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BIM's Role in Indonesia's Green Buildings: Benefits, Challenges, and Stakeholder Preferences

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Abstract

Green building standards have become mandatory in Indonesia's construction sector, driving environmental benefits while also adding complexity to the construction process. In response, the adoption of Building Information Modeling (BIM) in green buildings has increased; however, its applications and impact are not yet fully understood within the industry. This study aims to identify the benefits and challenges of BIM in GB projects and analyze their impact on stakeholder interest using a mixed-methods approach. The qualitative phase identified 20 benefits and 19 challenges, followed by a quantitative analysis yielding 3 benefit and four challenge factors. Regression results show that "Improvement of Project Sustainability Performance" and "Ease of Construction Visualization" significantly drive stakeholder interest. These findings reinforce the BIM Fields theory, highlighting that BIM's value extends beyond technology to include critical process and policy elements, aligning well with the GreenBIM Triangle for real-world application. However, further analysis is needed to strengthen the findings and optimize the integration of process and policy considerations to enhance BIM adoption.

INTRODUCTION

The construction sector is a key driver of economic growth, contributing 9.86% to Indonesia's GDP in 2023 (Badan Pusat Statistik, 2023). However, it also poses environmental challenges, responsible for 37% of global carbon emissions and 34% of global energy consumption (United Nations Environment Programme, 2024). In response, Indonesia has adopted green building principles, including Greenship from the Green Building Council Indonesia (GBCI) and the government's Green Building Performance Assessment System, as outlined in Minister of Public Works and Housing Regulation No. 21 of 2021.

Green buildings play a crucial role in reducing construction's environmental impact but often add complexity due to numerous sustainability criteria (Venkataraman & Cheng, 2018). In Indonesia, green building adoption has been slow (Kadek et al., 2021; Permana et al., 2023), with less than 5% of buildings meeting green standards (Ruliyanta et al., 2022).

Implementing green buildings necessitates the integration of advanced technologies to support sustainable construction practices (Cao et al., 2022; Oduyemi et al., 2017; A. M. Raouf & Al-Ghamdi, 2019; Rathnasiri & Jayasena, 2019; Wu & Issa, 2015). Therefore, green buildings require technology like Building Information Modelling (BIM), which enhances efficiency, streamlines workflows, and improves collaboration. (Heryanto et al., 2020).

Green BIM, the integration of BIM with green building principles, has gained significant attention for its ability to enhance environmental performance by optimizing energy use, reducing waste, and improving resource management (Carvalho et al., 2020; Ibrahim & Mohd, 2022; Lim et al., 2021; Mardhiyana, 2023; Ohueri et al., 2022). In Indonesia, this approach is supported by Government Regulation No. 16 of 2021 and Minister of Public Works and Housing Regulation No. 9 of 2021 which provide guidelines for sustainable construction and indirectly emphasize BIM's critical role in achieving green building standards (Di Gaetano et al., 2023; Ikudayisi et al., 2022; Maltese et al., 2017; A. Raouf & Al-Ghamdi, 2019; Zhang et al., 2019).

Despite mandates for green buildings and BIM, awareness and understanding of GreenBIM, especially for energy analysis, remain limited in Indonesia, with only 13.3% of stakeholders using it frequently (Subagio et al., 2022). Susanti et al. (2023) further highlights that while BIM awareness reaches 70%, actual implementation is low (38%) and mostly confined to large state projects due to unclear regulations.

Despite numerous studies on BIM and green building integration, awareness of GreenBIM's benefits and challenges remains limited among many stakeholders (Djokoto et al., 2014; Kineber & Hamed, 2022; Y. Mohammed et al., 2023). Understanding these factors is essential for effective adoption, as they directly influence the success of sustainable construction (Adekunle et al., 2023). However, research specifically addressing how GreenBIM’s benefits and challenges shape stakeholder interest and decision-making is still scarce, particularly in the Indonesian context (Ibrahim & Mohd, 2022).

To address this gap, this study aims to explore the benefits, challenges, and adoption preferences of GreenBIM from the perspective of key stakeholders, including construction professionals, students, and academics who are familiar with both BIM and green building principles. Using a cause-and-effect analysis framework, the study will assess how these factors influence stakeholders' interest in and willingness to adopt GreenBIM, providing insights for policy-making and project planning to promote sustainable construction at various levels.

LITERATURE REVIEW

Green buildings refer to structures that meet technical building standards and demonstrate significant measurable performance in energy, water, and resource conservation (Minister of Public Works and Housing Regulation No. 21 of 2021). These outcomes are guided by green building principles across all lifecycle stages, including BIM integration, for efficient and collaborative planning, design, and management.

BIM is a system that facilitates efficient and collaborative planning, design, and management of buildings. The integration of BIM in green building projects, often referred to as GreenBIM. According to previous studies, various benefits can be gained from the implementation of GreenBIM in Indonesia, such as improved building digitization, increased productivity and reduced errors, cost-effectiveness of projects, enhanced asset lifecycle management, and support for sustainability awareness. However, GreenBIM still faces many challenges, including low awareness of BIM, a lack of competent practitioners, and limited support in terms of education and government incentives. In addition, low client demand and the perception that BIM adds extra workload also hinder the adoption of GreenBIM (Zhabrinna et al., 2018; Ekasanti et al., 2021; Murti & Muslim, 2023).

To gain a deeper understanding of BIM’s role in green building projects, it is important to examine its key domains. Succar (2009) introduces the concept of BIM Fields, which consists of three interrelated components: process, technology, and policy. This framework serves as a foundational reference for assessing BIM maturity and delineating its scope. In this study, the categorization is adopted to provide a more comprehensive understanding of BIM implementation, particularly in the context of GreenBIM. The process field refers to the coordinated work activities performed over time and across locations to achieve project goals, involving stakeholders such as architects, engineers, and developers in generating BIM outputs. The technology field pertains to the application of scientific and technical knowledge, primarily through the development and use of software and hardware tools that support modeling and simulation. Lastly, the policy field encompasses the rules, regulations, and guidelines that shape decision-making, typically established by governmental institutions, professional bodies, and academia.

The application of BIM in green buildings is further explored in the GreenBIM Triangle proposed by (Lu et al., 2017; Mohammed, 2020). This concept highlights the relationship between BIM, green buildings, and project phases. The GreenBIM Triangle identifies key BIM attributes, including Visualization**,** Analysis and Simulation**,** Document Management**,** Database Integration and Decision-Making**.**

These attributes enable detailed assessments of green projects, covering aspects like energy consumption, emissions, natural and artificial lighting, ventilation, acoustics, water usage, materials, and waste management (Lu et al., 2017; Mohammed, 2020). Therefore, this theory was selected to define the subcategories because its framework offers a more practical and context-specific approach to understanding BIM in green building projects, making its suitable for capturing real stakeholder experiences, unlike broader models such as Succar’s (2009).

The integration of these frameworks supports the research objective by enabling a structured exploration of stakeholder perceptions on GreenBIM. Succar’s (2009) domain model offers a strategic categorization, while the operational subcategories from Lu et al. (2017) and Mohammed (2020) capture practical, context-specific experiences.

Together, they provide a comprehensive lens to identify the benefits and challenges of BIM across process, technology, and policy dimensions in green building projects.

METHODS

This study adopts a mixed-methods approach to investigate the role of BIM in Indonesia's green building sector, structured in two sequential phases. The first phase is exploratory, involving the collection of qualitative data through open-ended questionnaires. Applying grounded theory and content analysis, this stage identifies key benefits and challenges of BIM based on stakeholder perceptions, resulting in a set of variables and subcategories for further examination. The second phase is explanatory, utilizing a closed-ended questionnaire to collect quantitative data. It assesses the influence of the identified variables on stakeholders' BIM adoption preferences using Principal Component Analysis (PCA), factor analysis, and multivariate regression. Each phase serves a distinct purpose, exploration versus explanation; and employs different data types and analytical techniques. By combining qualitative insights with quantitative validation, this two-stage design offers a comprehensive understanding of BIM's impact, balancing depth of perspective with generalizability of findings.

First Stage Study

The first phase of data collection was conducted by distributing an open online questionnaire using a non-random sampling method with a purposive sampling technique. The questionnaire in the first stage was focusing on two main constructs:

1. Respondent Background and Familiarity with BIM and green buildings.
2. Perceived Benefits and Challenges of BIM in Green Buildings; to explore stakeholder views on how BIM supports or hinders green building implementation.

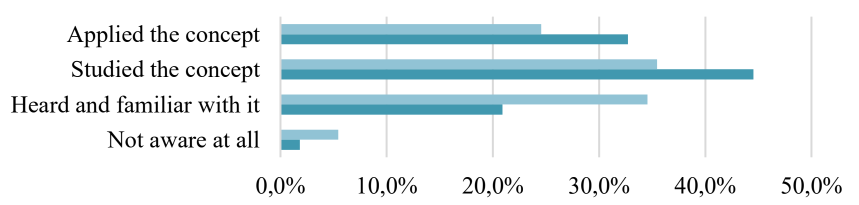
Example of questions from the online questionnaire can be seen in Table 1.

Table 1. Sample of Open-ended Questions

Attributes	Question
GreenBIM's Benefits	What are the benefits of BIM in implementing green building principles? *Open coding*
GreenBIM's Challenges	What are the main challenges that might be faced in implementing BIM in green buildings? *Open coding*

Data collection through the qualitative phase of the questionnaire was conducted from February 28, 2024, to March 21, 2024, yielding 110 respondents who were filtered based on their roles as construction stakeholders. Respondents represented a wide range of roles and experiences: construction professionals such as architects (29), contractors (13), construction management consultants (5), and government representatives (24); architecture and civil engineering students (28); academics (3); and other fields such as developers, green building assessors, and more (8).

The respondents' work experience ranged as follows: 0–2 years (32 respondents), 2–5 years (34 respondents), and more than 5 years (44 respondents). Additionally, the respondents' background knowledge leaned more toward studying and implementing green buildings than BIM. The respondents' level of involvement with BIM and green buildings is provided in Fig. 1.



	Not aware at all	Heard and familiar with it	Studied the concept	Applied the concept
BIM	5,45%	34,55%	35,45%	24,55%
Green	1,8%	20,91%	44,55%	32,73%

Fig. 1. Respondents' Involvement with BIM and Green Building
Source: Authors

Qualitative data were analyzed using content analysis in the form of open and axial coding, following the grounded theory approach(Glaser & Strauss, 1967):

1. Open coding: Identifying keywords and initial codes directly from responses.
2. Axial coding, consists of:
   a. Subcategory grouping: using inductive-deductive logic, referring to but also expanding beyond prior literature (Lu et al., 2017; Mohammed, 2020).
   b. Main category classification: using deductive coding based on BIM Fields (Succar, 2009).

Content analysis was chosen for its ability to interpret textual data and generate variables from a wide range of stakeholder inputs (Syafrina et al., 2018). The resulting output was a set of structured variables and categories representing the core benefits and challenges of BIM in green buildings, which became the foundation for the second phase.

Second Stage Study

The second phase of data collection was conducted through an online questionnaire distributed openly. This phase featured a closed-ended questionnaire with 3 main constructs,:

1. Respondent Background and Familiarity with BIM and green buildings;
2. Perceived Benefits and Challenges of BIM in Green Buildings;
3. Stakeholder Preference for BIM Use in Green Buildings.

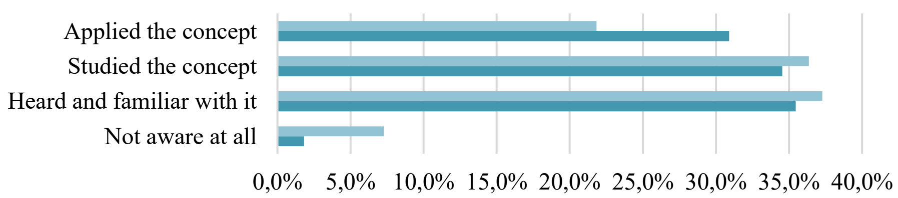
Example of questions from the online questionnaire can be seen in Table 2.

Table 2. Sample of Closed-ended Questions

Attributes	Scale
GreenBIM's Benefits	To improve the efficiency of time, cost, and quality in green building projects. 1 2 3 4 5 6 7 8 9 10 Strongly disagree Strongly agree
GreenBIM's Preference	Based on your understanding of the benefits and challenges of implementing GreenBIM, how high is your interest in using BIM for green building construction? 1 2 3 4 5 6 7 8 9 10 Strongly disagree Strongly agree

The second-phase questionnaire was distributed from April 27, 2024, to May 16, 2024, gathering responses from 113 participants who were different from the respondents in the first phase and who were filtered based on their roles as construction stakeholders. These respondents represented diverse construction industry roles, including architects (17), contractors (11), construction management consultants (5), government representatives (41), students (27), and others from fields such as private sector professionals and entrepreneurs (12). Respondents' work experience varied, with the majority having over 5 years (61 participants), followed by 2–5 years (19 participants) and 0–2 years (33 participants).

In this phase, respondents had slightly more experience applying green building principles compared to BIM. However, more respondents had studied BIM than those who had studied green building principles. Fig 2 summarizes respondents' understanding and involvement with BIM and green buildings.



	Not aware at all	Heard and familiar with it	Studied the concept	Applied the concept
Level of Understanding BIM	7,3%	37,3%	36,4%	21,8%
Level of Understanding Green	1,8%	35,5%	34,6%	30,9%

Fig. 2. Respondents' Understanding with BIM and Green Building
Source: Authors

The data that has been collected was then analyzed through the following three stages (Gniazdowski, 2021; Rodhiya et al., 2023) and were conducted using JMP Pro 16 software:

1. Principal Component Analysis (PCA): to filter variables and determine how many principal components significantly explain the variance in the GreenBIM benefits and challenges data;
2. Factor Analysis (FA): to uncover the latent factors that explain the relationships among variables; and
3. Multivariate Regression Analysis: to establish the cause-effect relationship between the variables. In this research, the benefits and challenges of GreenBIM represent the causes, while stakeholder preferences represent the effects. The assumptions will be checked with Residual Normality using Q-Q plot, Multicollinearity using VIF values, and Homoscedasticity Test using Predicted Values vs Residual Plot.

RESULTS AND DISCUSSION

Benefits and Challenges of BIM in Green Buildings

To successfully implement BIM in green building projects, construction stakeholders must understand its benefits and challenges. This understanding enables them to identify potential areas for improvement and develop strategies to maximize BIM's advantages.

In the first phase of the questionnaire, respondents provided open-ended answers about the benefits and challenges of using BIM in green buildings. Example of their responses include:

> "BIM facilitates the planning process by improving time and construction management, allowing human and natural resources to be used more efficiently." *(Female, Architect/Planner, explaining BIM's benefits in green buildings*).

The varied responses from respondents were then analyzed based on keywords using open and axial coding. The identified variables were subsequently grouped into subcategories and categories based on theories from previous journals, specifically the theory related to BIM's key attributes in GreenBIM Triangle according to (Lu et al., 2017; Mohammed, 2020) and the BIM Fields defined by (Succar, 2009).

Thus, the results of the inductive coding of variables were grouped into subcategories using the inductive-deductive coding method based on the theory of BIM's key attributes, because other subcategories were found beyond the factors mentioned in the key attributes of BIM. Meanwhile, the subcategories were then further grouped into pure categories from the BIM fields theory because it has a broader basic structure that can be used to group various elements or factors in the analysis, resulting in deductive coding statement groups categorized into benefits and challenges, as shown in Tables 3 and 4 below.

Table 3. BIM's Benefits in Green Buildings

Variables Source: Processed Questionnaire Data (Inductive Coding)	F	Subcategories Source: Mohammed, A. B. (2020); Lu, Y., et al. (2017) (Inductive-Deductive Coding)	F	Categories Source: Succar (2009) (Deductive Coding)	F
Knowledge and skills improvement	2	Knowledge, skills, and innovation improvement	4	Process	83
Contribution to innovation development	2				
Increased time, cost, and quality efficiency	14	Increased green building project performance	70		
Improved ease of green building project phases execution	31				
Easier monitoring, control, and evaluation	13				
Improved project accuracy	10				
Reduced construction process risks	2				
Easier collaboration and coordination	6	Communication and collaboration ease	9		
Easier decision-making	3				
Easier 3D modeling	11	Visualization ease	16	Technology	79
Easier work drawing visualization	3				
Easier construction process digitalization	2				
Easier data integration	8	Ease of data integration and management	15		
Easier data management	5				
Increased data accuracy	2				
Improved energy efficiency	8	Ease of sustainable analysis and simulation	48		
Improved resource efficiency	2				
Easier building performance analysis	29				
Easier building simulation	9				
Easier green building rating assessment	4	Green building standards compliance using BIM	4	Policy	4

Table 4. BIM's Challenges in Green Buildings

Variables Source: Processed Questionnaire Data (Inductive Coding)	F	Sub-categories Source: Mohammed, A. B. (2020); Lu, Y., et al. (2017) (Inductive-Deductive Coding)	F	Categories Sumber: Succar (2009) (Deductive Coding)	F
Limited knowledge and skills	35	Limited knowledge and skills	35	Process	94
Limitations of BIM technology tools	10	Complexity in project processes and management	43		
Time required for BIM adoption in green buildings	4				
High initial BIM implementation costs	16				
Complexity of BIM adoption throughout the project lifecycle	10				
Reluctance to adapt work systems/culture for BIM in green buildings	3				
Low significance of BIM's impact on green buildings	4	Disconnection between BIM and green buildings	9		
Organization's failure to involve construction stakeholders in BIM and green building use	5				
Need for organizational commitment to collaborate using BIM for green buildings	6	Commitment to coordination and collaboration through BIM	8		
Complexity in monitoring and evaluation processes	2				
Difficulty in data integration and development	10	Complexity in data integration and management processes	16	Technology	24
Differences in programs and formats for data integration	2				
Difficulty in data management and inventory control	4				
Complexity in simulating green building principles	3	Complexity in sustainability analysis and simulations	6		
Difficulty in analyzing green building performance	3				
BIM modeling complexity	2	Complexity in the visualization process	2		
Lack of regulations/standards related to BIM for green buildings	5	Limited program and regulations	11	Policy	11
Conflicting regulations/standards	1				
Lack of training on BIM for green buildings	5	Lack of trainings			

The measurable variables from the first stage of this study were then reconfirmed through the second stage of research, which required respondents to assess the level of each variable based on their understanding. It is important to note that the respondent group in the second stage was different from the group in the first stage.

Table 5. The latent variables from the BIM benefit's factor analysis with varimax rotation 3 main components

Measured Variables	Improvement of Project Sustainability Performance	Optimization of Data Management and Collaboration	Ease of Construction Visualization
Mean	**8.256**	**8.361**	**8.460**
Cronbach's α	**0.939**	**0.903**	**0.799**
Eigenvalue	**5.993**	**4.210**	**3.278**
Reduced construction process risks	0.765	0.282	0.162
Improved resource efficiency	0.759	0.412	0.060
Easier building performance analysis	0.753	0.362	0.215
Improved energy efficiency	0.660	0.546	0.086
Improved project accuracy	0.656	0.358	0.335
Increased contribution to innovation development	0.653	0.111	0.084
Increased time, cost, and quality efficiency	0.647	0.154	0.447
Improved knowledge and skills	0.644	0.139	0.373
Easier green building rating assessment	0.629	0.481	0.183
Easier monitoring, control, and evaluation	0.619	0.236	0.357
Improved ease of green building project phases execution	0.580	0.238	0.510
Easier building simulation	0.556	0.259	0.511
Easier data integration	0.196	0.815	0.255
Easier data management	0.386	0.812	0.193
Increased data accuracy	0.377	0.720	0.257
Easier collaboration and coordination	0.243	0.672	0.331
Easier decision-making	0.459	0.515	0.427
Easier 3D modeling	0.129	0.284	0.823
Easier work drawing visualization	0.281	0.242	0.816
Easier construction process digitalization	0.137	0.490	0.500

The data obtained from the respondents regarding the benefits of BIM for green buildings were processed using Principal Component Analysis (PCA), resulting in three main factors with eigenvalues greater than 1. These eigenvalues indicate that these factors can explain most of the information or variation in the data. These three factors were also supported by relatively high average responses from stakeholders, ranging from 8.2 to 8.4 on a scale of 10, as well as Cronbach's α values above 0.7 for each factor, indicating a good level of data reliability.

Based on the characteristics and keywords of the variables, these three factors were then analyzed as: 'Improvement of Project Sustainability Performance,' 'Optimization of Data Management and Collaboration,' and 'Ease of Construction Visualization.' This shows that these three aspects are the main benefits perceived or expected by the respondents in using BIM for green buildings, as shown in Table 5.

Meanwhile, the data obtained from respondents regarding the challenges of BIM in green buildings was also processed using PCA, resulting in 4 main factors with eigenvalue values greater than 1. These four factors also had relatively high average perception scores from the respondents, ranging from 6.6 to 7.8 on a scale of 10. Additionally, the Cronbach's α values for the four factors were quite good, although the 'Regulatory and Standard Challenges' factor was slightly below 0.7, at 0.683, its reliability was still acceptable.

Based on the characteristics and keywords of the variables, these can be categorized as the factors of 'Organizational and Data Management Challenges,' 'Technology and Green Principles Implementation Challenges,' 'BIM Adoption Infrastructure Challenges,' and 'Regulatory and Standards Challenges.' Based on the data obtained, the BIM challenge with the most variation lies within the 'Organizational and Data Management Challenges' factor, as shown in Table 6.

Table 6. The Latent Variables from the BIM Benefit's Factor Analysis with Varimax Rotation 4 Main Components

Measured Variables	Organizational and Data Management Challenges	Technology and Green Principles Imple-mentation Challenges	BIM Adoption Infra-structure Challenges	Regulatory and Standards Challenges
Mean	**7.836**	**6.688**	**7.460**	**7.438**
Cronbach's α	**0.919**	**0.857**	**0.789**	**0.683**
Eigenvalue	**5.583**	**3.668**	**2.145**	**1.678**
Limited knowledge and skills	0.785	0.195	0.074	0.114
Lack of training on BIM for green buildings	0.782	0.156	0.289	-0.024
Differences in programs and formats for data integration	0.781	0.300	-0.058	0.208
Complexity of BIM adoption throughout the project lifecycle	0.756	0.182	0.212	-0.105
Difficulty in data integration and development	0.755	0.427	-0.022	-0.084
Reluctance to adapt work systems/culture for BIM in green buildings	0.749	-0.039	0.168	0.318
Need for organizational commitment to collaborate using BIM for green buildings	0.672	-0.004	0.599	-0.128
Complexity in monitoring and evaluation processes	0.646	0.175	-0.157	0.367
Difficulty in data management and inventory control	0.633	0.602	-0.111	-0.039
Lack of training	0.611	0.013	0.189	0.243
Difficulty in simulating green building principles	0.175	0.833	0.170	0.160
Difficulty in analyzing green building performance	0.055	0.788	0.129	0.325
Time required for BIM adoption in green buildings	0.303	0.713	0.272	-0.024
BIM modeling complexity	0.231	0.634	0.434	0.093
Low significance of BIM's impact on green buildings	0.071	0.560	0.139	0.457
High initial BIM implementation costs	0.123	0.284	0.818	0.157
Limitations of BIM technology tools	0.043	0.304	0.693	0.301
Lack of regulations/standards related to BIM for green buildings	0.117	0.211	0.248	0.784
Conflicting regulations/standards	0.430	0.387	0.094	0.459

Thus, the latent variables obtained reveal three main factors of BIM benefits in green buildings and four main factors of BIM challenges in green buildings. These seven factors represent the benefits and challenges that stakeholders would encounter when implementing BIM in green buildings.

Based on the BIM fields identified in the benefits and challenges of BIM for green building projects in this first stage of the study, the findings highlight that GreenBIM also requires the involvement of process and policy domains in its implementation. In fact, process-related benefits, such as Improvement of Project Sustainability Performance factors; emerged as the most significant. This further demonstrates the necessity of the interconnection between BIM attributes, green attributes, and project phases as outlined in the GreenBIM Triangle, as they reflect real outcomes of interdisciplinary collaboration and coordinated project stages in actual practice.

Significance of BIM Benefits and Challenges for Green Buildings on Stakeholder Preferences

In addition to measuring the level of each variable from the qualitative stage, the second stage of the research also uncovered the level of preference among respondents to use and recommend BIM for green buildings based on the benefits and challenges outlined. From the 113 quantitative data collected, it was found that the average interest/preference in using and recommending BIM for green buildings reached a score of 8.3 out of 10. This indicates that respondents with a background related to BIM and green buildings have a very high interest in using and recommending BIM for green buildings. However, the factors of benefits and challenges that influence this interest level are shown through a cause-and-effect analysis.

The cause-and-effect relationship is defined through multivariate regression analysis, resulting in an RSq data value of 0.45 and a model P-Value of < 0.0001. This means that the regression model represents approximately 45% of the data, and the model is considered highly significant due to its P-Value being close to zero. Variance Inflation Factor (VIF) are also included to detect multicollinearity in the regression model, and it was found that all variables are ideal and acceptable. The parameter estimates are shown in the Table 7.

Table 7. Multivariate Regression Analysis of BIM Benefits and Challenges for Green Buildings on the Preference to Use and Recommend BIM for Green Buildings

Term	Estimate	Std Error	t Ratio	Prob>|t|	Significance Level	VIF
Intercept	**19.206.354**	**0.941558**	**2.04**	**0.0439**		
Improvement of Project Sustainability Performance	0.6412602	0.164757	3.89	0.0002	Highly Significant	3.01
Optimization of Data Management and Collaboration	0.0069484	0.161862	0.04	0.9658	Not Significant	3.23
Ease of Construction Visualization	0.2639368	0.117945	2.24	0.0273	Significant	2.10
Organizational and Data Management Challenges	0.1310588	0.098865	1.33	0.1878	Not Significant	1.61
Technology and Green Principles Implementation Challenges	-0.118412	0.093635	-1.26	0.2088	Not Significant	2.19
BIM Adoption Infrastructure Challenges	-0.109934	0.082625	-1.33	0.1862	Not Significant	1.80
Regulatory and Standards Challenges	-0.079767	0.083131	-0.96	0.3395	Not Significant	1.66

The main factors positively influence the effect variable

p<0,1 Small significant; p<0,05 Significant; p<0,001 Highly significant
VIF < 5 Ideal and Acceptable; 5 < VIF < 10 Moderate Multicollinearity; VIF>10 High Multicollinearity

Based on Table 7, it can be observed that not all the benefits and challenges of BIM in green buildings have a significant and positive relationship with the interest/preference in using BIM for green buildings. For further clarification, Table 7 will be explained through the following Fig 3.

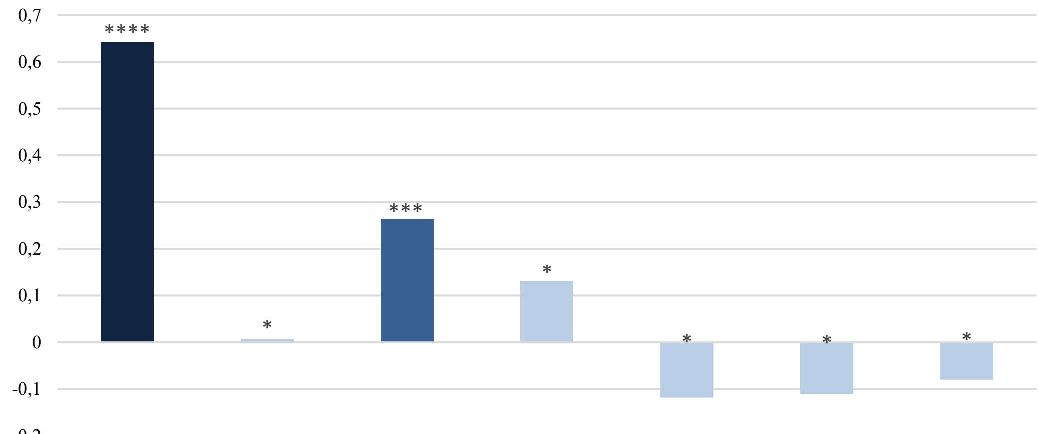
Based on Table 7 and Fig. 3, the most significant factors identified are those with a P-Value <0.001. The first is the Improvement of Project Sustainability Performance factor, with a P-Value of 0.0002 and an estimate of 0.641. This means that for every one-unit increase in this variable, the dependent variable increases by 0.641, assuming other variables remain constant. The second significant factor is Ease of Construction Visualization, with a P-Value of 0.0273 and an estimate of 0.264. This indicates that for every one-unit increase in this variable, the dependent variable increases by 0.264, assuming other variables remain constant.

Meanwhile, other factors are not considered significant due to their P-Value exceeding 0.1. Therefore, only these two main factors have a positive influence on the increasing interest/preferences of stakeholders in using and recommending BIM for green buildings, as summarized in Fig. 4.

According to Table 5, other benefits and challenges do not show a significant relationship or the analysis does not indicate a strong enough connection between the independent and dependent variables. For example, while 'Optimization of Data Management and Collaboration' benefit has a positive value, it is not significant. Similarly, 'BIM Adoption Infrastructure Challenges' factor shows a negative value, indicating that challenges in the design process slightly reduce the potential for BIM usage, but since it is not significant, it suggests that respondents do not perceive the design process as a major obstacle to using and recommending BIM for green buildings.

The significance of the 'Improvement of Project Sustainability Performance' and 'Ease of Construction Visualization' stand out as the most influential benefits. While other factors like Data Management Optimization and

Infrastructure Challenges show some effect, they are not perceived as major drivers or barriers. On the other hand, enhancing these less significant benefits and reducing adoption-related challenges could further improve interest in using BIM for green building projects.



	Improvement of Project Sustainability Performance	Optimization of Data Management and Collaboration	Ease of Construction Visualization	Organizational and Data Management Challenges	Technology and Green Principles Implementation Challenges	BIM Adoption Infrastructure Challenges	Regulatory and Standards Challenges
Estimated Value	0,6413	0,0069	0,2639	0,1311	-0,1184	-0,1099	-0,0798

P-Value: *p>0.1. Not significant; **p<0.1. Small significant; ***p<0.05 Significant; ****p<0,001 Highly significant

Fig. 3. Estimated Values and P-Value of Benefits and Challenges in Using BIM for Green Buildings on Stakeholder Preferences

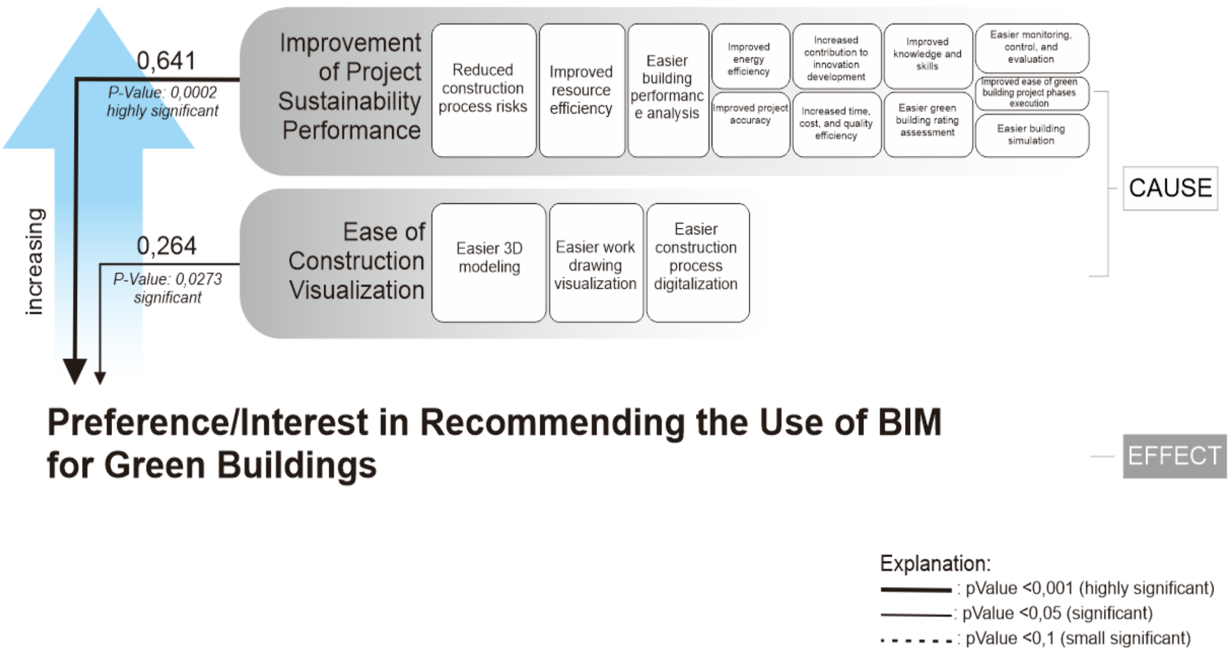


Fig. 4. Relationship between the Influence of Key Benefit Factors on the Interest/Preference in Using and Recommending BIM for Green Buildings

The results of this multivariate regression were then checked based on the assumptions of residual normality using a Q-Q plot, multicollinearity using the Variance Inflation Factor (VIF), and homoscedasticity test based on the comparison of residual and fitted values using JMP. While the VIF results are shown in Table 6, the Q-Q plot and homoscedasticity test results can be seen in Fig.5.

From Fig. 5, the residual normality test via the Q-Q plot shows that the residuals follow a normal distribution well, as the points align along the diagonal line. It ensures that the regression coefficients are unbiased and efficient, and that the resulting p-values and confidence intervals can be trusted, which ultimately supports the validity and robustness of the research findings. Table 6 also presents acceptable VIF results, with all values below 5, indicating that the independent variables are not highly correlated, ensuring stable regression coefficients.

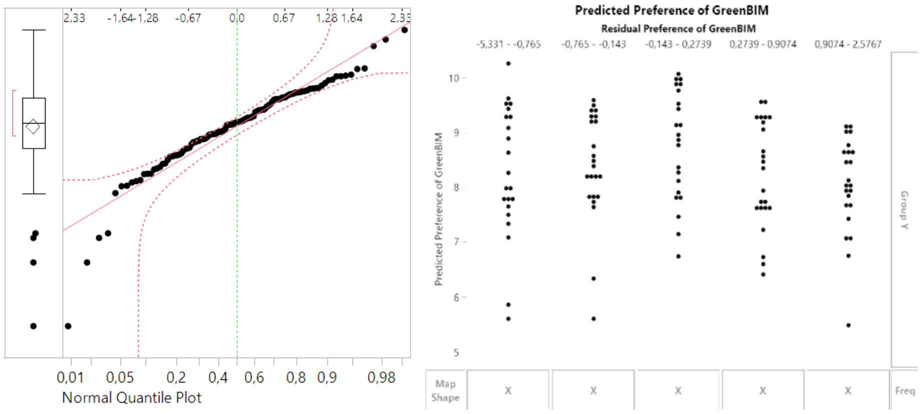


Fig. 5. Q-Q Plot (left) and Predicted Values vs Residual Plot (right)

However, the Predicted Values vs Residual Plot in Fig. 5 suggests potential heteroscedasticity, indicated by a non-random spread of residuals, which may affect the accuracy of standard error estimates. This could be due to variations in respondents' background and understanding of GreenBIM, as shown in Fig. 1 and 2. For instance, differences in GreenBIM awareness among respondents could lead to uneven response patterns, increasing the residual variance as the predicted values grow. It also noted by Schroeder et al. (2020) that heteroscedasticity often occurs in organizational studies due to differences in team composition or organizational climate.

Nevertheless, despite this indication of heteroscedasticity, the overall model remains statistically robust. The residuals follow a roughly normal distribution, while multicollinearity does not appear problematic and model's P-value is highly significant, with a value of < 0.0001, indicating strong overall model validity. These results collectively suggest that the model provides reliable parameter estimates, allowing for meaningful interpretation despite potential variance inconsistencies.

Compared to previous studies, these findings demonstrate that the integration of Succar's BIM Fields theory and the practical attributes of the GreenBIM Triangle is relevant for capturing the real-world context. For instance, the fact that "Improvement of Project Sustainability Performance" is the most significant benefit highlights that BIM's advantages extend beyond technology; it also impacts the process field, leading to valuable BIM outputs in the context of green buildings and even increasing its adoption rate. This reinforces Succar's theory, which states that BIM is not just about technology but also involves processes or systems and the policies that drive them.

When compared to the key attributes of GreenBIM in GreenBIM Triangle's theory, these findings further demonstrate how enhancing these key attributes, particularly in terms of ease of visualization; can increase the preference for using BIM in green buildings in real-world conditions.

Implications, Strategic Recommendations and Future Research

These findings reinforce the theoretical integration of Succar's BIM Fields and the GreenBIM Triangle by highlighting that BIM's value in green building projects extends beyond technology to include critical process and policy dimensions. The significance of the Improvement of Project Sustainability Performance emphasizes the importance of coordinated processes, while the prominence of Regulatory and Standards Challenges underscores the role of supportive policy frameworks. Practically, this suggests that effective GreenBIM implementation in Indonesia requires a balanced focus on technology, process coordination, and regulatory alignment to achieve both top-down and bottom-up adoption.

To support this, policymakers should establish clear, supportive regulations that not only mandate BIM use in green projects but also foster inter-organizational collaboration and data integration. Industry players are encouraged to invest in training and pilot initiatives that showcase BIM's practical benefits, especially in sustainability performance and visualization.

Nevertheless, this study has a limitation indicated by the heteroskedasticity result. Although this study demonstrates sufficient validity, with normally distributed residuals, low multicollinearity, and statistically significant P-values, the presence of heteroscedasticity warrants caution when interpreting the results, as it may lead to inaccurate standard error estimates. To address this, future research could consider using more robust statistical methods, such as Weighted Least Squares (WLS) or Generalized Least Squares (GLS), or selecting a more homogeneous sample based on experience or organizational roles to reduce variability. Future studies could also explore how less prominent attributes, such as data management and simulation, can be strengthened across different project types or stakeholder groups, as well as conduct longitudinal studies to assess how improvements in policy and process integration impact adoption over time.

CONCLUSION

The adoption of green building principles has become mandatory in the construction sector to reduce environmental impact, with BIM seen as an efficient enabler. In Indonesia, both are regulated under Government Regulation No. 16 of 2021 and Ministerial Regulations No. 21 of 2021 and No. 9 of 2021. This study explores stakeholders' understanding of the benefits and challenges of BIM in green buildings and how this relates to their interest in using and recommending it. This study also fills the knowledge gap regarding stakeholders' understanding and perspectives on the benefits and challenges of BIM in the context of green buildings in Indonesia.

Using open-ended questionnaires with qualitative coding, the study identified 20 benefit variables and 19 challenge variables related to BIM in green buildings, revealing a cause-effect link with stakeholder interest in adopting and recommending BIM, which currently has a preference score of 8.3 out of 10.

In the quantitative phase, using close-ended questionnaires with analysis methods such as PCA, FA, and multivariate regression, 3 main benefit factors and 4 main challenge factors were identified. Among them, two benefit factors, Improvement of Project Sustainability Performance and Ease of Construction Visualization; were found to have the most significant influence on respondents' interest. This indicates that the greater the perceived benefits of these two factors, the higher the interest in adopting BIM for green building projects.

These findings show that respondents are more likely to use and recommend BIM in green building projects due to its benefits for enhancing project sustainability performance. The findings also highlight several challenges that need to be addressed to increase stakeholder interest in using BIM for green buildings and, ultimately, enhance BIM adoption. If compared to the previous study, these findings also reinforce BIM Fields theory by demonstrating that BIM's value extends beyond technology to include essential process and policy aspects, while also validating the integration of this theory with the GreenBIM Triangle as a relevant approach for capturing real-world conditions; especially through the enhancement of key attributes like visualization that drive BIM adoption.

To accelerate BIM adoption in green building projects, stakeholders and the industry should be encouraged to develop supportive process and policy frameworks. However, this study acknowledges a limitation due to heteroscedasticity, and future research could address this by using more robust methods or selecting a more homogeneous sample. Additionally, future research could further explore how to strengthen less significant BIM attributes, such as data management and simulation, and conduct longitudinal studies to assess the long-term effects of policy and process integration on BIM adoption. These recommendations provided to accelerate BIM adoption in green building projects make an important contribution to the development of policies and practices within the industry.

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