MULTI-DIMENSIONAL BIM ADOPTION AT THE CITY SCALE: DETERMINANTS, BARRIERS, AND PERFORMANCE IMPLICATIONS IN DA NANG

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Abstract - This study investigates the determinants of multi-dimensional Building Information Modeling (BIM-nD) adoption and its relationship with organizational performance among construction-related firms in Da Nang, Vietnam. An analytical framework integrating the Technology–Organization–Environment (TOE) framework and BIM maturity concepts was developed to conceptualize BIM adoption as a progressive capability-building process. Survey data from 102 firms were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with bootstrapping. The results show that human competency is the strongest positive driver of BIM-nD adoption, whereas technological capability and external pressure exert significant negative effects. Organizational readiness and cost–benefit feasibility show no significant influence. BIM-nD adoption is also negatively associated with organizational performance, indicating short-term transitional challenges. The findings highlight the need to align human capability, organizational processes, and institutional support to enable effective BIM-nD implementation.

Key words - Building Information Modeling; BIM-nD; TOE framework; Partial Least Squares Structural Equation Modeling (PLS-SEM); digital transformation; construction industry; Vietnam

1. Introduction

Building Information Modeling (BIM) is widely recognized as a digital representation of the physical and functional characteristics of a facility that supports information sharing and decision-making throughout the project lifecycle. While early applications focused primarily on three-dimensional (3D) modeling, BIM has progressively evolved toward multi-dimensional implementations (BIM-nD), integrating time (4D), cost (5D), sustainability and energy performance (6D), and facility management (7D) within a unified digital environment [1]–[8]. Previous studies indicate that BIM-nD can enhance interdisciplinary coordination, reduce rework, and improve cost and schedule reliability, thereby supporting more effective project management.

Despite these advantages, BIM adoption remains uneven across regions. In developed economies, BIM implementation has gradually progressed toward standardized and integrated practices supported by coherent regulatory frameworks and industry standards. In contrast, many developing construction markets still exhibit fragmented adoption, where BIM is primarily used for visualization or clash detection and remains weakly embedded in organizational workflows and project management processes [5], [6]. This pattern suggests that BIM adoption represents not only a technological upgrade but also a broader socio-technical transformation involving organizational capability, human resources, and institutional conditions.

Vietnam reflects a similar pattern of uneven BIM diffusion. Although national strategies have been introduced to promote BIM implementation, adoption across regions and enterprises remains inconsistent [9], [10]. In many cases, BIM use is driven by individual initiatives, project-specific requirements, or isolated pilot projects rather than systematic organizational strategies. As a result, numerous construction-related firms continue to rely on basic BIM applications and face difficulties transitioning toward advanced BIM-nD practices capable of delivering sustained performance benefits.

At the local level, Da Nang has experienced rapid growth in infrastructure, residential, tourism, and public construction projects. This expansion increases pressure on local construction-related firms to adopt digital technologies to enhance productivity and competitiveness. However, available evidence suggests that BIM implementation in the city remains largely limited to basic applications, with relatively low diffusion of BIM-nD practices across the project lifecycle [8]. Understanding the determinants of advanced BIM adoption in this context therefore becomes an important research issue.

Existing studies have examined BIM adoption from technological, organizational, and environmental perspectives. Early research primarily addressed general barriers such as interoperability limitations, high initial investment costs, and organizational resistance to change [11]. More recent studies increasingly employ the TOE framework to explain organizational adoption behavior, emphasizing the combined influence of technological capability, organizational readiness, human competency, and external environmental pressure.

Nevertheless, evidence from emerging construction markets indicates that these relationships are strongly context-dependent. Factors such as regulatory uncertainty, fragmented standards, and limited client demand may weaken - or even alter - the role of external pressure in BIM adoption decisions [5]-[9]. Moreover, although BIM implementation is frequently associated with improved organizational performance in mature markets, empirical findings in developing contexts remain limited and sometimes inconclusive, particularly for advanced BIM applications beyond basic 3D modeling [10].

Recent international research has increasingly applied Partial Least Squares Structural Equation Modeling (PLS-SEM) to investigate BIM adoption mechanisms and their performance implications. These studies show that BIM adoption is a multi-factor process shaped by technological, organizational, and environmental conditions rather than purely technical considerations. TOE-based PLS-SEM analyses further suggest that human and organizational capabilities often exert stronger influence on BIM adoption than technological infrastructure alone, while higher levels of BIM implementation may generate short-term performance pressures due to learning costs and transitional inefficiencies [12], [13].

However, most existing studies still treat BIM adoption as a binary or single-dimensional concept, providing limited insight into the progressive nature of BIM-nD implementation. In addition, empirical evidence at the city scale in emerging construction markets remains scarce, and the mediating role of BIM-nD adoption in linking TOE conditions to organizational performance has not been adequately examined.

To address these gaps, this study conceptualizes BIM adoption as a progressive and multi-dimensional process measured through the level of BIM-nD implementation rather than simple BIM usage. By integrating the TOE framework with BIM maturity concepts and applying PLS-SEM to survey data collected from construction-related firms in Da Nang, the study provides empirical evidence at the city scale within an emerging construction market context. The results contribute to the literature by clarifying context-dependent TOE effects, emphasizing the role of human competency in BIM adoption, and showing that early-stage BIM-nD implementation may not immediately translate into performance gains due to transitional learning costs during digital transformation.

2. Literature Review

2.1. BIM and Multi-Dimensional BIM (BIM-nD)

BIM has evolved from a three-dimensional modeling tool into a multi-dimensional information management platform that supports collaboration and decision-making throughout the project lifecycle. In Vietnam, early BIM implementation has primarily focused on three-dimensional (3D) modeling for visualization and coordination purposes, with limited integration into project management and organizational processes [4]-[6].

Recent studies emphasize that BIM has progressively evolved toward multi-dimensional applications (BIM-nD), in which the digital model is integrated with additional dimensions such as scheduling, cost management, sustainability assessment, and lifecycle information. BIM-nD adoption has been shown to improve coordination efficiency, reduce design conflicts, and enhance decision-making in construction project management [8]. However, BIM-nD implementation requires higher levels of technological integration, organizational coordination, and human capability compared to basic BIM use.

Empirical evidence from Vietnam and similar emerging construction markets indicates that many enterprises struggle to move beyond basic BIM applications. Key challenges include limited technical integration, insufficient skilled personnel, and weak organizational alignment, which collectively constrain the diffusion of BIM-nD practices [4], [6], [8]. These findings suggest that BIM adoption should be understood as a progressive process rather than a binary decision, particularly when advanced BIM-nD applications are considered.

2.2. TOE Framework and BIM Adoption

The TOE framework has been widely applied to explain organizational adoption of information technologies by accounting for technological, organizational, and environmental conditions that shape adoption decisions. This framework is particularly relevant to BIM adoption, as BIM represents a socio-technical innovation that requires changes not only in technology but also in organizational processes and institutional arrangements.

Within the technological context, prior studies highlight the role of technological capability, system compatibility, and digital infrastructure in facilitating BIM adoption. In Vietnam, limited interoperability between software platforms and insufficient digital infrastructure remain major technological barriers to BIM implementation [2]-[4]. These constraints are further amplified when organizations attempt to adopt advanced BIM-nD applications that require integrated data environments.

The organizational context encompasses factors such as organizational readiness, management support, internal coordination, and availability of skilled human resources. Empirical studies consistently report that insufficient organizational preparedness and limited BIM expertise among staff significantly hinder BIM adoption in construction-related firms. Even when technological tools are available, the absence of organizational commitment and process reconfiguration often prevents BIM from being effectively embedded into routine project practices [6], [8], [10].

The environmental context reflects external pressures arising from regulations, client requirements, competitive dynamics, and industry standards. In mature BIM markets, regulatory mandates and standardized guidelines have been shown to accelerate BIM diffusion. However, studies focusing on Vietnam indicate that environmental pressure often exerts an ambiguous or weak influence due to fragmented regulations, unclear legal frameworks, and inconsistent client demand [5]-[7]. Under such conditions, external pressure may increase perceived risk rather than incentivize firms to invest in advanced BIM capabilities.

Overall, TOE-based studies in Vietnam and other emerging economies demonstrate that BIM adoption outcomes are highly context-dependent. Organizational and human-related factors frequently exert stronger influence than technological infrastructure alone, while environmental factors may act as barriers rather than enablers in the absence of coherent institutional support.

2.3. BIM Adoption and Organizational Performance

Beyond adoption determinants, several studies have examined the relationship between BIM adoption and organizational or project performance. BIM implementation has been associated with improvements in coordination, information accuracy, and project control, particularly when BIM is systematically integrated into project management processes [10], [12]. However, empirical evidence from emerging construction markets remains limited and mixed.

International studies using quantitative modeling approaches, such as PLS-SEM, suggest that BIM adoption does not necessarily lead to immediate performance improvements. Instead, performance outcomes may be moderated by organizational learning effects, implementation costs, and the maturity of BIM use. In developing contexts, where BIM adoption is often fragmented and uneven, short-term performance gains may be offset by transitional inefficiencies and skill gaps [13]-[16].

Moreover, most existing studies do not explicitly distinguish between basic BIM use and advanced BIM-nD adoption when evaluating performance outcomes. Research focusing on BIM-nD remains scarce and is largely limited to identifying technical and organizational barriers rather than examining performance implications at the organizational level [8]. Consequently, the relationship between BIM-nD adoption and organizational performance, particularly within city-scale and emerging market contexts, remains insufficiently explored.

3. Research Framework and Methodology

3.1. Conceptual research framework

To investigate BIM adoption and its performance implications in an emerging urban construction market, this study develops a conceptual framework integrating the TOE framework with BIM maturity and multi-dimensional adoption concepts.

Rather than treating BIM adoption as a binary decision, this study conceptualizes adoption as a progressive and multi-dimensional construct reflecting the extent to which BIM is implemented beyond basic 3D modeling toward advanced n-dimensional applications (BIM-nD). This approach captures variations in adoption depth across organizations.

Within the proposed framework, BIM-nD adoption represents an organizational implementation outcome through which technological, organizational, and environmental conditions may influence organizational performance. The model recognizes that resources or institutional pressures do not automatically translate into performance gains unless they are converted into effective BIM-enabled practices.

Accordingly, the research model includes seven latent constructs:

- Technological Capability (TC): availability of BIM-related hardware, software, and technical infrastructure;

- Organizational Readiness (OR): managerial support and internal coordination supporting BIM implementation;

- Human Competency (HC): BIM-related knowledge, skills, and experience of staff;

- External Environmental Pressure (EP): influence of regulations, client requirements, industry norms, and competition;

- Cost–Benefit Feasibility (CB): perceived balance between BIM implementation costs and expected benefits;

- BIM-nD Adoption Level (BIM): extent of BIM use across multiple project dimensions;

- Organizational Performance (OP): perceived improvements in coordination efficiency, cost control, schedule management, and competitiveness.

3.2. Research hypotheses development

Based on the TOE framework and BIM adoption literature, a set of hypotheses is proposed to examine how technological, organizational, and environmental factors affect BIM-nD adoption and how BIM-nD adoption influences organizational performance.

Technological capability and organizational readiness are widely recognized as key enablers of digital technology adoption. Adequate infrastructure and supportive organizational arrangements facilitate BIM implementation and interdepartmental collaboration.

Prior BIM adoption studies have consistently identified technological capability as a critical enabler of BIM implementation because adequate software infrastructure, interoperability, and digital integration capacity facilitate information exchange and multi-dimensional workflow coordination [6], [7], [11]. Within the TOE framework, organizations with stronger technological capability are generally better positioned to adopt advanced digital systems.

H1. Technological capability positively influences BIM-nD adoption.

- Organizational readiness, including management support, formal implementation procedures, and interdepartmental coordination, has been widely recognized as an important determinant of BIM adoption [6], [10, [15]. Organizations with higher levels of readiness are more likely to integrate BIM into routine project management processes and support organizational change associated with digital transformation.

H2. Organizational readiness positively influences BIM-nD adoption.

- Advanced BIM-nD implementation requires personnel capable of interpreting and coordinating multi-dimensional project information across disciplines. Prior studies consistently report that BIM-related knowledge, skills, and implementation experience significantly facilitate BIM adoption and integration [4], [8], [10].

H3. Human competency positively influences BIM-nD adoption.

- External environmental conditions, including regulatory requirements, client demand, industry standards, and competitive pressure, have frequently been identified as important drivers of BIM diffusion [5]-[7]. Within the TOE framework, stronger institutional and market pressure is generally expected to encourage firms to adopt BIM technologies.

H4. External environmental pressure positively influences BIM-nD adoption.

- Firms are more likely to adopt BIM when the expected operational and strategic benefits outweigh implementation costs [13], [14]. Perceived economic feasibility therefore represents an important consideration in BIM adoption decisions.

H5. Cost–benefit feasibility positively influences BIM-nD adoption.

- BIM implementation has frequently been associated with improvements in coordination efficiency, schedule reliability, cost control, and decision-making quality [11], [13], [16]. Advanced BIM-nD applications are expected to further enhance organizational performance through integrated lifecycle information management.

H6. BIM-nD adoption positively influences organizational performance.

3.3. Research methodology

3.3.1. Data collection

A questionnaire survey was conducted among construction-related enterprises operating in Da Nang, including contractors, consultants, design firms, and project management organizations. Da Nang was selected due to its rapid construction growth and increasing interest in digital transformation. A total of 102 valid responses were obtained, which exceeds the minimum sample size recommended for PLS-SEM relative to the complexity of the proposed model. The sample covers a range of organizational roles and project types, providing a representative overview of BIM adoption practices at the city level.

3.3.2. Measurement development

Measurement items were adapted from prior BIM adoption and information systems studies and adjusted to reflect BIM-nD adoption in an emerging construction market. All constructs were measured at the firm level in accordance with the TOE framework.

BIM adoption was operationalized as the extent of BIM implementation beyond 3D modeling toward scheduling, cost management, and lifecycle applications. Organizational performance was measured using perceptual indicators, which are commonly used in firm-level BIM studies when objective performance data are not consistently available.

All items were assessed using a five-point Likert scale ranging from 1 (“strongly disagree”) to 5 (“strongly agree”). The questionnaire was reviewed by domain experts to ensure clarity and content validity. Table 1 summarizes the constructs, measurement items, and corresponding literature sources.

Table 1. *Research constructs and measurement items (N = 102 firms)*

TOE dimension	Latent construct	Item codes	Measurement focus	Supporting literature
Technology	Technological Capability (TC)	TC1	The firm possesses sufficient BIM software tools (e.g., Revit, Navisworks, Tekla) to support BIM implementation.	[6], [7], [11]
		TC2	The firm’s IT infrastructure adequately supports BIM-based information exchange and collaboration.	
		TC3	BIM tools used by the firm are compatible with existing management and information systems.	
		TC4	The firm is technically capable of integrating BIM with schedule, cost, and other project data (BIM-nD).	
Organization	Organizational Readiness (OR)	OR1	Top management actively supports BIM implementation within the firm.	[6], [10], [15]
		OR2	The firm has formal BIM-related policies, guidelines, or internal procedures.	
		OR3	There is effective coordination among departments when implementing BIM.	
		OR4	BIM is integrated into routine project management processes.	
Human	Human Competency (HC)	HC1	The firm has personnel with adequate BIM-related technical skills.	[4], [8], [10]
		HC2	Personnel are capable of using BIM beyond basic 3D modeling (e.g., 4D, 5D applications).	
		HC3	The firm has practical experience implementing BIM in real projects.	
		HC4	Personnel are capable of coordinating BIM-based workflows with external stakeholders.	
Environment	External Environmental Pressure (EP)	EP1	Clients or project owners require the use of BIM in projects.	[5], [6], [7]
		EP2	Government policies and regulations encourage BIM adoption.	
		EP3	Competitive pressure from other firms motivates BIM adoption.	
		EP4	Local BIM standards and guidelines are sufficiently clear and applicable.	
Economic	Cost–Benefit Feasibility (CB)	CB1	The initial investment cost of BIM is acceptable for the firm.	[13], [14]
		CB2	The expected benefits of BIM outweigh its implementation costs.	
		CB3	The firm has sufficient financial capacity to sustain BIM investment over time.	
Adoption level	BIM-nD Adoption Level (BIM)	BIM1	BIM is used for design coordination and information integration (3D).	[8], [13], [16]
		BIM2	BIM is used for construction scheduling and time management (4D).	
		BIM3	BIM is used for cost estimation and cost control (5D).	
		BIM4	BIM is used for lifecycle management or operation-related purposes (6D-nD).	
Performance	Organizational Performance (OP)	OP1	BIM improves project coordination and communication efficiency.	[11], [13], [16]
		OP2	BIM contributes to better schedule control.	
		OP3	BIM contributes to better cost control.	
		OP4	BIM enhances the firm’s overall competitiveness.	

Note: All items were measured using a five-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. Measurement items were adapted from prior BIM adoption and TOE-based technology adoption studies and refined to reflect BIM-nD implementation conditions in emerging construction markets.

3.3.3. Data analysis method

PLS-SEM was employed due to its suitability for exploratory research, complex causal models, and relatively small samples. The PLS-SEM analysis was implemented using a customized MATLAB-based computational procedure developed for this study.

The analysis followed two main stages:

(1) Measurement model assessment, including indicator reliability, construct reliability, and validity evaluation;

(2) Structural model evaluation, involving estimation of path coefficients, coefficient of determination (R^2), and statistical significance using bootstrapping with 5,000 resamples.

This procedure allows examination of both the determinants of BIM-nD adoption and its relationship with organizational performance.

4. Results and Discussion

4.1. Sample characteristics

The survey dataset comprised 102 valid responses collected from construction-related enterprises operating in Da Nang, including contractors, consultants, design firms, and project management organizations. Although the sample size remains relatively modest, it is considered adequate for PLS-SEM, which is particularly suitable for exploratory studies involving complex causal relationships and emerging research contexts.

The participating firms represented diverse organizational functions and varying levels of BIM implementation experience, thereby providing a heterogeneous empirical basis for examining BIM-nD adoption behavior at the city scale. The sample reflects the current transitional condition of digital transformation within the local construction industry, where BIM implementation remains uneven and is often concentrated in organizations involved in technically demanding or large-scale projects.

The responses further indicate that BIM adoption in Da Nang is still predominantly oriented toward conventional 3D coordination and visualization practices, while integrated BIM-nD applications associated with scheduling, cost management, and lifecycle information management remain comparatively limited. This pattern is consistent with the broader characteristics of emerging construction markets, where technological diffusion frequently progresses faster than organizational and institutional adaptation.

4.2. Measurement model assessment

4.2.1. Reliability and convergent validity

Table 2 summarizes the reliability and convergent validity results. All indicator loadings exceeded the recommended threshold of 0.70, ranging from 0.781 to 0.931. Cronbach's alpha values ranged from 0.815 to 0.941, while composite reliability (CR) values varied between 0.878 and 0.958, indicating satisfactory internal consistency across all constructs.

Table 2. *Measurement model reliability and convergent validity results*

Construct	Item	Loading	Cronbach Alpha	Composite Reliability	AVE
TC	TC1	0.931	0.941	0.958	0.85
TC	TC2	0.91	0.941	0.958	0.85
TC	TC3	0.93	0.941	0.958	0.85
TC	TC4	0.917	0.941	0.958	0.85
OR	OR1	0.904	0.925	0.947	0.817
OR	OR2	0.912	0.925	0.947	0.817
OR	OR3	0.874	0.925	0.947	0.817
OR	OR4	0.923	0.925	0.947	0.817
HC	HC1	0.892	0.905	0.934	0.779
HC	HC2	0.862	0.905	0.934	0.779
HC	HC3	0.883	0.905	0.934	0.779
HC	HC4	0.893	0.905	0.934	0.779
EP	EP1	0.907	0.908	0.936	0.784
EP	EP2	0.887	0.908	0.936	0.784
EP	EP3	0.859	0.908	0.936	0.784
EP	EP4	0.888	0.908	0.936	0.784
CB	CB1	0.917	0.901	0.938	0.834
CB	CB2	0.907	0.901	0.938	0.834
CB	CB3	0.915	0.901	0.938	0.834
BIM	BIM1	0.851	0.872	0.912	0.722
BIM	BIM2	0.853	0.872	0.912	0.722
BIM	BIM3	0.849	0.872	0.912	0.722
BIM	BIM4	0.846	0.872	0.912	0.722
OP	OP1	0.781	0.815	0.878	0.643
OP	OP2	0.826	0.815	0.878	0.643
OP	OP3	0.804	0.815	0.878	0.643
OP	OP4	0.796	0.815	0.878	0.643

Convergent validity was also confirmed, with AVE values ranging from 0.643 to 0.850, all above the recommended threshold of 0.50. These results demonstrate that the latent constructs adequately capture the variance of their associated indicators. Figure 1 further illustrates the reliability and convergent validity statistics of the proposed PLS-SEM model. Overall, the measurement model exhibits acceptable psychometric properties for subsequent structural model analysis.

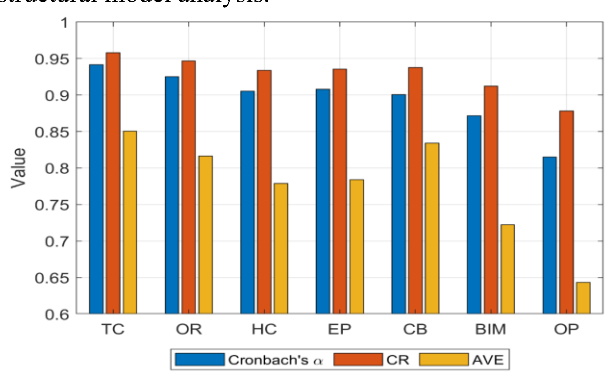

Figure 1. *PLS-SEM measurement model reliability*

4.2.2. Discriminant validity

Discriminant validity was assessed using the Fornell–Larcker criterion and the Heterotrait–Monotrait (HTMT) ratio. As shown in Figure 2, the square roots of AVE for all constructs exceeded the corresponding inter-construct correlations, confirming adequate discriminant validity.

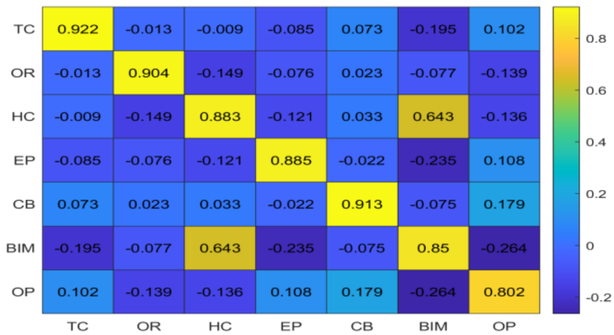

Figure 2. *Fornell–Larcker discriminant validity matrix*

Figure 3 presents the HTMT results. All HTMT values were below the recommended threshold of 0.85, with the highest value observed between HC and BIM (0.724). These findings indicate satisfactory construct distinctiveness and the absence of critical overlap among the latent variables. Overall, the measurement model was considered appropriate for subsequent structural model assessment.

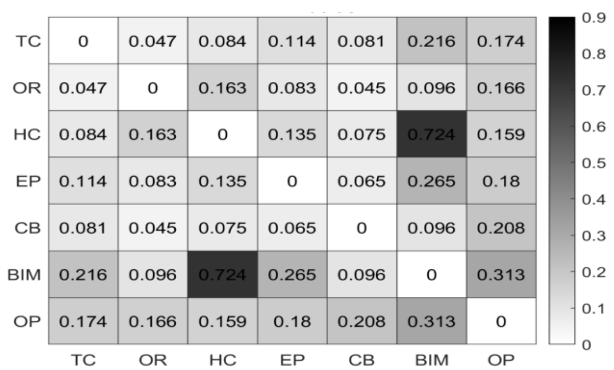

Figure 3. *HTMT ratio matrix of latent constructs*

4.3. Structural model assessment

After confirming the adequacy of the measurement model, the structural model was evaluated using path coefficients and bootstrap significance testing within the PLS-SEM framework. The results are summarized in Table 3. The structural model explained 48.8% of the variance in BIM-nD adoption and 7.0% of the variance in organizational performance, indicating moderate explanatory power for BIM-nD adoption but relatively limited explanatory capability for organizational performance.

Among the examined determinants, human competency (HC) showed the strongest positive effect on BIM-nD adoption ($\beta = 0.600$, $p < 0.001$), highlighting the critical role of skilled personnel, technical expertise, and BIM-related knowledge in supporting advanced BIM implementation. In contrast, technological capability (TC) exhibited a significant negative relationship with BIM-nD adoption ($\beta = -0.183$, $p = 0.004$), contrary to the proposed hypothesis. External pressure (EP) also showed a significant negative effect ($\beta = -0.171$, $p = 0.020$), suggesting that technological resources and institutional pressures alone may not ensure effective BIM-nD integration in emerging construction environments.

Table 3. *Structural model results and hypothesis testing*

Hypo-thesis	Structural Path	β	t-value	p-value	Decision
H1	TC → BIM	-0.183	-2.863	0.004	Significant but opposite direction
H2	OR → BIM	0.002	0.025	0.980	Not Supported
H3	HC → BIM	0.600	8.935	<0.001	Supported
H4	EP → BIM	-0.171	-2.333	0.020	Significant but opposite direction
H5	CB → BIM	-0.079	-1.197	0.232	Not Supported
H6	BIM → OP	-0.249	-2.676	0.007	Significant but opposite direction

Note: The structural model explained 48.8% of the variance in BIM-nD adoption ($R^2 = 0.488$) and 7.0% of the variance in organizational performance ($R^2 = 0.070$), where R^2 denotes the coefficient of determination.

Organizational readiness (OR) did not significantly influence BIM-nD adoption ($\beta = 0.002$, $p = 0.980$), indicating that formal organizational preparedness alone may be insufficient without adequate technical integration and workforce capability. Similarly, cost–benefit feasibility (CB) showed no significant relationship with BIM-nD adoption ($\beta = -0.079$, $p = 0.232$), implying that perceived economic considerations were not a primary driver of BIM implementation in the investigated context.

BIM-nD adoption was found to exhibit a significant negative short-term association with organizational performance ($\beta = -0.249$, $p = 0.007$). Although the hypothesized relationship was positive, the observed negative effect may reflect short-term transitional inefficiencies during the early stage of digital transformation. BIM-nD implementation often requires organizational restructuring, workforce training, workflow adaptation, and interoperability coordination, which may temporarily reduce operational efficiency before long-term benefits are realized.

Overall, the findings indicate that BIM-nD adoption in emerging construction markets is shaped not only by technological conditions, but also by broader organizational and institutional dynamics affecting digital transformation processes.

4.4. Discussion

4.4.1. Negative effects of technological capability

One of the notable findings of this study is the significant negative relationship between technological capability and BIM-nD adoption ($\beta = -0.183$, $p = 0.004$), contrary to the proposed hypothesis. While prior BIM studies generally suggest that technological readiness facilitates digital implementation, the present results indicate that technological resources alone may not guarantee effective BIM-nD integration in emerging construction markets.

In many local construction-related firms, technological capability is still largely associated with standalone software usage, visualization-oriented modeling, or fragmented digital tools that remain weakly connected to collaborative project delivery systems. As a result, organizations may possess BIM-related technologies while continuing to rely on conventional document-based coordination and traditional management practices.

The negative relationship observed in this study may therefore reflect a technological–organizational misalignment, where technological resources exceed the organization's actual capability to integrate BIM-nD workflows across project lifecycle activities. This finding suggests that successful digital transformation depends not only on technological infrastructure, but also on the alignment between technology, organizational processes, workforce competency, and institutional support.

Moreover, advanced BIM-nD implementation often introduces additional operational complexity, including interoperability issues, workflow restructuring, data coordination requirements, and increased training demands. In organizations with limited digital maturity, these implementation challenges may temporarily hinder effective BIM diffusion despite the availability of technological resources. Consequently, technological capability alone should not be considered a sufficient condition for successful BIM-nD adoption in emerging construction environments.

4.4.2. External pressure and institutional constraints

The analysis revealed a significant negative relationship between external pressure and BIM-nD adoption ($\beta = -0.171$, $p = 0.020$), contrary to the proposed hypothesis. This finding suggests that client demands, regulatory expectations, and competitive pressures do not necessarily promote effective BIM-nD implementation in emerging construction environments. Instead, externally driven adoption may encourage symbolic or compliance-oriented BIM practices rather than substantive digital transformation.

In practice, many construction-related firms adopt BIM-related procedures primarily to satisfy contractual or regulatory requirements while lacking the operational readiness and technical integration capacity required for advanced BIM-nD deployment. Under such conditions, external pressure may increase implementation fragmentation, procedural inconsistency, and isolated technology usage that fails to support collaborative project integration.

The negative relationship also reflects broader institutional constraints commonly observed in developing construction markets, where regulatory frameworks, BIM standards, and interdisciplinary collaboration mechanisms remain insufficiently mature to support advanced BIM implementation. As a result, external pressure may increase organizational burden without simultaneously strengthening the internal capabilities necessary for effective BIM-nD adoption.

Moreover, externally imposed BIM requirements can create additional short-term challenges, including higher coordination demands, implementation costs, and workflow adaptation pressures. In the absence of adequate institutional support, technical guidance, and workforce competency, organizations may struggle to translate external pressure into effective BIM-enabled innovation.

4.4.3. BIM-nD adoption and organizational performance

The study identified a significant negative relationship between BIM-nD adoption and organizational performance ($\beta = -0.249$, $p = 0.007$), contrary to the proposed hypothesis. This finding suggests that the benefits of advanced BIM implementation may not be immediately realized during the early stages of digital transformation in emerging construction markets.

In practice, BIM-nD implementation often requires organizational restructuring, workflow standardization, personnel training, and increased coordination efforts. These adjustments may initially increase operational complexity, implementation costs, and managerial burden, particularly in organizations with limited digital maturity and fragmented project management systems.

Moreover, multidimensional BIM applications require higher levels of interoperability, information management capability, and cross-disciplinary collaboration than conventional 3D BIM practices. In organizations where digital processes and collaborative workflows remain underdeveloped, BIM-nD implementation may temporarily disrupt established project routines and reduce short-term operational efficiency.

The negative relationship observed in this study should therefore not be interpreted as evidence that BIM-nD adoption is inherently ineffective. Rather, it indicates that organizational performance outcomes are strongly influenced by implementation maturity, organizational capability, workforce competency, and institutional support conditions. As organizations accumulate BIM experience and improve process integration, the long-term benefits of BIM-nD adoption are likely to become more substantial.

In summary, the findings reinforce the view that BIM adoption represents a gradual socio-technical transformation process rather than a purely technological intervention. Successful BIM-nD implementation requires not only technological resources, but also organizational adaptation, human capability development, and institutional alignment.

5. Conclusions

This study examined the determinants of BIM-nD adoption and its relationship with organizational performance among construction-related firms in Da Nang using a TOE-based PLS-SEM approach. The results identify human competency as the strongest positive driver of BIM-nD adoption, highlighting the importance of skilled personnel, BIM expertise, and interdisciplinary coordination capability in supporting advanced digital implementation.

In contrast, technological capability and external pressure showed significant negative effects on BIM-nD adoption. These findings suggest that the availability of technological resources and institutional pressures alone may not ensure effective BIM integration in emerging construction environments. Instead, insufficient organizational maturity, fragmented workflows, and limited institutional support may reduce the effectiveness of digital transformation initiatives. Organizational readiness and cost–benefit feasibility were not found to significantly influence BIM-nD adoption.

The study also revealed a significant negative relationship between BIM-nD adoption and organizational performance. This result indicates that advanced BIM implementation may initially generate operational and managerial challenges during the early stages of digital transformation, including workflow adaptation, interoperability issues, training demands, and implementation costs. Therefore, BIM-nD adoption should be understood as a gradual socio-technical transformation process rather than a purely technological intervention.

Overall, the findings demonstrate that successful BIM-nD implementation depends not only on technological infrastructure, but also on human capability, organizational integration, and institutional support conditions. The study contributes to the TOE-based BIM literature by showing that technological capability and environmental pressure may not always function as positive adoption drivers in developing construction markets.

Several limitations should be acknowledged. The study was based on a cross-sectional survey conducted within a single city and relied primarily on perceptual measures of organizational performance. Future research should incorporate longitudinal data, objective performance indicators, and comparative analyses across different institutional contexts to further examine the dynamics of BIM-nD adoption in emerging construction environments.

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REFERENCES

[1] N. H. Tran and N. T. Ngo, "Potential applications of Digital Twin and BIM technology in construction industry", *The University of Danang - Journal of Science and Technology*, vol. 23, no. 9D, pp. 106–112, 2025. https://doi.org/10.31130/ud-jst.2025.23(9D).573E

[2] V. T. Nguyen, A. D. Mai, and N. T. Ngo, "An application of Building Information Modeling (BIM) in construction schedule management – A case study of Olalani Riverside Tower project", *The University of Danang - Journal of Science and Technology*, vol. 23, no. 10C, pp. 13–17, 2025. https://doi.org/10.31130/ud-jst.2025.23(10C).657E

[3] N. T. Ngo, A. D. Pham, and A. D. Mai, "Development of an artificial intelligence model for predicting building energy consumption in Danang city", *The University of Danang - Journal of Science and Technology*, vol. 22, no. 11A, pp. 20–24, 2024. https://jst-ud.vn/jst-ud/article/view/9431

[4] P. N. Gade and T. H. Nguyen, "Challenges in adopting Building Information Modelling (BIM) in Vietnam: A decade's perspective", in *Proceedings of the 18th East Asia-Pacific Conference on Structural Engineering and Construction, Volume 3: EASEC-18*, Chiang Mai, Thailand. Singapore: Springer, 2024, pp. 24–30. https://doi.org/10.1007/978-981-95-0090-1_4

[5] T. Q. Nguyen and D. P. Nguyen, "Barriers in BIM adoption and legal considerations in Vietnam", *International Journal of Sustainable Construction Engineering and Technology*, vol. 12, no. 1, 2021. https://doi.org/10.30880/ijscet.2021.12.01.027

[6] N. V. Tam, T. N. Diep, N. Q. Toan, and N. L. D. Quy, "Factors affecting the adoption of Building Information Modeling in construction projects: The case of Vietnam", *Cogent Business & Management*, vol. 8, no. 1, 2021. https://doi.org/10.1080/23311975.2021.1918848

[7] N. V. Tam, N. Q. Toan, and V. V. Phong, "Investigating potential barriers to construction digitalization in emerging economies: A study in Vietnam", *International Journal of Information Management Data Insights*, vol. 4, no. 1, Art. no. 100226, 2024. https://doi.org/10.1016/j.jjimei.2024.100226

[8] L. D. T. Tin, D. T. Sy, and N. T. Viet, "Identifying barriers to BIM-nD implementation in construction project management", *Journal of Materials and Construction – Ministry of Construction (Vietnam)*, vol. 14, 2024. https://doi.org/10.54772/jomc.06.2024.804

[9] H. N. Minh, "Barriers to the integrated implementation of BIM and GIS in public construction projects in Vietnam", *Journal of Materials and Construction – Ministry of Construction (Vietnam)*, vol. 15, pp. 254–259, 2025. https://doi.org/10.54772/jomc.03.2025.968

[10] T. V. Tran, H. V. V. Tran, and T. A. Nguyen, "A review of challenges and opportunities in BIM adoption for construction project management", *Engineering Journal*, vol. 28, no. 8, pp. 79–98, 2024. https://doi.org/10.4186/ej.2024.28.8.79

[11] O. I. Olanrewaju, A. F. Kineber, N. Chileshe, and D. J. Edwards, "Modelling the impact of Building Information Modelling (BIM) implementation drivers and awareness on the project lifecycle", *Sustainability*, vol. 13, no. 16, Art. no. 8887, 2021. https://doi.org/10.3390/su13168887

[12] M. Ghobakhloo and M. Iranmanesh, "Digital transformation success under Industry 4.0: A strategic guideline for manufacturing SMEs", *Journal of Manufacturing Technology Management*, vol. 32, no. 8, pp. 1533–1556, 2021. https://doi.org/10.1108/JMTM-11-2020-0455

[13] A. O. Daoud, A. E. Oke, A. K. Singh, I. O. Famakin, K. M. Abdel Aziz, and T. M. Olayemi, "Exploring the Building Information Modelling benefits for sustainable construction using PLS-SEM", *Scientific Reports*, vol. 15, Art. no. 35781, 2025. https://doi.org/10.1038/s41598-025-14020-0

[14] H. A. Mohamed, N. Hashim, N. M. Yusuwan, M. H. Hanafiah, and S. M. Shamsuddin, "Assessing cost and benefit attributes of Building Information Modelling (BIM) implementation in a Malaysian public agency: A PLS-SEM approach", *Journal of Information Technology in Construction*, vol. 29, pp. 308–323, 2024. https://doi.org/10.36680/j.itcon.2024.015

[15] A. R. Radzi, N. F. Azmi, S. N. Kamaruzzaman, M. Algahtany, and R. A. Rahman, "Challenges in construction readiness for BIM-based building projects", *Journal of Asian Architecture and Building Engineering*, vol. 24, no. 4, pp. 1689–1704, 2025. https://doi.org/10.1080/13467581.2024.2343803

[16] G. E. Takyi-Annan and H. Zhang, "Assessing the impact of overcoming BIM implementation barriers on BIM usage frequency and the circular economy in the project lifecycle using partial least squares structural equation modelling (PLS-SEM)", *Energy and Buildings*, vol. 295, Art. no. 113329, 2023. https://doi.org/10.1016/j.enbuild.2023.113329