

Beyond Quantity Validation: Developing a BIM-Based Project Quantity Risk Index (PQRI) for Risk-Informed Construction Project Control

Sultan N. Alkarawi 

College of Engineering, Department of Civil Engineering, University of Diyala, Baqubah, 32001, Iraq
snmalk8@gmail.com

Abstract

The use of Building Information Modeling (BIM) in quantification has improved the efficiency and accuracy of estimation within construction projects. BIM quantity methods have remained limited to differences and accuracy measurements, without providing adequate support for project control decisions. In project management, quantity differences are effective only when they are translated into managerial, technical, or operational effects that may affect project performance. The Project Quantity Risk Index (PQRI) was proposed as a risk-based framework for transforming BIM quantification results into decision-support information. The Explanatory Risk Index (ERI), Managerial Impact (MI), and other indicators have been combined into a composite index to prioritize quantity-related risks. The framework was applied to a BIM-supported building project comprising 48 structural and finished elements. Descriptive statistics, correlation, and sensitivity analysis were used to examine the model's behavior and robustness. The results showed an average PQRI value of 0.379, indicating a moderate risk level. Internal Paint, Decorative Cladding, and Internal Wall Plaster were identified as the highest-risk elements. Correlation results indicated that explanatory and managerial factors were more strongly associated with PQRI than deviation measures alone. Overall, the proposed framework shifts BIM quantity validation from numerical comparisons toward risk-informed managerial prioritization and project control support.

Keywords: Project Quantity Risk Index (PQRI), (BIM), Project Control, Decision Support Systems, Project Risk Assessment.

Article history: Received: 14 Jun 2026, Accepted: 2 Aug 2026, Published: 15 Sep 2026.

This article is open-access under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Building information modeling (BIM) has become an essential part of the digital transformation in the architecture, engineering, and construction (AEC) sector. One of its most widely used applications is Quantity Take-off (QTO), which allows automated extraction of quantification from digital models, improving information consistency and supporting cost estimation, procurement planning, and project control activities [22] and [3]. The increasing reliance on BIM quantities has increased the efficiency of quantitative accounting and enhanced the traceability of information throughout the project lifecycle. The reliability of quantities extracted from BIM, referred

to as QBIM, remains related to model quality, information completeness, modeling assumptions, and level of development (LOD). In practice, differences between QBIM and actual executed quantities (QA) continue to emerge. They may affect cost forecasts, procurement procedures, and construction coordination [10] and [11]. Verification procedures have therefore become a necessary tool for examining the consistency of BIM-derived quantity information.

Current verification methods rely on indicators such as Percentage Deviation (PD), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE). These indicators only show the numerical difference and do not adequately reflect their administrative

importance. In construction projects, convergent variations may be recorded. At the same time, their effects vary depending on technical complexity, coordination requirements, and operational priority. So, differences in quantities are not explained by numerical comparison alone; they are related to the conditions of the affected activity. These oddities may be reflected in procurement planning, resource allocation, schedule performance, and management priorities [18], [8], and [20].

In previous studies, procedures for extracting and verifying quantities using BIM have been developed to a high degree of clarity. Automated inspection systems have contributed to improved technical accuracy. The interpretation of differences as project risks remained limited. In most studies, the differences between QBIM and QA were treated as separate digital outputs. At the same time, the specific technical and administrative conditions of their practical implications received insufficient attention. This deficiency limits the usefulness of verification results for project tuning. This constraint is addressed by developing the Project Quantity Risk Index (PQRI), so that quantitative verification does not stop at measuring differences. However, it extends to project tuning from a risk-based perspective. The Deviation Ratio (PD), Squared Error (SE), Explanatory Risk Index (ERI), and Managerial Impact (MI) are combined into a composite index, through which structural elements are assessed by their overall level of exposure to project risk, rather than by the magnitude of the deviation alone.

The focus of this research is on four points: building a framework that links quantitative variances to risk drivers and management impact indicators; formulating and evaluating the PQRI as a composite quantitative risk index; examining its application in a BIM-powered project; and verifying its relevance through expert opinions. Theoretically, quantification verification has been expanded from a measurement activity to a framework that supports decision-making and project control. By PQRI, the validation results were linked to risk drivers and managerial impact, supporting risk ranking within the project management literature and the BIM domain.

2. Literature Review

Quantity management in construction projects has been improved by Building Information Modeling (BIM). Automated quantity take-off (QTO) can be generated directly from the project's digital models. Prior research has demonstrated improvements in estimation efficiency, information consistency, and cost management processes, especially in projects that require complex design coordination [12], [3], and [22]. As BIM expanded, research attention has shifted from just quantity extraction to examining the reliability of the quantities generated from the model.

Recent studies have indicated that differences between quantities extracted from BIM (QBIM) and quantities actually executed (QA) are influenced by several factors, including model completeness, level of development (LOD), quality of element transactions, design adjustments, and interdisciplinary coordination [11], [9], and [14]. Automated validation procedures and model inspection techniques have enhanced the detection of quantity inconsistencies. These methods still measure differences primarily with numerical indicators such as Mean Squared Error (MSE), Percentage Deviation (PD), and Root Mean Squared Error (RMSE). The explanation of these variations from an administrative perspective is still insufficient. Structural elements may exhibit close deviations, while their impacts on the project are determined by the degree of associated coordination requirements, technical complexity, and operational importance. Digital deviation measures, therefore, provide only a partial reading of the level of exposure to the risks associated with the quantities.

Another research track has been towards project risk management and project control theories. Frameworks in this area focus on identifying sources of risk, assessing potential outcomes, and ranking management responses according to project exposure level [18], [8], and [7]. Although the role of BIM in supporting project control functions has expanded, the link between BIM-based quantitative measurement, project risk assessment, and management prioritization has remained limited. The studies summarized in Table 1 show that BIM research has often focused on quantitative extraction and verification accuracy. In contrast, project

management research has been oriented toward risk assessment and management prioritization.

Table 1: Summary of Previous Studies.

Authors & Ref.	Year	Research Focus	Main Contribution	Limitation
Monteiro & Poças Martins [12], and Yun & Kim [26]	2013	BIM-based quantity extraction	Improved digital quantity-estimation workflows	No project-risk assessment
Fazeli et al. [6] and Wahab & Wang [24]	2020 2021	BIM data quality evaluation	Examined the reliability of BIM quantity information	Limited managerial interpretation
Khosakitchalert et al. [9]	2019	Quantity take-off accuracy	Evaluated the accuracy of BIM-derived quantities	Focused on numerical validation
Kim et al. [11] and Sigalov & König [17]	2019 2017	Quantity discrepancy analysis	Identified sources of quantity variation	No risk-prioritization framework
Valinejadshoubi et al.[21], and Valinejadshoubi et al.[22]	2021 2024	Automated BIM validation	Developed automated quantity-control procedures	Limited integration with project management
Alathamneh et al. [3], and Volk et al. [23]	2024 2014	BIM-enabled quantity management	Enhanced quantity-estimation efficiency	No risk assessment component
Ahuja et al. [1], Olsen & Taylor [13], and Singh & Williams [18]	2017 2021	Project Risk Management	Established risk-prioritization principles	Not linked to BIM quantity validation
This Study		BIM quantity validation and project-risk assessment	Development of the Project Quantity Risk Index (PQRI)	Integrates discrepancies, contextual risk drivers, and managerial impact

The integration of these two paths within a unified framework remains insufficient. Differences in current verification methods are often interpreted as digital outputs. In contrast, quantitative verification information is not clearly integrated into project risk frameworks. This chapter limits the practical value of validation results for project tuning applications. This deficiency is addressed by developing the Project Quantity Risk Index (PQRI). The Percentage Deviation (PD) and Squared Error (SE) indices have been combined with the contextual factors of the Explanatory Risk Index (ERI) and Managerial Impact (MI). Through this mechanism, quantitative validation results are converted into project-related information used to rank risks, allocate resources, and support project control decisions in BIM-based construction environments.

3. Research Methodology

3.1 Research Framework and Data Collection

The methodological framework for this research was developed to convert BIM quantification results into project risk information to prioritize management and support project control decisions. As shown in **Fig. 1**, the mechanism first extracts BIM-based quantities (QBIM) and then compares them with the quantities actually executed (QA). The resulting differences are assessed using numerical indicators, which are then combined with contextual risk factors to formulate the Project Quantity Risk Index (PQRI). The pilot data included 48 structural and architectural elements from a BIM-supported building project, including construction and finishing works. For each component, quantitative data, explanatory risk characteristics, and management impact assessments were collected and structured for analysis.

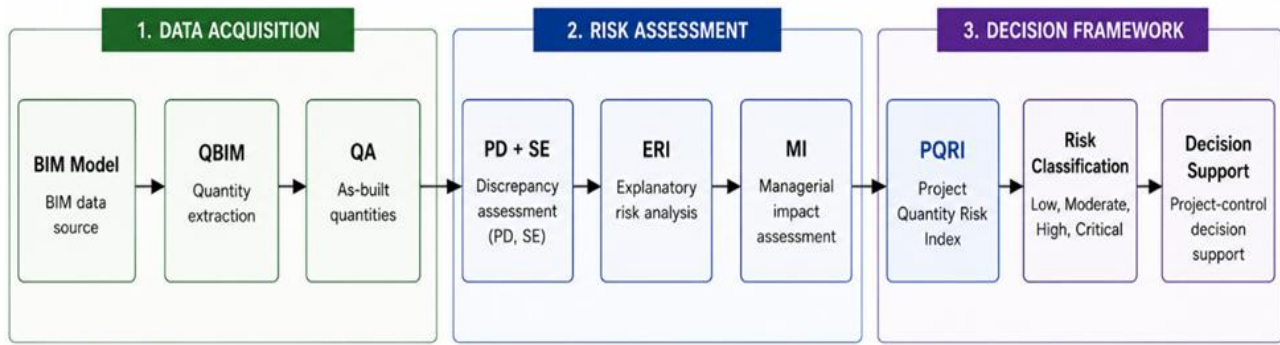


Fig. 1 Research Methodology Framework

Table 2 shows the variables used in the framework. It integrates quantitative, technical, and managerial features to assess project risks associated with quantities from a project-control perspective, rather than relying solely on digital comparisons.

Table 2: Dataset and Variable Summary

Category	Description
Project Type	Government Building Project
Number of Elements	48
Construction Categories	Structural and Finishing Works
Quantity Sources	BIM-Generated Quantities (QBIM) and As-Built Quantities (QA)
Discrepancy Measures	Percentage Deviation (PD), Squared Error (SE)
Risk Indicators	Explanatory Risk Index (ERI), Managerial Impact (MI)
Final Output	Project Quantity Risk Index (PQRI)

3.2 Discrepancy Assessment

The differences between BIM quantities (QBIM) and quantities actually executed (QA) were first examined. To measure it numerically, use Percentage Deviation (PD) according to Equation (1):-

$$PD(\%) = \frac{|Q_A - Q_{BIM}|}{Q_A} * 100 \quad (1)$$

Where: PD = Percentage Deviation (%), Q_A = As-built quantity, Q_{BIM} = BIM-generated quantity. Squared Error (SE) was subsequently calculated using Equation (2): -

$$SE = (Q_{AQ} - Q_{BIM})^2 \quad (2)$$

These indicators measure the severity of the differences and, based on them, build on the subsequent risk assessment phase.

3.3 Development of the PQRI Framework

Variance indicators alone do not capture quantity risk. Therefore, the Explanatory Risk Index (ERI) was developed to measure the technical conditions that affect changes in quantities. Additionally, the managerial Impact (MI) was introduced to represent the potential management impacts of the affected item. The ERI was calculated using Equation (3): -

$$ERI = \frac{C + DS + OD + LOD + RS + CI + RP + COE + MD}{27} \quad (3)$$

Where (C) = complexity, (DS) = Detail Sensitivity, (OR) = Opening Reliability, (LOD) = Level of Development Adequacy, (RS) = Revision Sensitivity, (CI) = Cost Impact, (RP) = Rework Potential, (COE) = Change Order Exposure, (MD) = Monitoring Difficulty.

The number (27) expresses the highest degree among the nine explanatory features. Higher ERI values indicate increased technical complexity, modification sensitivity, coordination requirements, and managerial accreditation. Thus, the structural element is exposed to higher risks. The inclusion of contextual factors shows that the project's exposure to risk is not limited to digital changes only. It is also affected by the technical and administrative conditions associated with the affected activity [19]. The final (PQRI) was calculated using Equation (4):

$$PQRI = 0.25(PD_n) + 0.25(SE_n) + 0.25(ERI) + 0.25(MI_n) \quad (4)$$

Where: PD_n = Normalized Percentage Deviation, SE_n = Normalized Squared Error, ERI_n = Normalized Explanatory Risk Index, MI_n = Normalized Managerial Impact. The aggregation of normalized indicators into a composite index follows established composite-indicator development procedures

commonly used in decision-support and risk-assessment studies [4] and [16].

Table 3. Weighting Structure of PQRI Components.

Component	Description	Weight
PD_n	Normalized Percentage Deviation	0.25
SE_n	Normalized Squared Error	0.25
ERI	Explanatory Risk Index	0.25
MI_n	Normalized Managerial Impact	0.25

In the present dataset (Table 3), equal weighting was applied to maintain transparency in index construction and reduce subjective bias, especially given that the analysis involves several risk dimensions in an exploratory setting [24] and [5].

Fig. 2 illustrates how to convert quantitative verification results into actionable information to inform the project, assess risk, and guide corrective actions.

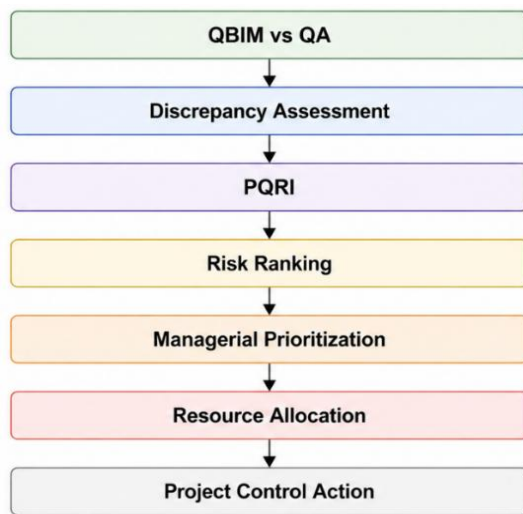


Fig. 2 PQRI-Based Project Control Decision Framework

3.4 Validation Procedures

Verification was done across two tracks: the first track focused on statistical verification. Descriptive statistics, order analysis, and correlation analysis were used. The relationship between PQRI and its component variables was examined. Correlation coefficients were used to estimate the impact of quantitative differences and contextual factors in project risk assessment. In the context of decision support and project management, integrating

statistical verification with expert assessment is essential to ensure analytical robustness and workability [25] and [18].

The second track included preliminary verification by three construction professionals: a Project Manager, a BIM Engineer, and a Cost Control Engineer. Each of them has over 10 years of experience. The framework was evaluated in terms of its relevance to project control, ease of understanding, ability to regulate risk, applicability, and its value in supporting the decision. This verification provided professional and empirical evidence of the usability and stability of the proposed framework.

4. Results and Discussion

4.1 Overall Risk Characteristics

Table 4 presents the key variables in the Project Quantity Risk Index (PQRI). The average PQRI was 0.379, and the project was ranked as Moderate Risk. The data indicate that quantitative risks were not evenly distributed but were concentrated in specific elements. Although the values of Percentage Deviation (PD) and Squared Error (SE) varied, the PQRI range appeared narrower because the level of risk was determined by the combined effect of the Explanatory Risk Index (ERI) and the Managerial Impact (MI). It is also inferred from $ERI = 0.678$ and $MI = 3.75$ that changes in quantities are explained not only numerically but also by their technical and administrative conditions [25].

Table 4: Descriptive Statistics of Major Variables

Variable	Mean	Std. Dev.	Min	Max
PD (%)	4.22	1.297	0	7.609
SE	138.92	530.313	0	3025
ERI	0.678	0.169	0.333	1
MI	3.75	0.838	2	5
$PQRI$	0.379	0.084	0.198	0.538

4.2 Priority Risk Elements

Table 5 and Fig. 3 show the items that need the most administrative follow-up. The highest values were recorded for Internal Paint ($PQRI = 0.538$), Decorative Cladding ($PQRI = 0.513$), and Internal Wall Plaster ($PQRI = 0.506$), all rated as High Hazard. It is noted that the arrangement was determined not solely by the magnitude of the

deviation but also by the heights of the ERI and MI. This shows the role of management impact and coordination requirements in prioritizing risks [5] and [7]. Project control resources are directed towards activities with the highest impact.

Table 5: Top-Ranked Construction Elements According to PQRI

Rank	Element	PQRI	Risk Level
1	Internal Paint	0.538	High
2	Decorative Cladding	0.513	High
3	Internal Wall Plaster	0.506	High
4	Waterproofing Layers	0.493	Moderate
5	Glass Partitions	0.493	Moderate
6	Gypsum Board Ceilings	0.491	Moderate
7	Ribbed Slabs	0.489	Moderate
8	Hollow Block Slabs	0.488	Moderate
9	Transfer Beams	0.486	Moderate
10	Deep Beams	0.485	Moderate

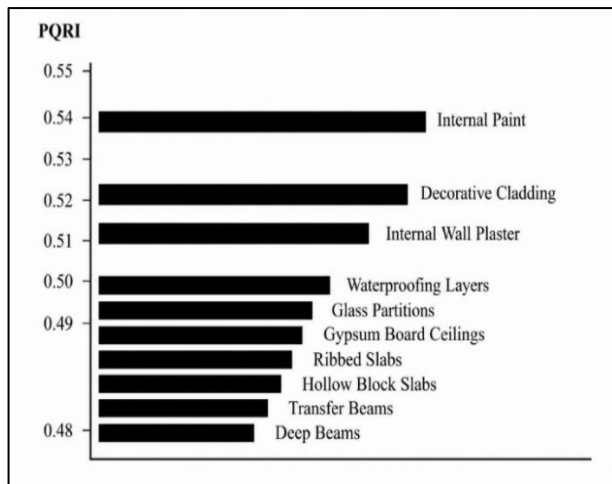


Fig. 3. The Top 10 Highest PQRI Scores of Construction Elements.

4.3 Validation of the PQRI Framework

Table 6 shows the correlation matrix for the variables within the PQRI framework. A positive relationship was recorded between PQRI and ERI ($r = 0.826$). A weak relationship between PQRI and PD ($r = -0.108$) was recorded, and a strong positive relationship was recorded between PQRI and MI ($r = 0.789$). The data

show that risk quantities were not affected solely by the size of the spreads. Rather, it was influenced by the technical and administrative context. Therefore, it supports the insertion of ERI and MI under PQRI. The priority of risk is explained more clearly in this context. They are not adequately explained by individual numerical indicators [15] and [2].

Table 6: Correlation Matrix of Major Variables

Variable	PD	SE	ERI	MI	PQRI
PD	1	-0.194	-0.118	0.031	-0.108
SE	-0.194	1	0.42	0.21	0.358
ERI	-0.118	0.42	1	0.703	0.826
MI	0.031	0.21	0.703	1	0.789
PQRI	-0.108	0.358	0.826	0.789	1

4.4 Expert Validation

The applicability of the framework in the construction sector was examined by three experts: a BIM Engineer, a Cost Control Engineer, and a Project Manager. Each one has more than ten years of experience. The average rating was 4.68/5. This indicates acceptance of the framework's usability and suitability. The highest rating was recorded for the risk rating support standard (4.9). The criterion of correlation with project control was recorded with a value of 4.8. Table 7 demonstrates how PQRI supports project tuning and management priorities in BIM-based construction settings.

Table 7: Expert Validation of the PQRI Framework

Validation Criterion	Mean Score (1–5)	Interpretation
Relevance to Project Control	4.8	Very High
Practical Applicability	4.6	Very High
Support for Risk Prioritization	4.9	Very High
Ease of Interpretation	4.4	High
Decision-Making Support	4.7	Very High
Overall Mean Score	4.68	Very High

5. Conclusions and Implications

The Project Quantity Risk Index (PQRI) was developed and assessed in this research. PQRI is regarded as a risk-based extension for checking BIM quantities. The Percentage Deviation (PD) and Squared Error (SE) indicators have been combined with the Explanatory Risk Index (ERI) and the Managerial Impact (MI). The frame was applied to 48 structural and architectural elements. The results show that the magnitude of the deviation alone does not limit quantitative risks.

Nevertheless, they are affected by technical complexity, coordination requirements, and administrative outcomes. The project was classified as moderate risk with an average PQRI score of 0.379. The highest levels of risk were detected in Internal Paint, Decorative Cladding, and Internal Wall Plaster. This indicates the need for closer follow-up and greater management attention. Correlation analysis showed that PQRI's relationship with ERI and MI was stronger than its relationship with other indicators. This supported the introduction of technical and managerial dimensions in quantitative risk assessment.

BIM quantities verification has been transformed from a measurement-focused process into a framework that supports project tuning and decision-making. The PQRI provides a structured mechanism for risk ranking, resource allocation, and corrective action prioritization. The study was limited to a single BIM-supported construction project. Equal weights were used for methodological clarity. The PQRI exam is recommended for various project types and geographical contexts. It also suggests studying alternative weighing methods, such as expert judgment, Delphi techniques, and machine learning-based risk models.

Acknowledgement

The authors would like to express their appreciation to the University of Diyala/ Department of Civil Engineering for supporting this study and to all parties involved. The authors also express their utmost appreciation to those who provided enormous assistance.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

References

- [1] Ahuja, R., Sawhney, A., & Arif, M. (2017). Prioritizing BIM Capabilities of an Organization: An Interpretive Structural Modeling Analysis. *Procedia Engineering*, 196, 2-10.
<https://doi.org/https://doi.org/10.1016/j.proeng.2017.07.166>
- [2] Akroyd, C., Barros, R. S., Löfvstål, E., Pan Fagerlin, W., & Wu, J. Y. (2026). Management control for innovation: a review and research directions. *Qualitative Research in Accounting & Management*, 23(3), 261-280.
<https://doi.org/10.1108/qram-02-2026-0050>
- [3] Alathamneh, S., Collins, W., & Azhar, S. (2024). BIM-based quantity take-off: Current state and future opportunities. *Automation in Construction*, 165, 105549.
<https://doi.org/https://doi.org/10.1016/j.autcon.2024.105549>
- [4] Center, J. R. (2008). *Handbook on constructing composite indicators: methodology and user guide*. OECD Publishing.
- [5] Chernyi, A., & Uotila, J. (2024). Prioritization of organizational stakeholders: A managerial decision-making perspective. *Journal of Business Research*, 185, 114882.
<https://doi.org/https://doi.org/10.1016/j.jbusres.2024.114882>
- [6] Fazeli, A., Dashti, M. S., Jalaee, F., & Khanzadi, M. (2020). An integrated BIM-based approach for cost estimation in construction projects. *Engineering, Construction and Architectural Management*, 28(9), 2828-2854.
<https://doi.org/10.1108/ecam-01-2020-0027>
- [7] Hutchins, G. (2018). *ISO 31000: 2018 enterprise risk management*. Greg Hutchins.
- [8] Kerzner, H. (2025). *Project management: a systems approach to planning, scheduling, and controlling*. John Wiley & Sons.
- [9] Khosakitchalert, C., Yabuki, N., & Fukuda, T. (2019). Improving the accuracy of BIM-based quantity take-off for compound elements. *Automation in Construction*, 106, 102891.
<https://doi.org/https://doi.org/10.1016/j.autcon.2019.102891>
- [10] Khosakitchalert, C., Yabuki, N., & Fukuda, T. (2020). Automated modification of compound elements for accurate BIM-based quantity take-off. *Automation in Construction*, 113, 103142.

- <https://doi.org/https://doi.org/10.1016/j.autcon.2020.103142>
- [11] Kim, S., Chin, S., & Kwon, S. (2019). A Discrepancy Analysis of BIM-Based Quantity Take-Off for Building Interior Components. *Journal of Management in Engineering*, 35(3), 05019001.
[https://doi.org/doi:10.1061/\(ASCE\)ME.1943-5479.0000684](https://doi.org/doi:10.1061/(ASCE)ME.1943-5479.0000684)
- [12] Monteiro, A., & Poças Martins, J. (2013). A survey on modeling guidelines for quantity takeoff-oriented BIM-based design. *Automation in Construction*, 35, 238-253.
<https://doi.org/https://doi.org/10.1016/j.autcon.2013.05.005>
- [13] Olsen, D., & Taylor, J. M. (2017). Quantity Take-Off Using Building Information Modeling (BIM), and Its Limiting Factors. *Procedia Engineering*, 196, 1098-1105.
<https://doi.org/https://doi.org/10.1016/j.proeng.2017.08.067>
- [14] Parsamehr, M., Perera, U. S., Dodanwala, T. C., Perera, P., & Ruparathna, R. (2023). A review of construction management challenges and BIM-based solutions: perspectives from the schedule, cost, quality, and safety management. *Asian Journal of Civil Engineering*, 24(1), 353-389.
<https://doi.org/10.1007/s42107-022-00501-4>
- [15] Pfister, J. A., Peda, P., & Otley, D. (2023). A methodological framework for theoretical explanation in performance management and management control systems research. *Qualitative Research in Accounting & Management*, 20(2), 201-228.
<https://doi.org/https://doi.org/10.1108/QRAM-10-2021-0193>
- [16] Schultz, R., Arndt-Basche, C., Davidson, P., & Gerloff, B. (2019). Better indicators for better regulation: the OECD iREG experience. *ICE, Revista de Economía*(907).
<https://doi.org/https://doi.org/10.32796/ice.2019.907.6806>
- [17] Sigalov, K., & König, M. (2017). Recognition of process patterns for BIM-based construction schedules. *Advanced Engineering Informatics*, 33, 456-472.
<https://doi.org/https://doi.org/10.1016/j.aei.2016.12.003>
- [18] Singh, H., & Williams, P. S. (2021). A guide to the project management body of knowledge: PMBOK® Guide. Project Management Institute,
- [19] Testorelli, R., Ferreira de Araújo Lima, P., & Verbano, C. (2022). Fostering project risk management in SMEs: an emergent framework from a literature review. *Production Planning & Control*, 33(13), 1304-1318.
<https://doi.org/10.1080/09537287.2020.1859633>
- [20] Turner, J. R. (2014). The handbook of project-based management (Vol. 92). McGraw-Hill Education, New York, NY.
- [21] Valinejadshoubi, M., Moselhi, O., Bagchi, A., & Salem, A. (2021). Development of an IoT and BIM-based automated alert system for thermal comfort monitoring in buildings. *Sustainable Cities and Society*, 66, 102602.
<https://doi.org/https://doi.org/10.1016/j.scs.2020.102602>
- [22] Valinejadshoubi, M., Moselhi, O., Iordanova, I., Valdivieso, F., & Bagchi, A. (2024). Automated system for high-accuracy quantity take-off using BIM. *Automation in Construction*, 157, 105155.
<https://doi.org/https://doi.org/10.1016/j.autcon.2023.105155>
- [23] Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in Construction*, 38, 109-127.
<https://doi.org/https://doi.org/10.1016/j.autcon.2013.10.023>
- [24] Wahab, A., & Wang, J. (2021). Factors-driven comparison between BIM-based and traditional 2D quantity take-off in construction cost estimation. *Engineering, Construction and Architectural Management*, 29(2), 702-715.
<https://doi.org/10.1108/ecam-10-2020-0823>
- [25] Yonts, T. D. (2025). The Evaluation of Uncertainty in the Early Phases of Project Management [The George Washington University].
- [26] Yun, S., & Kim, S. (2013). Basic research on BIM-based quantity take-off guidelines. *Architectural Research*, 15(2), 103-109.
<https://doi.org/http://dx.doi.org/10.5659/AIKA.R.2013.15.2.103>
- [27]