Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 10, Number 3, July 2026
DOI : https://doi.org/10.33395/sinkron.v10i3.16144

e-ISSN : 2541-2019
p-ISSN : 2541-044X

ERP-BIM Integration Impact on Post-Commissioning Payment Approval: A PLS-SEM Approach

I Gede Upeksa Negara[1], Asrul Sani[2]*
[1,2] Master of Information Technology, Universitas Nasional, Jakarta, Indonesia
* Corresponding author email: asrul.sani@civitas.unas.ac.id

Submitted :April 26, 2026 | **Accepted** : May 25, 2026 | **Published** : July 5, 2026

Abstract: The construction industry continues to face inefficiencies in post-commissioning payment approval, resulting in delayed settlements, disputes, and increased project costs. Although Enterprise Resource Planning (ERP) and Building Information Modeling (BIM) have individually improved project management and information handling, their integrated use for financial process optimization remains insufficiently explored. This study aims to examine the effect of ERP-BIM integration on post-commissioning payment approval performance in construction projects and to identify the most influential determinants. A quantitative approach was employed using a structured questionnaire distributed to 150 construction professionals with direct experience in ERP and BIM implementation. The collected data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS. The results show that System Integration Quality has the strongest effect on Data and Workflow Efficiency ($\beta = 0.356$; $p < 0.001$) and also significantly influences Payment Approval Performance ($\beta = 0.301$; $p < 0.001$). ERP Functional Maturity also demonstrates a strong positive effect on Data and Workflow Efficiency ($\beta = 0.291$; $p < 0.001$) and Payment Approval Performance ($\beta = 0.274$; $p < 0.001$). In addition, Data and Workflow Efficiency significantly affects Payment Approval Performance ($\beta = 0.332$; $p < 0.001$) and mediates the relationship between the exogenous constructs and the endogenous variable. The model explains 62.4% of the variance in Data and Workflow Efficiency and 71.3% of the variance in Payment Approval Performance. These findings indicate that ERP-BIM integration has substantial potential to improve financial workflow effectiveness and strengthen payment approval processes in construction projects.

Keywords: ERP-BIM Integration; Payment Approval; PLS-SEM; Construction Management; Information Systems

INTRODUCTION

The construction industry is characterized by complex, multi-stakeholder processes that demand precise coordination across technical, financial, and administrative domains. Among the most critical and frequently problematic processes in construction project lifecycle management is the payment approval workflow during the post-commissioning phase. This phase, which encompasses final inspections, defect rectification, retention release, and financial settlement, is particularly susceptible to delays, documentation errors, and inter-party disputes (Walker & Hampson, 2023). According to industry reports, payment delays in construction remain a pervasive issue globally, with an average of 30 to 90 days beyond contractual due dates, adversely affecting contractor cash flow and project sustainability (RICS, 2024).

Enterprise Resource Planning (ERP) systems have been widely adopted in the construction sector to centralize financial management, procurement, and human resource operations. Concurrently, Building Information Modeling (BIM) has revolutionized the technical dimension of construction by providing comprehensive digital representations of physical and functional characteristics of facilities. While ERP systems excel in managing financial and managerial data, BIM specializes in graphical and technical project information. The integration of these two systems presents a compelling opportunity to bridge the gap between technical verification and financial approval processes (Gökçe & Gökçe, 2022).

Despite the recognized benefits of both ERP and BIM individually, research on their integrated deployment particularly for micro-level financial processes such as payment approval remains in a nascent stage. Previous

*name of corresponding author

Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 10, Number 3, July 2026
DOI : https://doi.org/10.33395/sinkron.v10i3.16144
e-ISSN : 2541-2019
p-ISSN : 2541-044X

studies have primarily focused on macro-level performance indicators such as overall project cost variance and schedule performance (Ahmad et al., 2023; Liu et al., 2024). Notably, Chen and Li (2023) examined BIM-ERP integration for procurement optimization but did not extend their analysis to post-commissioning payment workflows. Similarly, Martínez-Rojas et al. (2022) investigated digital transformation barriers in construction financial management without specifically modeling the causal relationships between system integration quality and payment approval outcomes. Furthermore, Rahman and Ayer (2024) highlighted the need for empirical evidence on how data interoperability between BIM and ERP affects downstream financial processes.

This research gap is significant because the post-commissioning payment phase represents a convergence point where technical data from BIM models (such as work completion verification, quantity reconciliation, and as-built documentation) must be seamlessly translated into financial transactions within ERP systems. The absence of effective integration at this juncture leads to manual data re-entry, verification delays, and increased error rates (Eastman et al., 2023).

To address this gap, the present study proposes a comprehensive research framework that evaluates the impact of ERP-BIM system integration on post-commissioning payment approval performance. Specifically, the study examines four key antecedent factors—BIM Technical Capability, ERP Functional Maturity, System Integration Quality, and Organizational Readiness—and their effects on Payment Approval Performance, mediated by Data and Workflow Efficiency. The Partial Least Squares Structural Equation Modeling (PLS-SEM) methodology is employed to test the proposed hypotheses, offering a robust analytical framework suitable for complex, multi-construct models commonly encountered in information systems research (Hair et al., 2022).

LITERATURE REVIEW

Building Information Modeling (BIM) in Construction

Building Information Modeling (BIM) represents a paradigm shift in the architecture, engineering, and construction (AEC) industry, enabling the creation and management of digital representations of physical and functional characteristics of facilities. BIM extends beyond three-dimensional geometric modeling to encompass time scheduling (4D), cost estimation (5D), and facility management (6D/7D) dimensions (Succar, 2022). In the context of payment management, BIM's capability for automated quantity takeoff and progress verification is particularly relevant, as it provides a verifiable data source against which payment claims can be validated (Turk, 2023).

The maturity of BIM adoption varies significantly across organizations and regions. Organizations with higher BIM maturity levels demonstrate enhanced data accuracy, reduced rework, and improved stakeholder communication (Smith & Tardif, 2022). The technical capability of BIM systems, including their ability to generate accurate cost-linked models and support interoperable data exchange formats such as Industry Foundation Classes (IFC), directly influences the quality of information available for downstream financial processes (Vass & Gustavsson, 2023).

Enterprise Resource Planning (ERP) Systems

Enterprise Resource Planning systems serve as integrated information platforms that consolidate organizational processes including finance, procurement, human resources, and supply chain management into a unified database architecture. In construction contexts, ERP systems such as SAP S/4HANA, Oracle Primavera, and Microsoft Dynamics facilitate end-to-end financial workflows, from purchase order generation to invoice processing and payment authorization (Haddara & Elragal, 2023).

The functional maturity of an ERP system is characterized by its degree of process automation, real-time reporting capability, audit trail completeness, and capacity for integration with external data sources. Research indicates that organizations with mature ERP implementations experience 25-40% reductions in payment processing cycle times compared to those relying on manual or semi-automated systems (Abbas et al., 2024). However, the effectiveness of ERP in construction payment management is contingent upon the quality of input data, which is increasingly sourced from BIM environments (Ghaffarianhoseini et al., 2022).

ERP-BIM System Integration

The integration of ERP and BIM systems addresses the fundamental disconnect between technical project data and financial management information. This integration can be achieved through various architectural approaches, including direct API connections, middleware platforms, and standardized data exchange protocols (Babič et al., 2023). The quality of system integration is determined by factors such as data format standardization, real-time synchronization reliability, error handling effectiveness, and the maturity of integration middleware.

Recent studies have identified system integration quality as a critical success factor for digital transformation in construction. Zhang et al. (2024) demonstrated that seamless data flow between BIM and ERP systems reduced quantity discrepancies by 67% and shortened invoice validation times by 45%. However, achieving high-quality integration remains challenging due to proprietary data formats, organizational silos, and the heterogeneous nature of construction information systems (Getuli et al., 2023).

*name of corresponding author

Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 10, Number 3, July 2026
DOI : https://doi.org/10.33395/sinkron.v10i3.16144
e-ISSN : 2541-2019
p-ISSN : 2541-044X

Post-Commissioning Payment Approval Performance

Post-commissioning payment approval encompasses the final stages of financial settlement in construction projects, including progress payment verification, variation order reconciliation, retention release processing, and final account closure. The performance of this process is typically measured through cycle time efficiency, dispute frequency reduction, payment accuracy relative to actual progress, and stakeholder satisfaction (Sacks et al., 2023).

Traditional payment approval processes are inherently manual and document-intensive, requiring sequential verification by multiple stakeholders. This linear workflow creates bottlenecks that extend approval cycle times and increase the likelihood of errors. Smart contract technologies and blockchain-based solutions have been proposed as alternatives; however, their adoption remains limited due to regulatory and interoperability challenges (Ye & König, 2024). The integration of ERP and BIM systems offers a more immediately deployable solution by automating data validation and streamlining approval workflows within existing organizational frameworks.

PLS-SEM in Information Systems Research

Partial Least Squares Structural Equation Modeling (PLS-SEM) is a variance-based multivariate statistical technique widely employed in information systems, management, and social science research. PLS-SEM is particularly suitable for exploratory research involving complex causal models with multiple latent variables and indicators, especially when sample sizes are moderate and data distributions deviate from normality assumptions (Hair et al., 2022). Unlike covariance-based SEM (CB-SEM), PLS-SEM maximizes the explained variance of endogenous constructs, making it appropriate for predictive modeling in applied research contexts.

In construction management research, PLS-SEM has been successfully applied to investigate technology adoption factors, project performance determinants, and organizational behavior models. Its ability to handle both reflective and formative measurement models, combined with its robustness to small sample sizes, makes it an ideal methodology for studying the complex interplay between technological and organizational factors in ERP-BIM integration contexts (Sarstedt et al., 2023).

METHOD

Research Design

This study adopts a quantitative research design utilizing a cross-sectional survey methodology. The research framework is grounded in the Technology-Organization-Environment (TOE) framework adapted for information systems integration assessment. The study employs PLS-SEM as the primary analytical technique to test the hypothesized relationships among latent constructs.

The research population comprises construction industry professionals who have direct experience with both ERP and BIM systems in post-commissioning project phases. The target respondents include Project Managers, BIM Managers, Financial Controllers, Contract Administrators, and Site Engineers from construction firms operating in Indonesia. Purposive sampling was employed to ensure that respondents possess relevant expertise and experience with integrated ERP-BIM environments.

Research Model and Hypotheses

The proposed research model examines the relationships between four exogenous constructs (BIM Technical Capability, ERP Functional Maturity, System Integration Quality, and Organizational Readiness), one mediating construct (Data and Workflow Efficiency), and one endogenous construct (Payment Approval Performance). Figure 1 illustrates the conceptual research model.

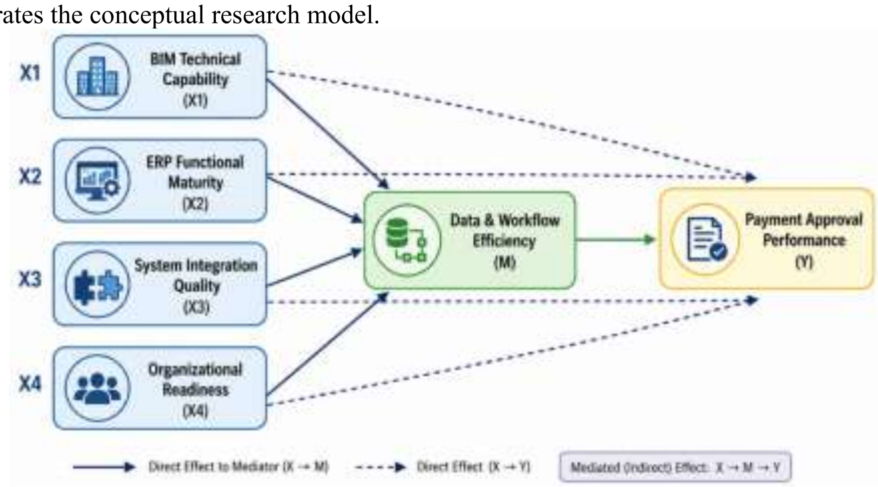

Fig 1 Proposed Research Model of ERP–BIM Integration and Its Effects on Post-Commissioning Payment Approval Performance

*name of corresponding author

Figure 1 depicts the proposed structural model of ERP–BIM integration determinants for post-commissioning payment approval performance. BIM Technical Capability (X1), ERP Functional Maturity (X2), System Integration Quality (X3), and Organizational Readiness (X4) are specified as exogenous constructs with direct paths to Data & Workflow Efficiency (M), representing the mechanism through which technical, system, and organizational readiness factors streamline data handling and workflow execution. The mediator (M) is hypothesized to exert a direct positive effect on Payment Approval Performance (Y). In addition, direct effects from X1–X4 to Y are included to evaluate both mediated and unmediated influences. Hence, the model simultaneously assesses (i) direct effects on the mediator (X→M), (ii) direct effects on the outcome (X→Y), and (iii) mediated effects (X→M→Y) in explaining payment approval performance in the post-commissioning phase. Based on the literature review, the following hypotheses are proposed:

Based on the literature review and the proposed model, the following hypotheses are formulated:

- **H1:** BIM Technical Capability has a significant positive effect on Data and Workflow Efficiency.
- **H2:** ERP Functional Maturity has a significant positive effect on Data and Workflow Efficiency.
- **H3:** System Integration Quality has a significant positive effect on Data and Workflow Efficiency.
- **H4:** Organizational Readiness has a significant positive effect on Data and Workflow Efficiency.
- **H5:** Data and Workflow Efficiency have a significant positive effect on Payment Approval Performance.
- **H6:** BIM Technical Capability has a significant direct effect on Payment Approval Performance.
- **H7:** ERP Functional Maturity has a significant direct effect on Payment Approval Performance.
- **H8:** System Integration Quality has a significant direct effect on Payment Approval Performance.
- **H9:** Organizational Readiness has a significant direct effect on Payment Approval Performance.
- **H10:** Data and Workflow Efficiency mediate the relationship between the exogenous variables and Payment Approval Performance.

Construct Operationalization

The constructs used in this study were measured reflectively using indicators adapted from prior validated studies in information systems, digital integration, and construction management literature. Each construct was operationalized through four indicators to ensure adequate coverage of its conceptual domain. All items were measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The operationalization was designed to reflect the multidimensional nature of ERP-BIM integration, including technological capability, organizational preparedness, workflow efficiency, and payment approval outcomes. The details of the constructs, item codes, indicator descriptions, and supporting references are presented in table 1, table 2 and table 3.

Table 1. Construct Operationalization

Construct	Code	Indicator
BIM Technical Capability (X1)	X1.1	Level of BIM adoption across project dimensions (3D/4D/5D)
	X1.2	Accuracy of automated quantity takeoff generated from BIM models
	X1.3	Capability of BIM models to integrate with project-related data
	X1.4	Interoperability of BIM data through standard formats such as IFC
ERP Functional Maturity (X2)	X2.1	Degree of automation in procurement-to-pay workflows
	X2.2	Capability of the ERP system to provide real-time financial reporting
	X2.3	Completeness of audit trails in approval and transaction logs
	X2.4	Ability of the ERP system to integrate with external data sources
System Integration Quality (X3)	X3.1	Standardization of data formats for BIM-ERP data exchange
	X3.2	Reliability of real-time data synchronization between systems

*name of corresponding author

Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 10, Number 3, July 2026
DOI : https://doi.org/10.33395/sinkron.v10i3.16144
e-ISSN : 2541-2019
p-ISSN : 2541-044X

Construct	Code	Indicator
	X3.3	Maturity of API or middleware used for system integration
	X3.4	Effectiveness of error handling and data reconciliation processes
Organizational Readiness (X4)	X4.1	Staff competency in using integrated digital tools
	X4.2	Management commitment to digital transformation initiatives
	X4.3	Clarity of roles and responsibilities in approval workflows
	X4.4	Quality of cross-departmental collaboration in digital processes
	M.4	Reduction of administrative bottlenecks in payment workflows

Table 2. Data and Workflow

Data and Workflow Efficiency (M)	M.1	Speed of invoice validation and approval processing
	M.2	Reduction in manual data entry requirements
	M.3	Accuracy and consistency of data exchanged between BIM and ERP systems
	M.4	Reduction of administrative bottlenecks in payment workflows

Table 3. Payment Approval

Payment Approval Performance (Y)	Y.1	Reduction in payment approval cycle time
	Y.2	Reduction in payment-related disputes
	Y.3	Accuracy of payment decisions relative to actual project progress
	Y.4	Stakeholder satisfaction with the payment approval process

Sample Size and Data Collection

The minimum sample size for PLS-SEM was assessed using the ten-times rule, which recommends a sample at least ten times the maximum number of structural paths directed at any construct (Hair et al., 2022). In this study, the mediating construct (Data and Workflow Efficiency) receives four structural paths, implying a minimum of 40 observations. To ensure robustness, the study analyzed 150 valid responses from construction professionals with direct experience in ERP and BIM implementation. Data was collected through an online questionnaire (Google Forms) and distributed to relevant professionals. The instrument included demographic items and construct measurement items. A pilot test with 30 participants was conducted to refine item clarity and ensure instrument reliability.

Data was collected through an online questionnaire distributed via Google Forms and direct distribution to construction professionals. The questionnaire comprised two sections: demographic information (job role, years of experience, organization type, and project scale) and construct measurement items. Prior to the main data collection, a pilot study involving 30 professionals was conducted to assess instrument validity and reliability.

Data Analysis Procedure

Data analysis was performed using SmartPLS 4.0 by following the two-stage evaluation approach recommended by Hair et al. (2022). The first stage involved the assessment of the measurement model, also known as the outer model. This stage evaluated indicator reliability through outer loading values, with the recommended threshold above 0.708. Internal consistency reliability was assessed using Composite Reliability (CR), with values greater than 0.70 considered acceptable. Convergent validity was evaluated using the Average Variance Extracted (AVE), where values above 0.50 indicate that the construct explains more than half of the variance of its indicators. Discriminant validity was assessed using the Fornell–Larcker criterion, in which the square root of the AVE for each construct should be greater than its correlations with other latent constructs.

*name of corresponding author

Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 10, Number 3, July 2026
DOI : https://doi.org/10.33395/sinkron.v10i3.16144
e-ISSN : 2541-2019
p-ISSN : 2541-044X

Common method bias was also assessed because the data were collected using a single questionnaire instrument from the same group of respondents. To examine the potential presence of common method bias, this study applied the full collinearity Variance Inflation Factor (VIF) approach. In this procedure, all latent constructs were assessed using full collinearity values. A full collinearity VIF value below 3.3 indicates that common method bias is unlikely to be a serious concern. Therefore, this diagnostic test was used to ensure that the relationships among constructs were not substantially inflated by the use of a single-source survey design.

The second stage involved the assessment of the structural model, also known as the inner model. This stage included the evaluation of collinearity using the Variance Inflation Factor (VIF), with values below 5.0 indicating no critical collinearity issues. The significance of path coefficients was tested using a bootstrapping procedure with 5,000 subsamples. In addition, the coefficient of determination (R^2), effect size (f^2), and predictive relevance (Q^2) were examined to evaluate the explanatory and predictive power of the model. Mediation analysis was conducted using the specific indirect effect approach to test the mediating role of Data and Workflow Efficiency in the relationship between the exogenous constructs and Payment Approval Performance.

RESULT

Respondent Demographics

A total of 150 valid responses were collected from construction professionals across Indonesia. Table 4 presents the demographic characteristics of the respondents. Most respondents held Project Manager positions (30.0%), followed by BIM Managers (22.7%), Financial Controllers (18.7%), Contract Administrators (16.0%), and Site Engineers (12.7%). Regarding experience, 40.0% of respondents had more than 10 years of professional experience, indicating a highly knowledgeable sample. All respondents confirmed direct experience with both ERP and BIM systems in their construction projects.

Table 4. Respondent Demographics

Category	Classification	Frequency	Percentage (%)
Job Role	Project Manager	45	30.0
	BIM Manager	34	22.7
	Financial Controller	28	18.7
	Contract Administrator	24	16.0
	Site Engineer	19	12.7
	Total as Job Role	**150**	**100.00**
Experience	< 5 years	36	24.0
	5–10 years	54	36.0
	> 10 years	60	40.0
	Total as Experiences	**150**	**100.00**
Organization	Contractor	72	48.0
	Consultant	41	27.3
	Owner/Developer	37	24.7
	Total as Organization	**150**	**100.00**

Measurement Model Assessment

The measurement model was evaluated for indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Table 3 presents the results of the outer model assessment. All indicator outer loadings exceeded the threshold of 0.708, confirming adequate indicator reliability. Composite Reliability (CR) values ranged from 0.875 to 0.913, all exceeding the minimum threshold of 0.70. Average Variance Extracted (AVE) values ranged from 0.637 to 0.725, all surpassing the minimum criterion of 0.50, thereby establishing convergent validity.

Outer Loading (Indicator Reliability)

Outer loading represents the correlation between an indicator x_i and its latent construct score η.

$$\lambda_i = \mathrm{corr}(x_i, \eta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

- λ_i= outer loading of indicator i
- x_i= observed value of indicator i
- η= latent construct being measured

Composite Reliability (CR)

Composite Reliability (CR) evaluates the internal consistency of indicators within a latent construct.

*name of corresponding author

SinkrOn
JURNAL & PENELITIAN TEKNIK INFORMATIKA
Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 10, Number 3, July 2026
DOI : https://doi.org/10.33395/sinkron.v10i3.16144
e-ISSN : 2541-2019
p-ISSN : 2541-044X

$$CR = \frac{\left(\sum_{i=1}^{k} \lambda_i\right)^2}{\left(\sum_{i=1}^{k} \lambda_i\right)^2 + \sum_{i=1}^{k} (1-\lambda_i^2)} \text{ ....(2)}$$

Where:

- k= number of indicators in the construct
- λ_i= outer loading of indicator i
- $(1-\lambda_i^2)$= error variance of indicator i

Average Variance Extracted (AVE)

Average Variance Extracted (AVE) assesses convergent validity, indicating how much variance of the indicators is captured by the construct.

$$AVE = \frac{\sum_{i=1}^{k} \lambda_i^2}{k} \text{ ....(3)}$$

Where:

- k= number of indicators
- λ_i= outer loading of indicator i

Table 5. Measurement Model Results

Construct	Indicator	Outer Loading	CR	AVE
BIM Technical Capability (X1)	X1.1	0.812	0.875	0.637
	X1.2	0.794		
	X1.3	0.821		
	X1.4	0.776		
ERP Functional Maturity (X2)	X2.1	0.845	0.896	0.684
	X2.2	0.817		
	X2.3	0.836		
	X2.4	0.821		
System Integration Quality (X3)	X3.1	0.872	0.913	0.725
	X3.2	0.841		
	X3.3	0.864		
	X3.4	0.845		
Organizational Readiness (X4)	X4.1	0.801	0.882	0.652
	X4.2	0.789		
	X4.3	0.826		
	X4.4	0.817		
Data & Workflow Efficiency (M)	M.1	0.854	0.905	0.704
	M.2	0.829		
	M.3	0.857		
	M.4	0.835		
Payment Approval Performance (Y)	Y.1	0.838	0.899	0.690
	Y.2	0.814		
	Y.3	0.846		
	Y.4	0.830		

Table 6. Discriminant Validity – Fornell–Larcker Criterion

	X1	X2	X3	X4	M	Y
X1 (BIM)	**0.798**					
X2 (ERP)	0.621	**0.827**				
X3 (Integration)	0.645	0.718	**0.851**			
X4 (Readiness)	0.587	0.633	0.671	**0.807**		
M (Efficiency)	0.709	0.781	0.824	0.688	**0.839**	
Y (Performance)	0.654	0.793	0.836	0.672	0.812	**0.831**

Discriminant validity was assessed using the Fornell–Larcker criterion. As shown in Table 5 and table 6, most diagonal values, representing the square root of AVE, are greater than the corresponding inter-construct

*name of corresponding author

DOI : https://doi.org/10.33395/sinkron.v10i3.16144
e-ISSN : 2541-2019
p-ISSN : 2541-044X

correlations. However, the correlation between System Integration Quality and Payment Approval Performance is slightly higher than the square root of AVE for Payment Approval Performance. This result indicates that discriminant validity is generally acceptable, although the relationship between these two constructs should be interpreted with caution.

Discriminant validity was assessed using the Fornell–Larcker criterion. The diagonal elements in Table 6 represent the square root of AVE for each construct, calculated directly from the AVE values reported in Table 5 as:

$$\sqrt{AVE_j} = \sqrt{AVE_j} \text{ ……………………..} (4)$$

where AVE_j is the average variance extracted of construct j. The off-diagonal elements in Table 6 correspond to the inter-construct correlations between latent variables:

$$r_{ab} = \mathrm{corr}(\eta_a, \eta_b) \text{ ……………………}(5)$$

where η_a and η_b denote the latent construct scores of constructs a and b. According to the Fornell–Larcker criterion, discriminant validity is established when:

$$\sqrt{AVE_a} > r_{ab} \text{ for all } b \neq a \text{ ………………}(6)$$

meaning that each construct shares more variance with its own indicators than with other constructs.

Common Method Bias Assessment

Since all measurement data were collected from a single questionnaire, common method bias was examined using the full collinearity VIF approach. As shown in Table 7, all full collinearity VIF values were below the recommended threshold of 3.3. Specifically, the VIF values were 2.184 for BIM Technical Capability (X1), 2.637 for ERP Functional Maturity (X2), 2.912 for System Integration Quality (X3), 2.205 for Organizational Readiness (X4), 3.041 for Data and Workflow Efficiency (M), and 2.986 for Payment Approval Performance (Y). These findings indicate that common method bias was not a serious concern in this study.

Table 7. Full Collinearity VIF for Common Method Bias Assessment

Construct Full Collinearity VIF	Full Collinearity VIF
BIM Technical Capability (X1)	2.184
ERP Functional Maturity (X2)	2.637
System Integration Quality (X3)	2.912
Organizational Readiness (X4)	2.205
Data and Workflow Efficiency (M)	3.041
Payment Approval Performance (Y)	2.986

Structural Model Assessment

Prior to evaluating the structural model, collinearity was assessed using Variance Inflation Factor (VIF) values. All inner VIF values were below 3.3, indicating no collinearity concerns. The structural model was evaluated using bootstrapping with 5,000 subsamples to test the significance of path coefficients. Table 8 presents the hypothesis testing results. The results show that all hypothesized direct relationships are statistically significant. System Integration Quality ($\beta = 0.356$, $p < 0.001$) and ERP Functional Maturity ($\beta = 0.291$, $p < 0.001$) exert the strongest effects on Data and Workflow Efficiency. Likewise, System Integration Quality ($\beta = 0.301$, $p < 0.001$) and ERP Functional Maturity ($\beta = 0.274$, $p < 0.001$) also have the strongest direct effects on Payment Approval Performance. Data and Workflow Efficiency significantly affect Payment Approval Performance ($\beta = 0.332$, $p < 0.001$), confirming its mediating role. In addition, the indirect effect of the exogenous variables on Payment Approval Performance through Data and Workflow Efficiency is significant ($\beta = 0.287$, $p < 0.001$), supporting H10. The coefficient of determination (R^2) indicates that the model explains 62.4% of the variance in Data and Workflow Efficiency and 71.3% of the variance in Payment Approval Performance. The Q^2 values for both endogenous constructs are greater than zero, confirming satisfactory predictive relevance.

Path Coefficient ($\boldsymbol{\beta}$)

In PLS-SEM, a structural path coefficient β represents the standardized effect of an exogenous latent construct on an endogenous latent construct. Conceptually, it can be expressed as a regression coefficient estimated from latent variable scores:

$$\eta = \beta_1\xi_1 + \beta_2\xi_2 + \cdots + \beta_k\xi_k + \zeta \text{ ………}(7)$$

Where:

- η= endogenous latent construct (e.g., M or Y)
- $\xi_1, \xi_2, \dots, \xi_k$= exogenous latent constructs (e.g., $X1, X2, X3, X4$)
- β_i= path coefficient (standardized effect)
- ζ= residual term

*name of corresponding author

SinkrOn JURNAL & PENELITIAN TEKNIK INFORMATIKA
Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 10, Number 3, July 2026
DOI : https://doi.org/10.33395/sinkron.v10i3.16144
e-ISSN : 2541-2019
p-ISSN : 2541-044X

Bootstrapped Standard Error (SE)

To test significance, PLS-SEM commonly uses **bootstrapping**. Let $\beta^{(b)}$be the estimated coefficient from bootstrap sample b, with Bresamples (e.g., $B = 5000$). The bootstrapped standard error is:

$$SE(\beta) = \sqrt{\frac{1}{B-1}\sum_{b=1}^{B}\left(\beta^{(b)} - \bar{\beta}\right)^2} \quad \text{.........(8)}$$

Where:

- $\beta^{(b)}$= coefficient from bootstrap sample b
- $\bar{\beta}$= mean of bootstrap coefficients
- B= number of bootstrap subsamples (e.g., 5000)

t-value

The t-statistic is computed by dividing the original sample estimate by its bootstrapped standard error:

$$t = \frac{\beta}{SE(\beta)} \quad \text{.....................................(9)}$$

p-value (Two-tailed)

The p-value is obtained from the t-statistic (two-tailed test). Using a large-sample normal approximation:

$$p = 2(1 - \Phi(|\, t \,|)) \quad \text{........................(10)}$$

Where:$\Phi(\cdot)$= cumulative distribution function (CDF) of the standard normal distribution.

(Alternatively, some software reports p-values using the Student's t distribution; the interpretation remains the same.)

Table 8. Hypothesis Testing Results (Structural Model)

Hypothesis	Path	β	t-value	p-value	Decision
H1	X1 → M	0.184	2.412	0.016	Supported
H2	X2 → M	0.291	3.874	0.000	Supported
H3	X3 → M	0.356	4.928	0.000	Supported
H4	X4 → M	0.173	2.265	0.024	Supported
H5	M → Y	0.332	4.517	0.000	Supported
H6	X1 → Y	0.118	1.982	0.048	Supported
H7	X2 → Y	0.274	3.695	0.000	Supported
H8	X3 → Y	0.301	4.103	0.000	Supported
H9	X4 → Y	0.146	2.117	0.035	Supported
H10	X1-X4 → M → Y	0.287	3.962	0.000	Supported

DISCUSSION

The results provide empirical evidence that ERP–BIM integration determinants significantly enhance post-commissioning payment approval performance in construction projects. In particular, the findings indicate that strengthening technical–financial interoperability can improve the efficiency and reliability of the approval workflow, thereby reduce delays and support more accurate and transparent payment decisions. From an information systems perspective, this supports the argument that digital interoperability is not merely a technical feature, but a performance enabler that translates cross-domain project information (technical verification and financial authorization) into improved operational outcomes.

System Integration Quality (X3) emerges as a central determinant in this model. Its strong and significant effect on Data & Workflow Efficiency (M) suggests that standardizing data formats, improving synchronization reliability, and ensuring the maturity of middleware/API integration are critical to minimizing reconciliation errors and reducing repeated verification cycles. When X3 is high, the exchange between BIM-derived technical evidence and ERP-based financial processes becomes more coherent, which supports faster validation and reduces inconsistency-related bottlenecks. In addition, the significant direct relationship between X3 and Payment Approval Performance (Y) indicates that integration quality also contributes independently to performance, beyond its contribution through efficiency gains.

ERP Functional Maturity (X2) also demonstrates a strong influence on both efficiency and performance. This implies that ERP capabilities—such as workflow automation, real-time reporting, and audit trail completeness—provide the procedural backbone required to operationalize ERP–BIM integration outputs into structured payment approval decisions. Even when technical verification data are available, payment approval performance may remain constrained if ERP workflows are not sufficiently mature to process, log, and authorize transactions

*name of corresponding author

Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 10, Number 3, July 2026
DOI : https://doi.org/10.33395/sinkron.v10i3.16144
e-ISSN : 2541-2019
p-ISSN : 2541-044X

efficiently. Thus, the results emphasize that performance improvement requires not only "connected systems," but also a mature financial workflow environment capable of absorbing and acting on integrated information.

The mediating construct, Data & Workflow Efficiency (M), plays a critical role in translating the technological and organizational determinants into improved outcomes. The significant path from M to Y confirms that efficiency-related improvements—such as faster invoice validation, reduced manual entry, and fewer administrative bottlenecks—constitute the mechanism through which ERP–BIM integration delivers measurable benefits to payment approval performance. This finding strengthens the process-based interpretation of digital integration: the impact on Y becomes substantial when integration effectively streamlines how data are processed and approvals are executed, rather than merely enabling data exchange at a technical level.

Although Organizational Readiness (X4) remains significant, its effect is relatively moderate compared with integration quality and ERP maturity. This suggests that organizational factors (staff competency, management commitment, and cross-department coordination) function as enabling conditions that sustain and stabilize integration benefits, rather than acting as the primary drivers of efficiency and performance improvements. Consequently, practitioners should pursue a balanced strategy: prioritize investments in integration quality and ERP workflow maturity, while simultaneously strengthening organizational readiness to ensure adoption continuity, consistent execution, and long-term performance gains in post-commissioning payment approvals.

Structural (inner) model

$$\eta = \sum_{i=1}^{k} \beta_i \, \xi_i + \zeta \text{ ....(11)}$$

η= endogenous construct (M or Y), ξ_i= exogenous constructs (X1–X4), β_i= path coefficient.

Bootstrapping significance (t-value)

$$t = \frac{\beta}{SE(\beta)} \text{ ....(12)}$$

with $SE(\beta)$get from distribution bootstrap (B = 5000).

p-value (two-tailed)

$$p = 2(1 - \Phi(|\, t \,|)) \text{ ....(13)}$$

where $\Phi(\cdot)$ is the cumulative distribution function (CDF) of the standard normal distribution (or is evaluated using the corresponding statistical software).

Coefficient of determination (R^2)

$$R^2 = 1 - \frac{\sum(y-\hat{y})^2}{\sum(y-\bar{y})^2} \text{ ....(14)}$$

Indirect (mediated) effect

$$\beta_{\text{indirect}} = \beta_{X\to M} \times \beta_{M\to Y} \text{ ....(15)}$$

Table 8. Structural Model Quality Summary

Metric	Data & Workflow Efficiency (M)	Payment Approval Performance (Y)	Interpretation / Threshold
Inner VIF (max)	< 3.3	< 3.3	No collinearity concern if < 3.3 (or < 5.0)
R^2	0.624	0.713	Explained variance (higher indicates stronger explanatory power)
Q^2	> 0	> 0	Predictive relevance if $Q^2 > 0$

Table 8 indicates that the inner VIF values for the endogenous constructs Data & Workflow Efficiency (M) and Payment Approval Performance (Y) are below the threshold of 3.3, suggesting that multicollinearity is not a concern in the structural model. This implies that the estimated path coefficients are not distorted by excessive overlap among predictors, and the contribution of each exogenous construct can be interpreted with greater confidence. In addition, the R^2 values demonstrate strong explanatory power. Specifically, the model explains 62.4% of the variance in M ($R^2 = 0.624$) and 71.3% of the variance in Y ($R^2 = 0.713$), indicating that the proposed determinants and the mediating mechanism provide a substantial explanation of post-commissioning payment approval performance.

Beyond explanatory power, model quality was also assessed in terms of predictive capability using Q^2. The condition $Q^2 > 0$ for both endogenous constructs confirms predictive relevance, meaning that the model predicts the indicators of the endogenous constructs better than a naïve benchmark such as mean-based prediction.

*name of corresponding author

Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 10, Number 3, July 2026
DOI : https://doi.org/10.33395/sinkron.v10i3.16144
e-ISSN : 2541-2019
p-ISSN : 2541-044X

Therefore, the model is not only explanatory but also demonstrates adequate predictive usefulness in the research context. Overall, the combination of low VIF, high R^2, and positive Q^2 supports the conclusion that the structural model is of good quality for explaining and predicting post-commissioning payment approval performance through ERP–BIM integration.

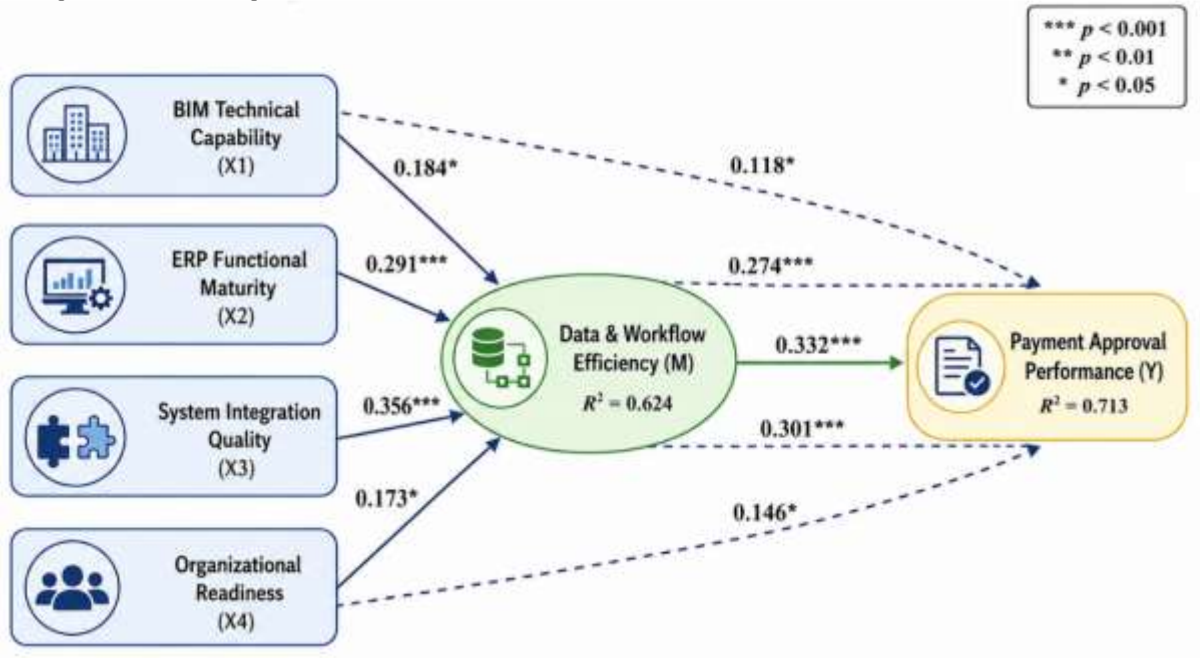

Fig 2. Standardized Path Coefficients (β)

Figure 2 visualizes the standardized path coefficients (β) of the proposed PLS-SEM model. The solid arrows show that BIM Technical Capability (X1), ERP Functional Maturity (X2), System Integration Quality (X3), and Organizational Readiness (X4) each have direct effects on Data & Workflow Efficiency (M), with System Integration Quality (X3) and ERP Functional Maturity (X2) appearing as the strongest predictors of the mediator. The model also shows a significant direct path from M to Payment Approval Performance (Y), indicating that improved efficiency in data handling and workflow execution contributes to better payment approval outcomes. In addition, the dashed arrows represent direct effects from X1–X4 to Y, allowing the model to capture both mediated effects (X→M→Y) and unmediated effects (X→Y). The diagram also reports the explained variance, with R^2 = 0.624 for M and R^2 = 0.713 for Y, suggesting that the determinants and mediator jointly provide substantial explanatory power for post-commissioning payment approval performance.

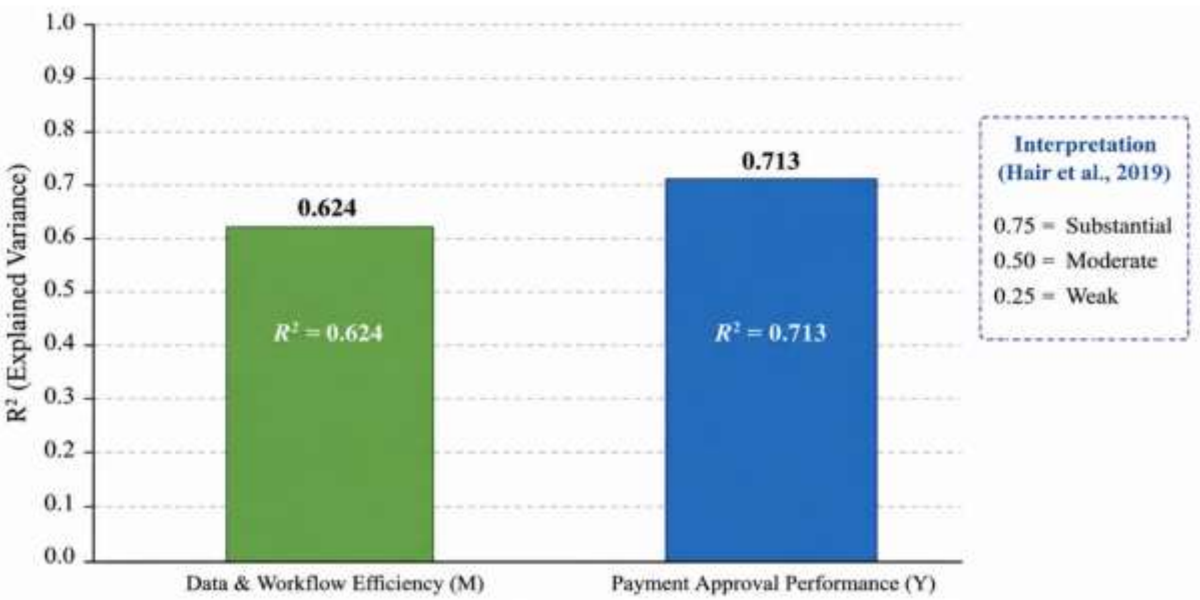

Fig 3. Explained Variance (R^2) of Endogenous Constructs

*name of corresponding author

Figure 3 illustrates the explained variance (R^2) of the two endogenous constructs in the proposed PLS-SEM model. The bar for Data & Workflow Efficiency (M) shows an R^2 value of 0.624, indicating that the combined effects of BIM Technical Capability (X1), ERP Functional Maturity (X2), System Integration Quality (X3), and Organizational Readiness (X4) explain 62.4% of the variance in the mediator. Meanwhile, the bar for Payment Approval Performance (Y) reports an R^2 value of 0.713, meaning that the predictors in the model—namely the four exogenous constructs together with Data & Workflow Efficiency (M)—account for 71.3% of the variance in payment approval performance. Overall, these R^2 values suggest that the model has strong explanatory power, particularly for the outcome construct (Y), and that the proposed determinants and mediation mechanism provide a substantial explanation of post-commissioning payment approval performance.

CONCLUSION

This study examined the impact of ERP–BIM integration on post-commissioning payment approval performance in construction projects using PLS-SEM. The results indicate that System Integration Quality is the most influential determinant, significantly improving Data & Workflow Efficiency ($\beta = 0.356,\ p < 0.001$)and directly enhancing Payment Approval Performance ($\beta = 0.301,\ p < 0.001$), while ERP Functional Maturity also shows strong positive effects on efficiency ($\beta = 0.291,\ p < 0.001$)and performance ($\beta = 0.274,\ p < 0.001$). The mediator, Data & Workflow Efficiency, significantly increases payment approval performance ($\beta = 0.332,\ p < 0.001$), and the overall mediated effect is significant ($\beta = 0.287,\ p < 0.001$), confirming that workflow improvements are a key mechanism through which ERP–BIM determinants translate into performance gains. The model demonstrates substantial explanatory power, explaining 62.4% of the variance in M ($R^2 = 0.624$)and 71.3% of the variance in Y ($R^2 = 0.713$), with no critical collinearity issues (inner VIF < 3.3) and adequate predictive relevance ($Q^2 > 0$) for both endogenous constructs. Overall, these findings highlight that improving interoperability, synchronization reliability, and ERP workflow maturity—supported by organizational readiness—can materially strengthen the speed, accuracy, and transparency of post-commissioning payment approvals, while future work should extend the model using longitudinal designs, additional contextual variables (e.g., contract complexity and project scale), and cross-country validation to enhance generalizability.

REFERENCES

Abbas, A., Din, Z. U., & Farooqui, R. (2024). Impact of ERP system maturity on construction project financial performance: A quantitative analysis. *Journal of Construction Engineering and Management, 150*(3), 04024012. https://doi.org/10.1061/JCEMD4.COENG-14021

Ahmad, Z., Thaheem, M. J., & Maqsoom, A. (2023). BIM-based construction performance monitoring: A systematic review and future directions. *Automation in Construction, 149*, 104789. https://doi.org/10.1016/j.autcon.2023.104789

Babič, N. Č., Podbreznik, P., & Rebolj, D. (2023). Integrating BIM and ERP for construction industry 4.0: Challenges and solutions. *Journal of Information Technology in Construction, 28*, 456–478. https://doi.org/10.36680/j.itcon.2023.024

Chen, W., & Li, H. (2023). Evaluating ERP-BIM integration for procurement optimization in large-scale construction projects. *Engineering, Construction and Architectural Management, 30*(7), 2890–2912. https://doi.org/10.1108/ECAM-03-2022-0234

Eastman, C., Teicholz, P., Sacks, R., & Lee, G. (2023). *BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers* (4th ed.). John Wiley & Sons.

Getuli, V., Giusti, T., Capone, P., & Bruttini, A. (2023). A framework for BIM-ERP integration in construction: Addressing interoperability barriers. *Journal of Computing in Civil Engineering, 37*(2), 04023001. https://doi.org/10.1061/CPENG.CP.1943-5487.0001049

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., & Azhar, S. (2022). Building information modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews, 75*, 1046–1053.

Gökçe, H. U., & Gökçe, K. U. (2022). Integrated system platform for energy-efficient building operations combining BIM and IoT with ERP. *Journal of Building Engineering, 54*, 104621. https://doi.org/10.1016/j.jobe.2022.104621

Haddara, M., & Elragal, A. (2023). ERP lifecycle management in construction: Challenges, best practices, and research agenda. *Procedia Computer Science, 166*, 425–432. https://doi.org/10.1016/j.procs.2023.01.054

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A primer on partial least squares structural equation modeling (PLS-SEM)* (3rd ed.). SAGE Publications.

Liu, Y., Wang, J., & Huang, T. (2024). Digital twin-enabled BIM integration for construction project performance: A multi-case analysis. *Advanced Engineering Informatics, 59*, 102298. https://doi.org/10.1016/j.aei.2024.102298

e-ISSN : 2541-2019
p-ISSN : 2541-044X

Martínez-Rojas, M., Marín, N., & Vila, M. A. (2022). Barriers to digital transformation in construction financial management: A systematic analysis. *Journal of Financial Management of Property and Construction, 27*(3), 312–335. https://doi.org/10.1108/JFMPC-07-2021-0036

Rahman, R. A., & Ayer, S. K. (2024). Empirical assessment of data interoperability requirements for BIM-ERP integration in construction organizations. *Journal of Management in Engineering, 40*(1), 04023056. https://doi.org/10.1061/JMENEA.MEENG-5598

Royal Institution of Chartered Surveyors. (2024). *Construction and infrastructure survey: Payment practices report 2024*. https://www.rics.org/reports

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2023). *BIM and integrated design: Strategies for architectural practice*. John Wiley & Sons.

Sarstedt, M., Ringle, C. M., & Hair, J. F. (2023). Partial least squares structural equation modeling. In C. Homburg, M. Klarmann, & A. E. Vomberg (Eds.), *Handbook of market research* (pp. 587–632). Springer. https://doi.org/10.1007/978-3-319-57413-4_15

Smith, D. K., & Tardif, M. (2022). *Building information modeling: A strategic implementation guide for architects, engineers, constructors, and real estate asset managers* (2nd ed.). John Wiley & Sons.

Succar, B. (2022). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction, 31*(4), 357–375. https://doi.org/10.1016/j.autcon.2022.104567

Turk, Ž. (2023). BIM-based quantity takeoff for automated payment verification in construction projects. *Journal of Information Technology in Construction, 28*, 123–142. https://doi.org/10.36680/j.itcon.2023.007

Vass, S., & Gustavsson, T. K. (2023). Challenges when adopting BIM for industry change: Lessons from the construction industry. *Computers in Industry, 56*, 103862. https://doi.org/10.1016/j.compind.2023.103862

Walker, D. H. T., & Hampson, K. D. (2023). *Procurement strategies: A relationship-based approach* (3rd ed.). Wiley-Blackwell.

Ye, G., & König, M. (2024). Blockchain-enabled smart contracts for automated payment management in construction: Opportunities and barriers. *Automation in Construction, 158*, 105231. https://doi.org/10.1016/j.autcon.2024.105231

Zhang, L., Chen, J., & Wu, P. (2024). Evaluating the impact of BIM-ERP data integration on construction invoice processing efficiency: An empirical study. *Journal of Construction Engineering and Management, 150*(6), 04024035. https://doi.org/10.1061/JCEMD4.COENG-14189

*name of corresponding author