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Analysis of implementation factors in the application of building information modeling (BIM) in construction projects: Enhancing disaster preparedness

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ABSTRACT
Background: Building Information Modeling (BIM) technology is game-changing in the AEC industry. BIM can significantly improve team coordination, construction productivity, project performance, and profits. The conventional construction process, where there are often conflicts between stakeholders regarding the workflow in a job, will change with the application of BIM in construction projects. In the construction sector in Indonesia, the knowledge and experience of construction service provider companies (consultants and contractors) in Indonesia needs to be studied and documented academically to enrich the body of knowledge of BIM implementation. **Methods**: The data used in this study are primary data obtained through questionnaires. The data used in this study are quantitative data processed using the Partial Least Square (PLS) method with SmartPLS 4.0 software. **Conclusion**: From the results of this study, it is concluded that the implementation factor has a significant influence on Building Information Modeling (BIM). Based on the outer model analysis of the SmartPLS 4.0 software, it is found that the greatest influence of the implementation factor relationship on Building Information Modeling (BIM) is 0.757 or it can be said that it is 75.7%. **Novelty/Originality of this article:** This study provides a unique contribution by focusing on the implementation of Building Information Modeling (BIM) in the Indonesian construction sector, particularly through the lens of construction service providers' knowledge and experience, using a robust quantitative approach with SmartPLS 4.0 to analyze the influence of implementation factors on BIM adoption.

KEYWORDS: BIM implementation; Surabaya construction; SmartPLS analysis.

1. Introduction

In the industrial era, where the virtual world is utilized as an integrated or internet-connected automation machine, namely the era of revolution 4.0 (Amarta, 2022), provides an impulse to revitalize the Indonesian industrial sector (Hatmoko & Pandarangga, 2021). This affects the development of construction services in Indonesia, as Indonesia is competitive worldwide (Amarta, 2022). By using technology in the digital 4.0 era, it will facilitate the integration of production or construction processes into digital systems. Then productivity will grow better. Today's construction world requires the ability to increase productivity (Fadhilah et al., 2022).

Building Information Modeling (BIM) technology is game-changing in the AEC industry. BIM can significantly improve team coordination, construction productivity, project

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performance, and profit (Patel et al., 2021). The physical character and functional character of a building are drawn by BIM as a digital representation (Utomo, 2019). With these digital representations, BIM stores, maintains, and shares information in the form of a cloud rather than recording it in the form of images (Aziz et al., 2022). This significantly reduces errors during the design process (Yusuf, 2018).

BIM or Building Information Modeling is a set of technologies, policy processes that all processes run in an integrated manner in a digital model, which is then translated as a 3D image (Pusdiklat SDA dan Konstruksi, 2018). Building in BIM terms means "constructing" not "building". Information is the core of BIM, which consists of 3D geometry models, non-graphical information, documents, and drawings. Modeling means the process of generating geometric models, simulating the various design phases of an asset whether structural, architectural, MEP, service functions and others (Putera, 2022).

BIM technology is the process of collecting and managing construction data throughout its lifecycle (Pusdiklat SDA dan Konstruksi, 2018). In addition, BIM is a project simulation in the form of a 3D model consisting of project components and connected to all information about project planning, design, construction, and operation (Pratama & Marzuki, 2023). BIM contains information about buildings, which helps all parties involved in the project plan, design, implement, and maintain the building and its infrastructure for all parties involved in the project (Pusdiklat SDA dan Konstruksi, 2018).

The construction process, which is usually done conventionally (Barrung & Napitupulu, 2022), the construction process is divided into 7 iterative stages, starting from planning to decommissioning (Pratama & Marzuki, 2023). Planning is a decision-making action that includes data and information and facts about activities that will be selected and will be carried out in the future (Mahapatni, 2019). Design is an advanced stage of the planning stage, which includes the design of the area and the facilities and infrastructure needed for construction implementation (Febrianti, 2022). Furthermore, construction, at this stage the portion of decision making is more in the hands of project implementers. Commissioning, at this stage the decision-making portion is more in the hands of the project implementer (Anasstasia & Utami, 2022). Utilization is the provision of digital mock-ups to the owner to organize the operation or utilization of the building. Digital mock-ups are created during the design phase and updated until the utilization phase (Pratama & Marzuki, 2023). Maintenance or maintenance in buildings is intended as a combination of technical and administrative actions, which are intended to maintain, and restore the function of the building as previously planned (Sari & Triwuryanto, 2021). And finally decommissioning, at the end of the building's service life, the main model is used as a reference in demolition. This determines the main components of the structure so that the demolition process is carried out appropriately (Pratama & Marzuki, 2023).

There are often conflicts between stakeholders regarding the workflow in a job, will change with the application of BIM in construction projects (Barrung & Napitupulu, 2022). This application needs to be done because in the world of AEC (Architectural, Engineering, and Construction), being able to complete each construction project on time is very important. Every construction project is expected to complete the project according to the scheduled time and expected budget (Tan et al., 2022).

Indonesia first implemented BIM in 2012. This shows that the implementation of BIM in Indonesia lags behind other countries. With so many projects running in Indonesia, regulations governing the implementation of BIM in Indonesia do not yet exist. BIM is only used by large-scale projects even though it is only used as a supporting force. This is supported by the level of awareness of BIM knowledge of 70% with a BIM implementation rate of 38% (Puspita & Patriotika, 2021).

The public works agency issued a BIM adoption guide in 2018 with reference to developed countries such as Singapore (Utomo, 2019). In addition, in accordance with Circular Letter number: 11/SE/Db/2021 concerning "Application of Building Information Modeling in Technical Planning, Construction, and Maintenance of Roads and Bridges at the Directorate General of Highways" the implementation of BIM must be mandatory in the type of road and bridge construction work that is development in the form of complex roads, expressways, toll roads, tunnels, and special bridges (Barrung & Napitupulu, 2022).

In the construction sector in Indonesia, the knowledge and experience of construction service provider companies (consultants and contractors) in Indonesia needs to be studied and documented academically to enrich the body of knowledge of BIM implementation (Mieslenna & Wibowo, 2023). Several studies that have been conducted previously discuss various perspectives in BIM implementation such as implementation factors, barriers, and BIM readiness. Another example is using BIM with Autodesk Revit and critical path method in project planning. Or using 3D Laser Scanner to create 3D models of cultural heritage buildings (Rani et al., 2023).

Based on this background, the application of BIM in Indonesia is low. It is necessary to analyze construction service provider companies to assess how well construction workers understand BIM technology, especially in the city of Surabaya. The Implementation factor is an important indicator as a basis for implementing BIM. Therefore, this study aims to analyze the influence of implementation factors in the application of BIM to construction service providers in Surabaya city to maximize proper implementation.

2. Methods

The research was conducted with the aim of knowing how much influence the implementation factors have on the implementation of BIM in the city of Surabaya. The data used in this study are quantitative data processed using the Partial Least Square (PLS) method to determine the magnitude of the influence of implementation factors on BIM.

The data used in this study are primary data obtained through direct questionnaire distribution, construction companies and projects, and online via Google Form. Respondents who filled out the questionnaire were construction professionals, including consultants and contractors. The questionnaire assessment in this study uses a Likert scale as follows, scale 1 = strongly disagree; scale 2 = disagree; scale 3 = neutral; scale 4 = agree; scale 5 = strongly agree.

The questionnaires that have been collected are processed using the Partial Least Square (PLS) method. Data processing with PLS is carried out using the help of Smart PLS 4.0 software. Data processing with PLS is divided into two parts, namely the Outer Model and Inner Model. Implementation factors are categorized as independent variables, namely X. To get the results of the influence of implementation factors on BIM, the test carried out is testing the outer model.

Outer model is a test carried out to evaluate the measurement model to obtain the analytical value based on specific provisions. These provisions include removing indicators that have a convergent validity value equal to or less than 0.5, conducting a test for discriminant validity, eliminating indicators with an Average Variance Extracted (AVE) value less than or equal to 0.5, and discarding indicators whose composite reliability value is less than or equal to 0.7.

The results of this study were obtained from questionnaire processing, with a description of the analysis, namely analyzing each existing implementation factor and the relationship between these implementation factors to BIM implementation. The relationship value is obtained from the convergent validity value.

3. Results and Discussion

3.1 Respondents profile

Respondents in this study are individuals who have been involved or have worked on BIM-based projects. Questionnaires were distributed to 46 construction service provider companies in Surabaya with a total of 276 questionnaires distributed. Based on a total of 276 questionnaires distributed, 92 questionnaires were returned from 28 construction service provider companies in Surabaya. The survey results show, 18 of the 92 questionnaires were obtained online via Google Form. The remaining 74 questionnaires were obtained through direct distribution to project sites or construction companies. Based on the number of questionnaires obtained, only 43 questionnaires or respondents can be used for data processing. Respondent profiles based on occupation are grouped into two, Consultants and Contractors. The profile can be seen in the following Table 1.

Table 1. Profile of respondents based on occupation

No.	Occupation	Number of Respondents	Percentage
1	Contractor	31	72%
2	Consultan	12	28%
Total of Respondents		43	100%

While the respondent profile based on position is grouped into 6, the position grouping can be seen in the following Table 2. The distribution of respondents shows that the largest group is comprised of executors (33%), followed by site managers (21%) and project managers (19%). This indicates that the majority of responses come from operational-level roles who are directly involved in field activities. The relatively smaller proportions of company directors (5%) and site engineers (7%) suggest limited representation from top-level management and technical design roles, respectively. This composition reflects a strong operational perspective in the data collected, which could be beneficial for studies focusing on implementation-level insights in project execution or construction-related fields.

Table 2. Profile of respondents based on occupation

No.	Position	Number of Respondents	Percentage
1	Company director	2	5%
2	Project manager	8	19%
3	Site manager	9	21%
4	Site engineer	3	7%
5	Executor	14	33%
6	Drafter	7	16%
Total of Respondents		43	100%

3.2 Mean and standard deviation analysis

Descriptive statistical analysis was conducted to determine the general description of the data analyzed. The results of the descriptive analysis for each indicator of the implementation factor are shown in table 3 below. All indicators show positive perceptions of BIM implementation, with the highest mean on project size (4.256) and the lowest on cost savings (3.767). This suggests BIM is seen as most beneficial for large projects, while views on cost efficiency are more moderate.

Table 3. Descriptive statistical

No.	Indicator	Mean	Standard Deviation
1	Cost savings from using BIM (X.1)	3.767	0.831
2	Improved quality of work and compliance with planned time and cost by using building models (X.2)	4.047	0.746
3	Individual understanding of the BIM (X.3)	4.093	0.830
4	Design and build improvement (X.4)	4.070	0.759
5	Synergy in the use of BIM (X.5)	3.930	0.759
6	Project duration (X.6)	3.791	1.090
7	Project size (dimensions of building construction) (X.7)	4.256	0.685

3.3 Convergent validity

In convergent validity, the relationship between indicator score and construct score is seen. The output results are shown from the outer loading value on each indicator which must be> 0.5 and with this value the indicator is declared valid for use in research. The results of the outer loading analysis from SmartPLS processing can be seen in the Table 4 below.

Table 4. Outer loading value-1

Variable	Dimension	Indicator	Loading Factor
BIM	Implementation Factors	X.1	0.380
		X.2	0.634
		X.3	0.601
		X.4	0.842
		X.5	0.709
		X.6	0.546
		X.7	0.678

In the value of indicators that do not meet the outer loading value> 0.5 are eliminated as indicators that do not meet. The outer loading value of each indicator from the second analysis can be seen in the Table 5 below. All indicators have outer loading values above 0.5, meaning they meet the validity criteria and are retained in the model. The highest loading is on X.4 (0.839), indicating it is the strongest contributor to the BIM implementation factor.

Table 5. Outer Loading Value -2

Variable	Dimension	Indicator	Loading Factor
BIM	Implementation Factors	X.2	0.656
		X.3	0.590
		X.4	0.839
		X.5	0.702
		X.6	0.561
		X.7	0.683

Based on table 5, it is known that the indicator has an outer loading value of more than 0.5. However, the AVE value in the SmartPLS analysis results does not meet the requirements so it is necessary to eliminate the indicator with the smallest value, namely the outer loading limit to be> 0.6 from each X indicator. The outer loading value of each indicator of the third analysis results can be seen in the Table 6 below.

Table 6. Outer Loading Value -3

Variabel	Dimensi	Indikator	Loading Factor
BIM	Implementation Factors	X.2	0.673
		X.4	0.839
		X.5	0.679
		X.7	0.688

Based on table 6, it is known that each indicator has an outer loading value> 0.6. So it can be said that the above indicators are good and can be used for further research analysis. In addition, the influence value is obtained for the relationship between the implementation factor and BIM. Each indicator that has a value of more than 0.6 is said to have a good relationship or can be said to have a significant influence. The greatest influence of the Implementation Factor relationship on BIM is obtained from indicator X.4 of 0.839 or 83.9%. Where indicator X.4 is an indicator of increased design and build.

3.4 Discriminant validity

Furthermore, discriminant validity testing is carried out by looking at the cross loading value. Good discriminant validity is indicated by the variable correlation value is the largest compared to other variables. The results of the cross loading calculation analysis can be seen in the table below (Table 7)

Table 7. Results of analysis cross loading

	BIM	Implementation Factors (X)
X.2	0.673	0.717
X.2	0.673	0.717
X.4	0.839	0.847
X.4	0.839	0.847
X.5	0.679	0.766
X.5	0.679	0.766
X.7	0.688	0.748
X.7	0.688	0.748

3.5 Average variance extracted (AVE) & composite reliability

Furthermore, the AVE value analysis is carried out. Variables are said to have good validity values if the AVE value is> 0.5. Based on the results of the analysis, the AVE value> 0.5 was obtained. The results of the AVE analysis are shown in the Table 8 below. All variables have AVE values greater than 0.5, indicating they meet the criteria for good convergent validity. This means the indicators reliably reflect their respective constructs.

Table 8. Value of average variance extracted (AVE)

Variable	AVE	AVE^2	Description
BIM	0.523	0.274	Valid
Implementation Factors (X)	0.594	0.353	Valid

Composite reliability of a variable is a value used to calculate its stability and consistency in measuring combined reliability. The value of Crobach's alpha and composite reliability must have a value of> 0.7 so that it is said that the variable is reliable. The results of the analysis can be seen in the Table 9 below. Based on the calculations in the table above, it can be seen that all variables have a Cronbach's alpha value and composite reliability> 0.7 and it can be said that all variables are reliable. So that the model obtained is good.

Table 9. Value of composite reliability

Variable	Cronbach's Alpha	Composite Reliability	Description
BIM	0.898	0.916	Reliable
Implementation Factors (X)	0.772	0.854	Reliable

3.6 Application of BIM in Indonesia

Building Information Modeling (BIM) has emerged as a revolutionary technology in the global construction industry and has gradually gained traction in Indonesia. Since its formal introduction by the Indonesian Ministry of Public Works and Housing (PUPR) in 2017, the application of BIM has grown in various national strategic projects. However, this growth has not been evenly distributed across all sectors of the construction industry. Research by Hatmoko et al. (2019) indicates that although a significant number of construction stakeholders in Indonesia are familiar with BIM, its utilization remains inconsistent and mostly limited to the design and planning phases. In many projects, BIM is used primarily for project simulation, 3D visualization, and design clash detection, which have proven to significantly enhance data accuracy and efficiency. Commonly used BIM software in Indonesia includes Autodesk Revit, Tekla Structures, and ArchiCAD, which support the development of integrated 3D models.

In practice, several major projects have successfully implemented BIM throughout the project lifecycle. A notable example is the construction of the Presidential Palace building in the new capital city, Nusantara, where BIM has been employed from the planning stage to facility operation. This project showcases cross-disciplinary collaboration, facilitated by BIM, which enables smooth communication and data synchronization among architects, structural engineers, and contractors. In the infrastructure sector, state-owned enterprises such as PT Waskita Karya have adopted BIM up to 7D levels, including facility management after construction. This indicates an increasing awareness of the long-term benefits of BIM—not only during construction but also in ensuring efficient operation and maintenance of built assets.

The benefits of BIM implementation in Indonesia are multifaceted. One of the most prominent advantages is the improvement of project time and cost efficiency. BIM enables early detection of design errors, minimizing rework and helping projects stay on schedule and within budget. Moreover, BIM facilitates a collaborative process among project stakeholders. By working on a shared and integrated data model, all parties can coordinate in real time, reducing miscommunication and improving overall project outcomes. In addition, BIM contributes to sustainable project development. Through its ability to simulate energy performance and material efficiency, designers are better equipped to create environmentally friendly buildings that optimize resource use.

Despite these advantages, the implementation of BIM in Indonesia faces several challenges. One major barrier is the limited knowledge and skill level of professionals in using BIM technology. Many construction workers and engineers, especially from small and medium-sized enterprises, lack comprehensive understanding and technical expertise in BIM. This issue stems from the limited availability of formal training and the fact that many academic institutions have yet to fully integrate BIM into their curricula. Furthermore, the high initial investment required for BIM software and hardware presents a significant obstacle, particularly for companies with constrained budgets. The absence of a mandatory national regulation or standard for BIM implementation further hinders its widespread adoption. Although the PUPR has issued technical guidelines, there is currently no legal obligation for BIM usage in public construction projects.

To address these challenges, several strategic efforts have been initiated. Higher education institutions in architecture and engineering are gradually incorporating BIM into their academic programs, although practical application and professional certification remain areas that need strengthening. Meanwhile, professional organizations such as INKINDO and LPJK have begun offering training sessions and workshops to improve the technical capabilities of industry professionals. There is also growing advocacy for the government to provide financial incentives and to establish clearer regulatory frameworks. Some experts have proposed the development of a national standard (SNI) specifically for BIM, which would offer structured guidelines and benchmarks for its implementation across the industry.

Overall, while the adoption of BIM in Indonesia is still in its developing stages, the potential for growth is substantial. With sustained government support, improved human capital development, and increasing awareness among industry players, BIM is poised to become a standard tool in project planning and execution throughout the country. Not only does it enhance construction accuracy and efficiency, but it also lays the foundation for a more digital, collaborative, and sustainable construction industry in Indonesia.

3.7 Implementation factors in the application of building information modeling (BIM)

The successful implementation of Building Information Modeling (BIM) is influenced by a complex set of interrelated factors that vary depending on regional context, industry readiness, organizational culture, and government support. In Indonesia, as in many developing countries, these factors play a crucial role in determining the extent and quality of BIM adoption across construction projects. One of the most significant determinants is the level of awareness and technical competence among stakeholders. BIM requires a paradigm shift from traditional 2D-based processes to a more collaborative, data-driven approach. As such, the knowledge and skill set of professionals, including architects, engineers, contractors, and project managers, are central to the implementation process. Without sufficient training and continuous professional development, the adoption of BIM tends to be superficial, limited only to visualization functions rather than full integration across all project stages (Yusof & Brahim, 2019).

Institutional support and organizational readiness also serve as critical internal factors in BIM implementation. Construction firms with strong leadership, a clear digital transformation strategy, and a commitment to innovation are more likely to invest in the necessary infrastructure and software. Moreover, companies that foster interdisciplinary collaboration and open communication channels among departments often experience smoother BIM workflows. However, in Indonesia, many small and medium enterprises (SMEs) in the construction sector face limitations in terms of budget and organizational capacity. This hinders their ability to procure BIM-compatible technology and hire or train BIM-literate personnel (Hatmoko et al., 2019). As a result, the benefits of BIM remain concentrated in large-scale projects typically managed by state-owned enterprises or multinational firms.

Another influential factor is the availability of national guidelines, legal mandates, and standardized procedures. The absence of a formal, government-enforced BIM mandate in Indonesia has resulted in fragmented implementation efforts. While the Ministry of Public Works and Housing has issued several technical guidelines promoting BIM usage, these have not yet been transformed into mandatory regulations (PUPR, 2019). Consequently, many construction companies adopt BIM only when explicitly required by clients or international partners. The lack of standardization in data formats, modeling protocols, and collaborative platforms also complicates the interoperability among project teams, thereby reducing the effectiveness of BIM implementation (Succar et al., 2013).

External support mechanisms, such as education and training programs, also play a significant role in enhancing BIM implementation. Universities and polytechnic institutions in Indonesia have only recently begun integrating BIM into their curricula. While this marks a positive shift, the pace of adaptation is still relatively slow and uneven across regions. In addition, professional certification programs specific to BIM are limited, which makes it difficult for companies to evaluate and recruit qualified personnel. Industry associations and government agencies are encouraged to facilitate more structured training initiatives and certification systems to build a stronger talent pipeline (Abdirad & Dossick, 2016).

Technological infrastructure and access to digital tools further influence the success of BIM application. Stable internet connectivity, high-performance computing devices, and secure cloud-based platforms are essential components for real-time collaboration in BIM environments. In areas where digital infrastructure is underdeveloped, such as remote or rural regions in Indonesia, implementing BIM at full capacity remains a significant challenge. Moreover, the initial cost of software licenses, server maintenance, and data security measures often discourages smaller firms from adopting BIM, despite its long-term benefits (Khosrowshahi & Arayici, 2012; Zahrizan et al., 2013).

Cultural and behavioral factors, though often overlooked, are also fundamental in shaping the effectiveness of BIM implementation. Resistance to change, fear of technological disruption, and reliance on conventional practices still prevail in many organizations. In hierarchical workplace cultures, such as those common in Southeast Asia, communication barriers and lack of cross-functional engagement may hinder the collaborative spirit required for BIM success. Therefore, fostering a mindset of innovation, openness, and continuous learning is essential to overcoming these cultural challenges (Gu & London, 2010).

In conclusion, the implementation of BIM in Indonesia is influenced by a multifaceted set of factors ranging from human capital and organizational readiness to technological infrastructure and government policy. A holistic approach that addresses these variables simultaneously is necessary to maximize the potential of BIM as a transformative tool in the construction sector. Efforts to improve training, regulation, and digital access must be accompanied by cultural change and strategic leadership within firms to ensure long-term and meaningful integration of BIM into construction practices across the country.

4. Conclusions

From the results of this study, it is concluded that the implementation factor has a significant influence on Building Information Modeling (BIM). Based on the outer model analysis of the SmartPLS 4.0 software, it is found that the greatest influence of the implementation factor relationship on Building Information Modeling (BIM) is 0.757 or it can be said that it is 75.7%.

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Author Contribution

The authors designed and conducted this research independently, with the help of her supervisor, Michella Beatrix. The entire process, from concept development, data collection, result analysis, to manuscript writing and editing was conducted by the author.

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We encourage all authors of articles published in this journal to share their research data. This section provides details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. A statement is still required when no new data is created or unavailable due to privacy or ethical restrictions.

Conflicts of Interest

The authors declare no conflict of interest.

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