Validating the measurement model of factors influencing BIM adoption in construction project management in Vietnam using confirmatory factor analysis (CFA)

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Abstract: This study validates the measurement model of factors influencing the adoption of Building Information Modeling (BIM) in construction project management in Vietnam using Confirmatory Factor Analysis (CFA) with a sample of 200 experts. Six latent constructs were examined, including Institutional - Policy, Human Resources, Management, Technology, Economics, and Environment. The results indicate that the measurement model achieved a good overall model fit ($\chi^2/df = 1.925$; GFI = 0.901; CFI = 0.932; TLI = 0.918; RMSEA = 0.054). The measurement scales demonstrated satisfactory composite reliability (CR $\geq$ 0.89), convergent validity (AVE $\geq$ 0.57), and discriminant validity. This research contributes a statistically validated measurement instrument tailored to the Vietnamese context, providing a solid academic foundation for subsequent causal relationship analyses in future studies.

Keywords: BIM, CFA, measurement model, construction project management, Vietnam.

1. Introduction

In the era of digital transformation in the construction industry, Building Information Modeling (BIM) has emerged as a strategic technological platform enabling data integration, design simulation, schedule, and cost management across the project life cycle (Volk, 2014). Globally, BIM adoption has been mandated in several leading countries, including the UK, Singapore, South Korea, and China (Ghaffarianhoseini A. et al, 2017). In Vietnam, however, BIM implementation remains limited in scale, uneven across stakeholders, and largely concentrated in the design phase rather than in project management activities (Mui T. V. and Hoang V. G., 2018).

International studies highlight that BIM adoption is influenced by multiple factor groups: institutional, human, organizational, technological, economic, and collaborative environment whose interactions are complex and multi-directional (Zhang, 2020). Without a validated measurement framework, analyses can yield inconsistent or biased results. Although some Vietnamese studies have examined BIM adoption using quantitative approaches (e.g., Nguyen et al., 2021; Tran & Hoang, 2018), most focus on exploratory factor identification rather than validating a full measurement model using Confirmatory Factor Analysis (CFA). Furthermore, existing scales have not been systematically adapted to the institutional, technological, and managerial context of Vietnam.

This reveals a significant research gap: Vietnam lacks a statistically validated measurement model accurately reflecting the relationships between observable indicators and latent constructs of BIM adoption. Validating such a model is indispensable before conducting causal analyses using Structural Equation Modeling (SEM), as recommended by contemporary methodological guidelines (Hair, 2019).

While earlier BIM studies in Vietnam have largely relied on exploratory approaches such as Exploratory Factor Analysis (EFA), a statistically validated measurement model remains limited. Accordingly, this study applies Confirmatory Factor Analysis (CFA) to confirm the theoretically grounded factor structure prior to SEM-based causal analysis.

This study develops and validates a CFA-based measurement model composed of six latent factors synthesised from literature and expert consultation:

(1) Institutional and Policy (TCCS)
(2) Human Resources (NNL)
(3) Management (QL)
(4) Technology (CN)
(5) Economics (KT)
(6) Environment (MT)

Each factor is operationalised using multiple reflective indicators relevant to BIM-based project management. CFA is used to examine the model's overall fit, reliability, convergent validity, and discriminant validity (Fornell, 1981).

The study aims to validate a measurement model of six factor groups influencing BIM adoption in Vietnam through a survey of 200 construction experts. The outcomes of the CFA provide:

(i) a standardised measurement scale adapted to Vietnam's construction sector.

(ii) a validated basis for subsequent SEM causal analysis.

(iii) empirical insights to support policymaking, capacity development, and BIM implementation strategies.

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Received 22nd Nov. 2025
Accepted 23rd Dec. 2025
Publication date 31st Dec. 2025

Table 1.1. Observed Variables for BIM Factors

No.	Factors
1	Legal regulations on BIM implementation for construction projects
2	BIM guidelines, norms, and technical standards
3	Legal regulations on intellectual property rights related to BIM
4	Regulations on unit prices and cost norms for BIM implementation
5	Regulations on contractor selection and BIM-related contractual
6	Regulations on BIM implementation roadmaps corresponding to specific application contents
7	Regulations on types of construction projects eligible for BIM
8	Regulations on project implementation phases corresponding to BIM application contents
9	Regulations on BIM model management, storage, and approval
10	Competency of individuals involved in BIM implementation for
11	Workforce awareness of the perceived usefulness of BIM
12	Availability of personnel capable of using BIM in projects
13	Professional qualifications aligned with assigned BIM roles in projects (including BIM training and certification)
14	Work motivation of individuals involved in BIM implementation for
15	Management capability of the construction project management
16	Organizational demand for BIM technology adoption
17	Level of organizational interest in using BIM technology
18	Organizational BIM implementation process
19	Organizational capability to implement BIM applications
20	Content of the organization's BIM execution plan / BIM task
21	Management mechanisms of BIM consulting organizations
22	Capability to independently deploy BIM technological solutions for
23	Availability of BIM software suitable for project requirements
24	Internet network infrastructure of the organization
25	Common Data Environment (CDE) for BIM model storage and
26	Requirements for BIM deliverables and output formats
27	Hardware and equipment used for BIM implementation in projects
28	Perceived benefits of BIM for the organization
29	Costs of training and technology transfer
30	Hardware investment costs
31	Software license and package investment costs
32	Costs of hiring BIM implementation experts
33	Costs of hiring consultants for BIM model checking and acceptance
34	Trust and collaboration among stakeholders in BIM-based projects
35	Working environment of organizations adopting BIM
36	Regulations on information exchange between project owners and BIM consulting organizations
37	Data sharing and collaboration across different project phases

2. Theoretical Foundations and Measurement Model

2.1. Theoretical Framework and Model Basis

A substantial body of international research has applied theoretical frameworks such as the Technology - Organization - Environment (TOE) framework, the Technology Acceptance Model (TAM), and the Theory of Planned Behavior (TPB) to analyze behavioral determinants of BIM adoption in the construction industry (Nguyen T. V. et al., 2021). These models consistently emphasize that technology acceptance is shaped by multiple groups of determinants originating from different domains, including technological factors, organizational factors, environmental factors, and individual cognitive or perceptual factors (Zhang, 2020).

Based on an extensive synthesis of international theories and the contextual characteristics of Vietnam's construction sector, this study proposes an analytical framework consisting of six latent factor groups influencing BIM adoption in construction project management:

Institutional - Policy (TCCS): representing the legal, regulatory, procedural, and standardization aspects established by governmental authorities concerning BIM implementation.

Human Resources (NNL): reflecting the capabilities, experience, qualifications, and awareness of project participants.

Management (QL): capturing the capacity for coordination, leadership, control, and decision-making within project organizations.

Technology (CN): describing technical infrastructure readiness, software compatibility, data interoperability, and BIM tool capabilities.

Economics (KT): denoting investment costs, perceived benefits, financial viability, and economic efficiency of BIM implementation.

Environment (MT): reflecting collaborative culture, trust among stakeholders, market support mechanisms, and client requirements.

These six factor groups are derived from the theoretical model developed in the authors' doctoral dissertation and supported by empirical insights from a survey of 200 construction experts in Vietnam. Each factor is operationalized through multiple observed indicators capturing specific dimensions of the corresponding latent construct.

2.2. Concept of the Measurement Model in CFA

In Structural Equation Modeling (SEM), the measurement model specifies the relationships between latent variables and their observed indicators. Latent variables cannot be measured directly; instead, their presence and intensity must be inferred from multiple observable items designed in the survey instrument (Hu L., 1999).

In this study, the measurement model is conceptualized as a reflective measurement model since all observed indicators were designed to reflect experts' perceptions or evaluations of a single underlying concept.

2.3. Criteria for Evaluating the Measurement Model

The validation of the measurement model using CFA is conducted based on three categories of criteria as recommended in the literature (Fornell, 1981), (Marsh H. W., 2004):

(1) Overall Model Fit

The goodness-of-fit is evaluated using the following indices:

- $\chi^2/df \leq 3$
- Goodness of Fit Index (GFI) ≥ 0.90
- Comparative Fit Index (CFI) ≥ 0.90
- Tucker–Lewis Index (TLI) ≥ 0.90
- Root Mean Square Error of Approximation (RMSEA) ≤ 0.08

These indices collectively assess the degree of correspondence between the hypothesized model and the empirical covariance matrix derived from the survey data.

(2) Reliability and Convergent Validity

Composite Reliability (CR) ≥ 0.70, indicating stable and internally consistent measurement.

Average Variance Extracted (AVE) ≥ 0.50, demonstrating that the latent construct explains more than half of the variance in its indicators.

Standardized Factor Loadings ≥ 0.60, statistically significant at $p < 0.05$.

(3) Discriminant Validity

Assessed through two widely accepted methods:

Fornell - Larcker Criterion: the square root of AVE for each construct must exceed its maximum correlation with any other construct.

Heterotrait–Monotrait Ratio (HTMT) < 0.85.

These criteria confirm that the constructs measure conceptually distinct phenomena and avoid conceptual overlap.

2.4. Proposed Measurement Model

Based on the theoretical synthesis and initial qualitative validation, the proposed measurement model comprises six latent constructs and 37 observed indicators, as illustrated in Figure 1. The model assumes that all six constructs contribute to explaining the dependent variable "BIM Adoption" within construction project management contexts.

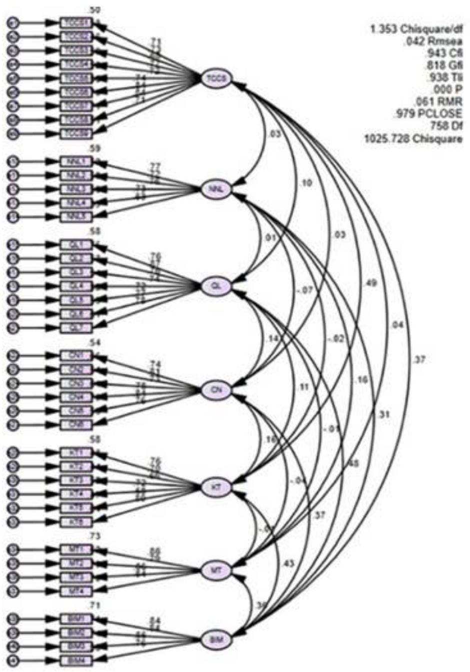

Figure 1. Measurement model of factors influencing BIM adoption in construction project management in Vietnam

2.5. Measurement Hypotheses

In CFA, instead of testing causal relationships, the study establishes measurement hypotheses to verify whether each group of indicators adequately reflects its corresponding latent construct. The hypotheses are formulated as follows:

H1: The observed indicators of the Institutional and Policy construct have standardized factor loadings ≥ 0.60 and are statistically significant.

H2: The observed indicators of the Human Resources construct have standardized factor loadings ≥ 0.60 and are statistically significant.

H3: The observed indicators of the Management construct have standardized factor loadings ≥ 0.60 and are statistically significant.

H4: The observed indicators of the Technology construct have standardized factor loadings ≥ 0.60 and are statistically significant.

H5: The observed indicators of the Economics construct have standardized factor loadings ≥ 0.60 and are statistically significant.

H6: The observed indicators of the Environment construct have standardized factor loadings ≥ 0.60 and are statistically significant.

When all hypotheses H1–H6 are supported, the measurement model is deemed valid and ready for subsequent structural model (SEM) analysis in the next stage of the research.

3. Research Methodology

3.1. Research Design and Implementation Procedure

This study adopts a quantitative research design, aiming to validate the reliability and construct validity of the six-factor measurement model influencing BIM adoption in construction project management in Vietnam. The research procedure was carried out in three main stages, as illustrated in Figure 2.

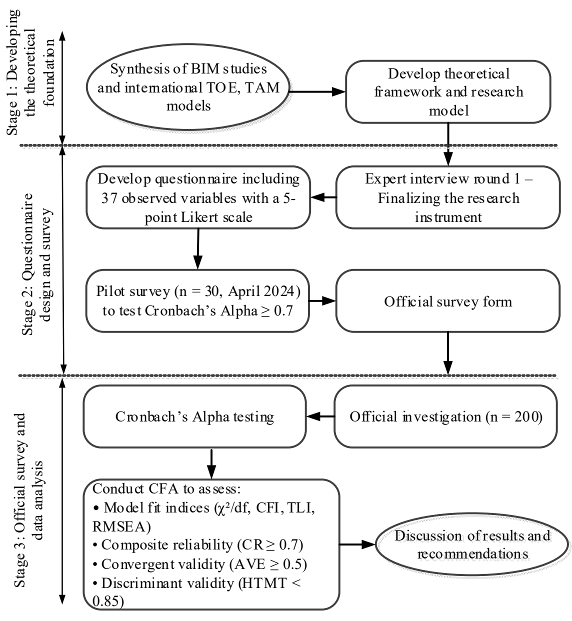

Figure 2. Research procedure for validating the BIM measurement model using CFA

Development of the Theoretical Basis and Preliminary Measurement Scale: The theoretical foundation and initial measurement scale were developed through an extensive synthesis of national and international studies related to BIM adoption and technology acceptance frameworks (TOE, TAM). In addition, an expert consultation process was conducted with five project management experts and three BIM lecturers to refine and contextualize the scale for the Vietnamese construction environment.

Questionnaire Design and Pilot Survey: The questionnaire consisted of 37 observed variables, measured using a 5-point Likert scale (1 - No influence; 2 - Slight influence; 3 - Moderate influence; 4 - Strong influence; 5 - Very strong influence). A pilot survey of 30 experts conducted in April 2024 assessed semantic clarity and preliminary reliability of the scale. All constructs achieved Cronbach's Alpha ≥ 0.70, indicating acceptable internal consistency.

Main Survey: The main survey was administered from May to July 2024, resulting in 200 valid responses collected from project owners, design consultants, construction contractors, and government regulatory agencies. Data were collected using a controlled purposive sampling approach to ensure balanced representation across stakeholder groups and enhance the generalizability of the results.

Data Analysis: Data were processed using SPSS 26 and AMOS 24 following two sequential steps:

(i) reliability testing using Cronbach's Alpha and Corrected Item–Total Correlation (CITC > 0.3).

(ii) Confirmatory Factor Analysis (CFA) to validate the measurement model, including assessments of overall model fit, composite reliability (CR), convergent validity (AVE), and discriminant validity.

3.2. Characteristics of the Survey Sample

The sample consisted of 200 experts working in project management, architectural/engineering design, construction execution, and construction consultancy in major cities such as Hanoi, Ho Chi Minh City, Da Nang, and other provinces with strong infrastructure development.

Table 3.1. Survey Respondent Groups

No.	Respondent Group	Quantity	Percentage (%)
1	Project Owners / Project Management Units	58	29%
2	Design Consultants	52	26%
3	Construction Contractors	60	30%
4	Government Agencies / Research Institutes	30	15%
	Total	**200**	**100%**

Work experience: 45% of respondents had more than 10 years of professional experience; 33% had between 5 and 10 years; and the remaining had less than 5 years of experience.

Educational background: 70% held a bachelor's degree, 25% held a master's degree, and 5% held a doctoral degree.

Level of BIM Knowledge: 60% had directly participated in BIM-enabled projects, while 40% possessed basic knowledge of BIM through training programs or professional seminars.

The diversity of the sample ensures a broad representation of professional perspectives and provides a reasonably comprehensive reflection of stakeholder perceptions regarding BIM adoption in Vietnam's construction sector.

3.3. Data Processing and Statistical Assumption Testing

Before conducting CFA, the dataset was screened and cleaned following rigorous statistical procedures (Volk, 2014):

Missing data: No variable exhibited more than 5% missing values; minor missing entries were replaced using median substitution.

Multivariate outliers: Identified and removed using Mahalanobis distance (D^2) with a significance threshold of $p < 0.001$, resulting in the elimination of 3 outlier cases.

Normality assessment: Skewness and Kurtosis values for all variables were within the acceptable range of ±2, meeting the assumptions required for CFA (Hair, 2019).

Multicollinearity check: All Variance Inflation Factor (VIF) values were below 3.3 and Tolerance values exceeded 0.3, confirming the absence of serious multicollinearity issues.

Common Method Bias (CMB): Harman's single-factor test indicated that the largest factor accounted for only 34.7% of the total variance (<50%). The ULMC (Unmeasured Latent Method Construct) test conducted in AMOS further confirmed that CMB did not materially affect the measurement model.

These procedures ensured the cleanliness, standardization, and inferential validity of the dataset prior to performing CFA.

3.4. CFA Model Evaluation Criteria

The evaluation of the measurement model followed three levels of assessment, based on the recommendations of (Hu & Bentler, 1999), (Hair, 2019), and (Henseler, 2015).

Overall Model Fit (Model Fit Indices):

- Chi-square/df (CMIN/df) ≤ 3.0
- Goodness of Fit Index (GFI) ≥ 0.90
- Comparative Fit Index (CFI) ≥ 0.90
- Tucker–Lewis Index (TLI) ≥ 0.90
- Root Mean Square Error of Approximation (RMSEA) ≤ 0.08

• A model that satisfies these thresholds is considered to demonstrate good overall fit.

Scale Reliability:

• Cronbach's Alpha ≥ 0.7

• Composite Reliability (CR) ≥ 0.7

Convergent and Discriminant Validity:

• Average Variance Extracted (AVE) ≥ 0.5

• Fornell–Larcker Criterion: the square root of AVE for each construct must be greater than its highest correlation with any other construct.

• HTMT (Heterotrait-Monotrait Ratio) < 0.85 for all construct pairs.

4. Results of Confirmatory Factor Analysis (CFA)

4.1. Preliminary Reliability Assessment

Before performing CFA, all measurement scales were evaluated using Cronbach's Alpha to ensure internal consistency. As shown in Table 4.1, all factor groups achieved Alpha coefficients above 0.70, meeting the reliability requirements.

Table 4.1. Cronbach's Alpha Results for the Factor Groups

No.	Factor	N of Items	Cronbach's Alpha	Notes
1	Institutional–Policy (TCCS)	6	0.916	Acceptable
2	Human Resources (NNL)	5	0.879	Acceptable
3	Management (QL)	6	0.901	Acceptable
4	Technology (CN)	6	0.883	Acceptable
5	Economics (KT)	5	0.864	Acceptable
6	Environment (MT)	4	0.821	Acceptable

All observed variables recorded Corrected Item–Total Correlation (CITC) values greater than 0.4, and none showed improved Alpha values upon deletion. This confirms that the scales are stable and suitable for CFA.

4.2. Results of the Overall Measurement Model Evaluation

CFA was conducted in AMOS 24 using the dataset of 200 samples. The results indicate that the six-factor measurement model with 37 observed variables demonstrates good fit with the empirical data, meeting international standards recommended by (Hu and Bentler, 1999).

Table 4.2. Model Fit Indices

Index	Symbol	Value	Threshold	Assess
Chi-square/df	CMIN/df	1.982	≤ 3.0	Good
Goodness of Fit Index	GFI	0.903	≥ 0.90	Good
Comparative Fit Index	CFI	0.942	≥ 0.90	Good
Tucker–Lewis Index	TLI	0.931	≥ 0.90	Good
Root Mean Square Error of Approximation	RMSEA	0.056	≤ 0.08	Accept-able
Standardized Root Mean Square Residual	SRMR	0.042	≤ 0.08	Good

Evaluating the overall model fit is essential to verify the alignment between the theoretical structure and the empirical data. Six standard CFA indices (Chi-square/df, GFI, CFI, TLI, RMSEA, SRMR) were used. The results - CMIN/df = 1.982, GFI = 0.903, SRMR = 0.042, CFI = 0.942, TLI = 0.931, and RMSEA = 0.056 - show that all values meet recommended thresholds. These fit indices confirm that the measurement model achieves strong goodness-of-fit and satisfies key methodological requirements, providing a solid basis for subsequent assessments of reliability, convergent validity, and discriminant validity across the six latent constructs.

4.3. Results of Composite Reliability and Convergent Validity Assessment

The Composite Reliability (CR) and Average Variance Extracted (AVE) values were calculated for each latent construct (Table 4.3). All CR values exceeded 0.7 and all AVE values were greater than 0.5, indicating good convergent validity of the measurement model (Marsh H. W., 2004).

Table 4.3. Composite Reliability and Convergent Validity of the Constructs

No.	CR	AVE	Standardized Loadings (λ)	Conclusion
TCCS	0.928	0.682	0.70–0.87	Acceptable
NNL	0.894	0.628	0.68–0.84	Acceptable
QL	0.915	0.654	0.73–0.86	Acceptable
CN	0.887	0.610	0.67–0.82	Acceptable
KT	0.876	0.593	0.64–0.80	Acceptable
MT	0.842	0.573	0.66–0.79	Acceptable

All standardized factor loadings (λ) were above 0.6 and statistically significant at $p < 0.001$, confirming that the indicators adequately reflect the latent constructs they represent.

4.4. Discriminant Validity Assessment

Discriminant validity is essential for confirming that each latent construct in the measurement model represents a unique conceptual domain. In this study, discriminant validity was assessed using both the Fornell - Larcker Criterion and the Heterotrait - Monotrait Ratio (HTMT). All HTMT values were below 0.85, satisfying the recommended threshold (Marsh H. W., 2004).

Table 4.4. Discriminant Validity Test Using the Fornell - Larcker Criterion

No.	TCCS	NNL	QL	CN	KT	MT
TCCS	**0.826**					
NNL	0.514	**0.792**				
QL	0.486	0.471	**0.809**			
CN	0.502	0.435	0.497	**0.781**		
KT	0.468	0.448	0.409	0.421	**0.770**	
MT	0.459	0.412	0.395	0.437	0.384	**0.757**

The square roots of AVE (diagonal elements) for each construct were higher than their correlations with other constructs, satisfying the Fornell - Larcker Criterion. This confirms that the six constructs in the model exhibit clear discriminant validity, are measured by distinct sets of indicators, and are conceptually separate from one another.

4.5. Theoretical and Practical Implications of CFA Findings

Theoretical implications: The successful validation of the six-factor measurement model demonstrates that the scales used in the Vietnamese context possess high reliability, strong convergent validity, and clear discriminant validity. This contributes to standardizing BIM measurement instruments for future quantitative research. The findings also confirm the suitability of applying CFA - SEM to BIM studies, aligning with international research trends on technology perception and behavioral modeling (Marsh H. W., 2004).

Practical implications: The validated factor structure helps identify core determinants that should be prioritized when implementing BIM in Vietnam, particularly Institutional and Policy factors, managerial capability, and technological infrastructure. This measurement model can be utilized to assess BIM readiness within organizations, serve as a supporting tool for policy development, or provide an evaluation framework for national BIM pilot projects.

5. Discussion and Research Implications

5.1. Analysis of Key Findings

The CFA results confirm that the six-construct measurement model with 37 observed variables meets international standards of reliability and validity, demonstrating its robustness and suitability for analyzing BIM adoption in the Vietnamese construction context.

The Institutional - Policy factor (TCCS) exhibits the strongest reliability (CR = 0.93, AVE = 0.68), reaffirming the decisive role of regulatory frameworks in driving BIM adoption, as observed in several Asian countries. In Vietnam, however, fragmented implementation and limited technical guidance continue to weaken the effectiveness of recent policy initiatives.

The Management (QL) and Human Resources (NNL) factors show high reliability and validity (CR > 0.88; AVE > 0.62), underscoring their mediating role between policy and practice. This highlights the critical importance of managerial commitment and workforce capability in a context where BIM expertise and standardized competencies remain limited.

The Technology factor (CN) demonstrates adequate convergent validity (CR = 0.887, AVE = 0.610), confirming the relevance of interoperability and infrastructure, yet technological readiness - particularly among SMEs - remains constrained, indicating that technology alone is insufficient without supportive management and awareness.

Finally, the Economic (KT) and Environment (MT) constructs meet validity thresholds (AVE = 0.59 and 0.57), reflecting persistent cost barriers, collaboration culture, and market pressure. Overall, the validated model provides a solid foundation for subsequent SEM-based causal analysis of BIM adoption in developing-country contexts.

5.2. Theoretical Contributions

The CFA results yield three major academic implications:

(i) Theoretical implications:

The study establishes a validated six-construct, 37-indicator measurement scale tailored to Vietnam, expanding the use of SEM in construction management research. The model confirms that BIM adoption is shaped by multidimensional interactions among institutional, human, managerial, technological, economic, and environmental factors - supporting the call for context-specific SEM frameworks in BIM research.

(ii) Methodological implications:

The analysis demonstrates that a 200-respondent dataset is adequate for validating a complex measurement model with six latent variables. Adherence to model fit, CR, AVE, and discriminant validity criteria strengthens methodological rigor, an aspect often lacking in previous domestic BIM studies. The combined use of Cronbach's Alpha and CFA ensures reliability and construct validity as a foundation for subsequent SEM analysis.

(iii) International comparative implications:

Compared with findings from Bahrain, Malaysia, China, and South Africa, Vietnam's measurement scale reflects stronger institutional and regulatory influences. This highlights the central role of government policy in early-stage BIM implementation - contrasting with developed countries, where user perception and organizational performance factors dominate.

6. Conclusion

This study validates a six-factor measurement model of BIM adoption in Vietnam's construction project management using CFA on data from 200 experts. The results confirm strong model fit, high reliability, and satisfactory convergent and discriminant validity, demonstrating the robustness of the proposed measurement framework.

The model captures six key determinants - Institutional - Policy, Human Resources, Management, Technology, Economic, and Environment - reflecting the realities of digital transformation in Vietnam's construction sector. Institutional - policy conditions, managerial capability, and technological readiness emerge as the most influential dimensions shaping BIM adoption.

Moreover, the standardized set of 37 observed variables provides a reliable measurement instrument for future quantitative BIM research, applicable both to Vietnam and to international comparative studies. The rigorous CFA procedures also establish a solid methodological foundation for subsequent SEM-based causal analysis, contributing to improved research quality in construction management studies.

Future research should extend this work by examining causal relationships among the factors, exploring mediating or moderating effects, and expanding samples across stakeholder groups to support evidence-based BIM policymaking in Vietnam.

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