a positive outcome at the conclusion of the study, as well as benefits for others. This study looked over and communicated information from research articles and journals over the past ten years. The implications of construction were discovered and summarized by the author.

Development of Questionnaire

A primary research technique used in this study was an online questionnaire survey. A questionnaire is a research tool that consists of a series of questions used to collect data from respondents. Respondents read the questions, determine what is required, and provide responses on their own. Questions were constructed based on the study's scope and ultimate objective. The questionnaire's reliability can be reproduced by other researchers for further research, and the study's results can be compared between different studies. Data consistency demonstrates that the obtained result is appropriate and precise for analysis. Questionnaires are a low-cost, stress-free, and quick way to gather a high number of responses from various sources. The data for this study was gathered through a questionnaire survey of the construction sector, focusing on workers in the construction industry in the Penang area.

The survey focused on the effect of Building Information Modeling (BIM) implementation on labor productivity, and the questionnaire was created based on the objectives indicated in Chapter One. The questionnaire consisted of four sections: Section A gathered respondents' demographic details such as gender, state, academic qualification, working experience, designation, and years of involvement in BIM projects. Section B sought information on factors affecting construction labor productivity, divided into four categories: human/labor factors, management factors, technical and technology factors, and external factors. Section C inquired about the major BIM-related factors affecting construction project performance, divided into five categories: human factors, management factors, project factors, project performance, and external elements. The last section sought information on the potential use of the BIM method at construction sites. he questions in this section aimed to understand the respondents' perception of BIM's benefits, challenges, and its impact on various aspects of construction project performance.

To ensure the validity and reliability of the questionnaire, a pilot test was conducted with a small group of construction professionals who had experience with BIM projects. Their feedback and suggestions were taken into account, and necessary modifications were made to improve the clarity and effectiveness of the questionnaire.

Data Collection

The data for this study was collected through an online survey using the questionnaire developed in the previous section. The survey was distributed to construction professionals working in the Penang area. Various methods were employed to reach potential respondents, including email invitations, online forums, and social media platforms. The survey was designed to be user-friendly and accessible on different devices, ensuring convenience for the participants.

The respondents were assured of the confidentiality and anonymity of their responses, and they were encouraged to provide honest and accurate information. The survey period lasted for three weeks, during which reminders were sent to maximize the response rate. A total of 250 responses were collected within the survey period, representing a diverse range of construction professionals, including architects, engineers, project managers, and contractors.

Data Analysis

The collected data was analyzed using the Statistical Package for the Social Sciences (SPSS) software. Descriptive statistics such as frequency distributions, percentages, and means were calculated to provide a comprehensive overview of the respondents' demographic profile and their perspectives on the factors affecting construction labor productivity and BIM-related project performance. Inferential statistical techniques, such as correlation analysis and regression analysis, were employed to examine the relationships between variables and test the research hypotheses. Furthermore, qualitative data obtained from open-ended questions in the questionnaire were analyzed using thematic analysis. The responses were coded and categorized to identify recurring themes and patterns, providing additional insights into the participants' opinions and experiences related to BIM implementation and its impact on construction project performance.

Results and Discussion

Demographics of Respondents

A detailed discussion of responses will be provided in this section to examine their opinions on the issues discussed. There were a total of 43 respondents, both male and female, who have worked in the construction industry. The analysis is based on data from respondents who identified themselves as accountable parties in the construction industry. The demographic data includes respondents' level of academic qualification, working experience, designation in the company, and years of involvement in BIM projects.

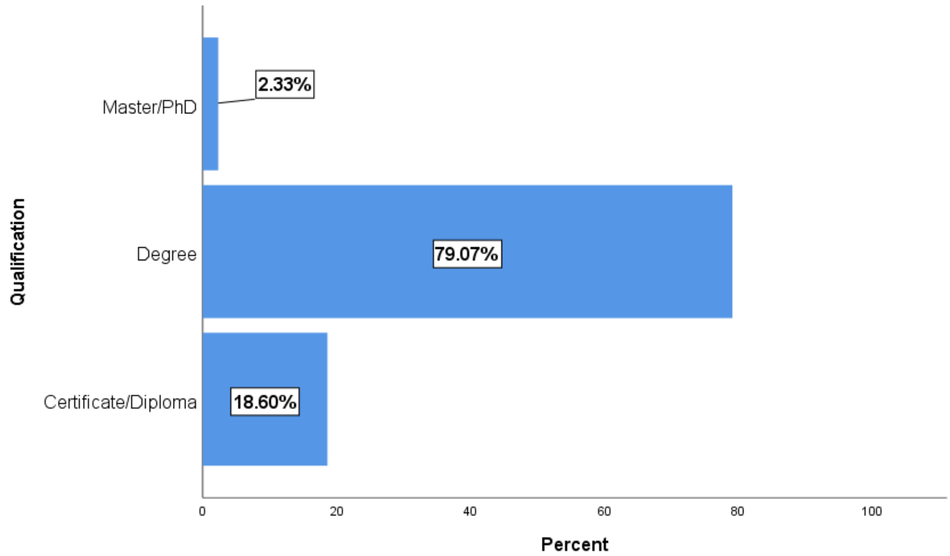

Figure 4.1: Respondents' Academic Qualification.

Figure 4.1 represents a graph of respondents' academic qualifications, which include certificate/diploma, degrees, and master/PhD. The majority of respondents had degrees, with 34 out of 43 having a bachelor's degree, accounting for 79.07% or over half of the respondents. Meanwhile, 8 respondents (18.6%) had a certificate/diploma, while 1 respondent (2.33%) had a master's or PhD degree. Respondents with degrees and master's/PhD degrees are likely to be engineers, while those with certificate/diploma qualifications may be supervisors.

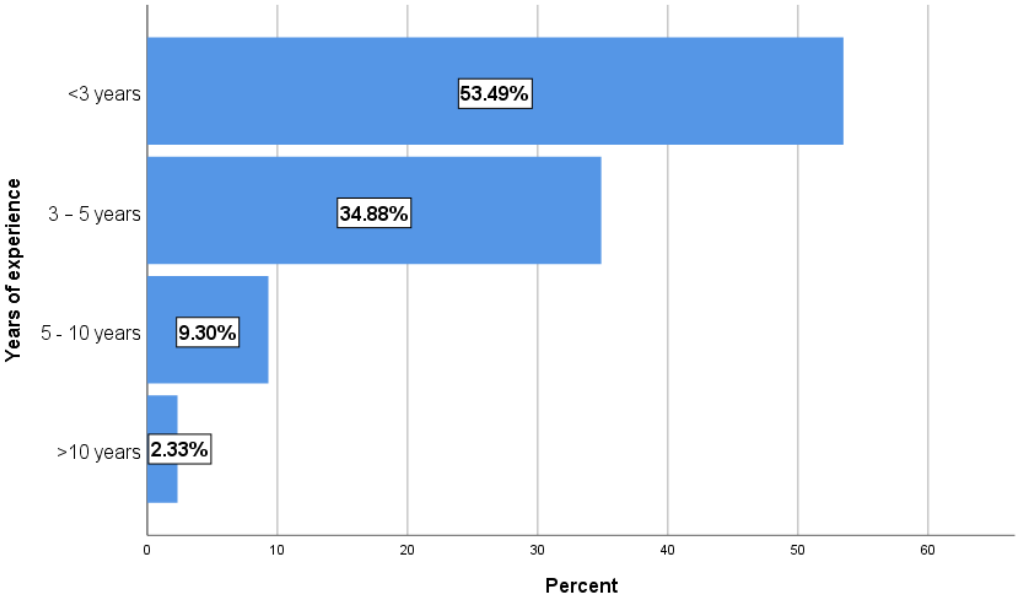

Figure 4.2: Respondents' Working Experience.

Working years are essential to the study as they represent the professionalism of respondents. Therefore, information on work experience was collected and incorporated into the questionnaire. Figure 4.2 depicts the total number of respondents with less than 3 years, 3 to 5 years, 5 to 10 years, and more than 10 years of work experience. Out of the 43 respondents, 23 (53.5%) reported having less than 3 years of job experience. The second highest score was 3 - 5 years, with 15 respondents (34.88%), followed by 5 - 10 years, which received 4 (9.3%) responses. Finally, out of the 43 responses, 1 (2.33%) reported having more than 10 years of work experience. It can be concluded that the majority of respondents are fresh graduates, and half of them have experience in construction projects.

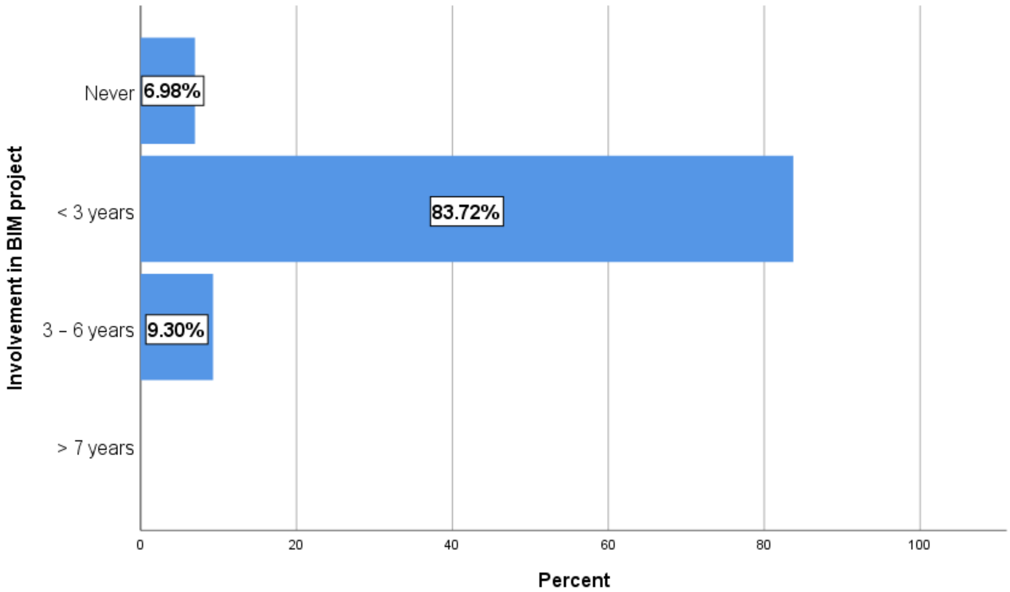

Figure 4.3: Involvement in BIM Project.

Additionally, the respondents were asked about their years of involvement in BIM projects. Figure 4.3 shows that the largest number, 36 respondents (83.72%), had less than 3 years of involvement in BIM projects. The second highest score was 3 - 6 years, with 4 respondents (9.3%). It can be concluded that the majority of respondents are still new to involvement in BIM projects.

Factors Affecting Construction Labor Productivity

In the construction industry, productivity is the most important factor as it encourages cost savings and efficient resource utilization. It is the most critical concern in both developed and developing countries (Tahir et al., 2015). According to Mahamid and Aichouni (2013), labor productivity is an important factor in project success but can be influenced by several unexpected factors. These factors can include labor, materials, tools and equipment, construction processes, politics, financing, and the environment. Poor labor productivity is one of the biggest causes of cost and time overruns in construction projects. Therefore, this element should be given special attention in the construction sector.

Table 4.1
Ranking Group of Factors Affecting Construction Labor Productivity

Groups	**Mean**	**Rank**
External factors	4.19	1
Management factors	4.17	2
Technical and technological factors	4.14	3
Human/labour factors	4.08	4

The findings of the ranking of factors affecting construction labor productivity, as presented in Table 4.1, provide valuable insights into the relative importance of different factor groups. The external factors group emerges as the top-ranking group, with a mean value of 4.19, indicating its significant influence on labor productivity. Following closely behind is the management factors group, which is rated second with a mean value of 4.17. This highlights the crucial role of effective management practices in optimizing productivity on construction sites. The technical and technological factors group ranks third, with a mean value of 4.14, underscoring the importance of leveraging advanced technologies and tools to enhance productivity.

Interestingly, the human/labor factors group ranks fourth, with a mean value of 4.08, which may come as a surprise given the commonly recognized importance of skilled labor in construction projects. In contrast to other studies where skilled labor ranked higher, the factors "clarity of instructions and communication on the site" and "leadership and efficiency in site management" take the top positions in the overall ranking of factors affecting construction labor productivity. This finding highlights the critical role of effective communication and strong leadership in driving productivity gains on construction sites.

However, it is worth noting that skilled labor remains an important aspect within the human/labor factors group. Other studies have emphasized the significance of skilled labor, with experience being a key factor contributing to productivity growth. For instance, Hiyassat et al. (2016) found that experience had a direct relationship with productivity, as productivity increases with greater experience. Skilled labor can be further classified into two categories: "shortage of experienced labor" and "lack of labor experience." The availability of trained and experienced labor directly affects construction productivity. According to Jarkas and Bitar (2012), unskilled labor is associated with poor outputs, high inputs, and increased costs. Their work may often face rejection by the supervision team, leading to rework, reconstruction, or repairs, which are not only time-consuming but also costly. In contrast, experienced workers possess a range of intellectual talents, practical problem-solving abilities, and high technical and motor skills, all contributing to higher productivity, reduced labor costs, and improved quality outputs.

The findings suggest that while human/labor factors rank fourth overall, specific aspects within this group, such as effective communication and leadership, hold significant potential to positively impact productivity. Therefore, it is important to focus on addressing these specific factors to enhance labor productivity in construction projects. By fostering clear communication channels and promoting efficient site management practices, construction firms can harness the full potential of their human resources and drive productivity gains. Overall, these findings emphasize the complex interplay between various factor groups in influencing construction labor productivity. While external and management factors hold prominent positions in the ranking, the significance of skilled labor within the human/labor factors group should not be overlooked. By understanding and effectively managing these factors, construction industry stakeholders can make informed decisions to optimize labor productivity and improve project performance.

Major BIM-Related Factors Affecting Construction Project Performance

In Section C of the questionnaire survey, respondents were asked to rank the Likert Scale from 1 to 5 (Strongly Disagree to Strongly Agree) to share their opinions on five major BIM-related factors affecting construction project performance. These factors were categorized into human factors, management factors, project factors, project performance, and external factors.

Table 4.2
Ranking Category of Major BIM-Related Factors Affecting Construction Project Performance

Category	Mean	Rank
Project performance factors	4.21	1
Project factors	4.16	2
Human factors	4.16	2
External factors	4.13	3
Management factors	4.12	4

Table 4.2 presents the results of the ranking of the major BIM-related factors affecting construction project performance. Overall, the data collected from the questionnaire survey and literature review synthesis indicate that most respondents emphasized the importance of project performance factors as the major BIM-related factors affecting construction project performance. The attribute associated with affecting construction project performance ranked first with a mean value of 4.21. The next two group factors demonstrated the same highest mean value of 4.16, indicating that most respondents feel that the major BIM-related factors affecting construction project performance are project factors and human factors.

Project factors encompass characteristics such as 3D modeling/design, 4D modeling/construction activity scheduling, 5D modeling/material take-off/cost estimates, improved coordination of construction methods, improved predictability of project outcomes, enhanced conflict detection and modification for changes in design, and safe and secure construction methods. Previous studies by Enegbuma and Ali (2011) have shown that BIM selection and implementation improve construction project performance, resulting in various advantages for infrastructure projects. Enhanced drawing quality was identified as a key advantage of BIM adoption. Furthermore, BIM can effectively identify potential conflicts and avoid drawing modifications throughout the design process (Ibrahim & Rashidi, 2014).

For human factors, attributes associated with this component include the lack of BIM users on the project, limited or no previous experience working with other companies on BIM projects, lack of interoperability between teammates' BIM software, lack of experienced professionals to manage BIM tools, and social and habitual resistance to change. These characteristics are seen as obstacles to BIM implementation and use in construction projects. According to Chien, Wu, and Huang (2014), the most common risk factors at all levels include a lack of accessible trained individuals and insufficient project experience. Additionally, with a mean value of 4.13, external factors rank third. The BIM-related factors directly associated with external factors include the high cost of BIM training, the lack of an enabling environment (government policy and legislation), a lack of BIM guidelines and standards, the expensive demand for BIM technology, the lack of insurance applied to BIM implementation, and the lack of a standard form of contract for BIM implementation. Previous studies by Rogers et al. (2015) have shown that financial and legal barriers (such as lack of insurance applicable to BIM implementation and lack of an enabling environment), as well as technological barriers (such as the high cost of BIM training and BIM technology), are obstacles to BIM implementation.

Lastly, the management factors category ranks last with a mean value of 4.12. Attributes associated with this group include improved construction project management, enhanced constructability, reduced time spent resolving conflicts, improved operations, maintenance, and facility management, simplified product transfer, accelerated regulatory approval, advanced stakeholder communication, and improved project data management. Previous research by Noor et al. (2018) has shown that these BIM-related elements improve building performance and quality. With BIM implementation, facility managers can access product specifications, warranties, product lifetime, maintenance controls, replacement pricing, installation and repair processes, and even place orders for replacements by simply clicking on a link for any equipment or fixture.

Conclusion

In conclusion, this study examined the impact of Building Information Modelling (BIM) implementation on labor productivity in Penang's construction industry. The findings underscore the positive influence of BIM adoption on labor productivity and project performance. Through an analysis of professional construction players' responses, including architects, consultants, and contractors involved in construction projects, several key factors affecting construction labor productivity were identified. Notably, "clarity of instructions and communication on the site" and "leadership and efficiency in site management" emerged as top-ranking factors within the human/labor category. These findings highlight the significance of effective communication and strong leadership in optimizing labor productivity. Furthermore, the study explored major BIM-related factors affecting construction project performance. The results indicated that project factors, such as 3D modeling/design and improved coordination of construction methods, along with human factors like the availability of experienced BIM users and interoperability between teammates' BIM software, play crucial roles in enhancing project performance. The significance of this study lies in its contribution to the construction industry's understanding of BIM implementation and its impact on labor productivity. By shedding light on the benefits of BIM adoption, this research provides valuable insights for construction firms in Penang, empowering them to make informed decisions regarding its implementation. Additionally, this study contributes to the broader body of research on BIM in Malaysia, paving the way for further advancements in construction practices. While this study has yielded valuable findings, it is important to acknowledge its limitations. The response rate of 61% and the focus on construction firms in Penang restrict the generalizability of the results. Future research should consider expanding the sample size, encompassing a broader geographical scope, and involving diverse stakeholders to enhance the study's external validity. Moreover, exploring additional benefits derived from BIM utilization beyond labor productivity would provide a more comprehensive understanding of its potential impact on construction projects. In conclusion, this study highlights the positive effects of BIM implementation on labor productivity in Penang's construction industry. As Malaysia continues to embrace digital transformation, further research addressing the identified limitations and investigating the multifaceted benefits of BIM adoption will contribute to the advancement of construction practices, fostering sustainable growth in the industry.

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