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Performance Monitoring Model for Time and Cost Efficiency in Building Construction Projects: An Empirical Study Supporting SDG 9

Bukhori[1*], Antonius[2], Kartono Wibowo[2]

[1]Universitas Swadaya Gunung Jati, Cirebon, Indonesia
[2]Sultan Agung Islamic University, Semarang, Indonesia.

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ABSTRACT

Objective: *To develop and evaluate an integrated performance monitoring model based on Earned Value Management (EVM) and Building Information Modeling (BIM) to improve time, cost, and quality efficiency in building construction projects.* ***Method:*** *A quantitative case study approach was applied using data from 204 building construction projects in Indonesia. The analysis employed Earned Value Analysis (EVA), correlation analysis, and multiple linear regression, with support from SPSS and BIM-based simulation tools.* ***Results:*** *The findings show that 50% of projects achieved a Cost Performance Index (CPI) between 1.0 and 1.1, while 60% recorded a Schedule Performance Index (SPI) between 0.9 and 1.1. In addition, 75% of projects met quality standards as measured by the Quality Performance Index (QPI). The integrated model significantly improves the early detection of project deviations and enhances the efficiency of corrective actions.* ***Novelty:*** *Integration of Earned Value Management (EVM) and Building Information Modeling (BIM) into a unified performance monitoring framework that enables real-time, data-driven decision-making for cost, time, and quality control in construction projects under external uncertainty conditions. This integrated framework also provides practical contributions to SDG 9 (Industry, Innovation and Infrastructure) by supporting innovative, resilient, and efficient infrastructure project management through digital performance monitoring.*

INTRODUCTION

Building construction projects are an important sector that supports infrastructure development worldwide, especially in developing countries such as Indonesia. In recent decades, the demand for commercial, residential, and public facilities has continued to increase along with population growth and urbanization. However, despite the increasing need for infrastructure, building construction projects often face significant challenges related to implementation time and costs. Inaccuracy in project planning and execution often causes delays in completion and budget overruns. This phenomenon, in addition to affecting the company's productivity and reputation, reduces the project's overall efficiency (Memon et al., 2011).

Many construction projects experience delays due to inaccurate planning, design changes during construction, and ineffective coordination among project stakeholders. These conditions result in significant cost increases, especially during critical phases of construction. In addition, external factors such as macroeconomic changes, government regulations, and construction material market conditions also contribute to uncertainty in the implementation of building construction projects (Aziz, 2013). Therefore, a comprehensive approach is needed to track project progress in real time, so that deviations from the initial plan can be identified early and corrective actions can be taken immediately.

Earned Value Management (EVM) is one of the most widely used methods for monitoring the performance of construction projects, especially in time and cost management. EVM provides important indicators, such as the Cost Performance Index (CPI) and Schedule

Performance Index (SPI), which help project managers in evaluating project performance quantitatively (Aliverdi et al., 2013). With EVM, project managers can assess how efficiently the budget is being used and how closely the project is staying on schedule. In addition, this method enables more accurate monitoring of deviations during the construction process, enabling faster, more targeted corrective actions.

However, in this digital era, traditional monitoring methods such as EVMs need to be strengthened by integrating more sophisticated technologies. One technology that has proven effective in increasing the efficiency of construction projects is Building Information Modeling (BIM). BIM is a digital platform that enables project stakeholders to collaborate in an integrated environment, where all information on the design, construction, and management of a building is stored within a three-dimensional virtual model (Kim et al., 2013). This technology not only enables comprehensive project visualization before construction begins but also helps detect potential problems during construction, such as design clashes or the use of inappropriate materials. A study by Latiffi et al. (2015) showed that BIM implementation significantly reduces the risk of costly design changes and improves time and cost efficiency. In addition, BIM enables project simulations across various scenarios, allowing project managers to make better decisions regarding resource allocation and scheduling.

These developments are closely aligned with Sustainable Development Goal 9 (SDG 9), which emphasizes building resilient infrastructure, promoting sustainable industrialization, and fostering innovation. The adoption of digital technologies such as EVM and BIM in construction project management represents an important step toward improving infrastructure efficiency, strengthening project resilience, and supporting data-driven decision-making in the construction industry. Therefore, innovative performance-monitoring approaches are increasingly needed to address the growing complexity and uncertainty in infrastructure development projects. This is in line with the results of research by Kim et al. (2013), which found that using BIM in construction projects can improve collaboration among teams and reduce errors caused by miscommunication.

Time management in construction projects is one of the main challenges often faced by project managers. Delays in project completion can be caused by various factors, ranging from inadequate planning to unexpected design changes during implementation. According to Navon (2005), the use of Earned Value Management (EVM) for monitoring project time performance allows project managers to identify deviations from the predetermined schedule more clearly. EVM provides indicators such as the Schedule Performance Index (SPI), which describes how well the project is running on schedule. If the SPI is below 1, the project is behind schedule, and the project manager needs to take immediate action to improve the situation.

In addition to EVM, the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) are widely used techniques for managing construction project time. CPM helps identify the critical path in a project, which is the sequence of activities that must be completed on time for the project to meet the set schedule (Hegazy & Ayed, 1998). Meanwhile, PERT allows for more flexible scheduling by accounting for the uncertainty in each activity's duration. By using these two techniques, project managers can plan time more accurately and anticipate potential delays.

Cost management in construction projects is also a very crucial aspect. According to Memon et al. (2011), effective cost management depends not only on the accuracy of budget estimates but also on project managers' ability to monitor and control expenditures during project implementation. Earned Value Management (EVM) allows the evaluation of project cost performance by measuring the difference between the value of work completed and the actual costs incurred. The Cost Performance Index (CPI) generated by the EVM indicates whether the project is under, within, or over the established budget.

However, the challenges in cost management do not come only from internal project factors. However, they are also influenced by external factors, such as fluctuations in material prices and changes in government regulations (Enshassi et al., 2009). For example, increases in raw material prices, such as steel and cement, driven by changes in global economic conditions, can significantly raise a project's total cost. In addition, government regulations, which often change, can result in additional costs to ensure compliance with established standards. Therefore, a deep understanding of market conditions and applicable regulations is essential for project managers to manage costs effectively.

The use of Building Information Modeling (BIM) technology not only helps in time management but also plays an important role in managing construction project costs. With BIM, project managers can simulate budgets and identify potential cost waste before the project begins (Kim et al., 2013). BIM also facilitates coordination among the design team, implementers, and project management, thereby reducing the risk of miscommunication that can lead to additional costs during project implementation, it can see in Figure 1.

Figure 1. Illustration of project monitoring using BIM technology

In addition to technical factors, external factors such as government regulations and economic conditions significantly impact construction project performance. According to Enshassi et al. (2009), strict regulations regarding occupational safety, environmental protection, and technical standards can add an administrative burden to construction projects, thereby increasing costs and delaying completion times. On the other hand, economic fluctuations affecting raw material prices and labor availability can also complicate project planning and implementation. Therefore, project managers need to anticipate these changes and prepare effective contingency plans. Overall, this study focuses on developing a performance-monitoring model for implementation in building construction projects to address challenges in time and cost management. By integrating the Earned Value Management (EVM) method and Building Information Modeling (BIM) technology, this model is expected to improve the efficiency of building construction projects through more comprehensive, real-time monitoring.

In addition, this model aims to assist project managers in dealing with external factors, such as economic changes and government regulations, that can affect overall project performance.

RESEARCH METHODS

Research approach

This study uses a quantitative approach with a case study design on building construction projects in Indonesia. The quantitative approach was chosen because it focuses on measuring and analyzing numerical data related to project cost and time performance using the Earned Value Management (EVM) and Building Information Modeling (BIM) methods (Balali et al., 2020; Elsaid et al., 2025; Elseufy et al., 2026). The case study design allows researchers to explore in depth the application of performance monitoring models in real contexts (Annamalah, 2024; Cespedes-Cubides & Jradi, 2024; Ebneyamini & Sadeghi Moghadam, 2018). The data used include project reports, field observation results, and interviews with project stakeholders. This study aims to evaluate the effectiveness of the performance monitoring model in improving cost and time efficiency, as well as to provide implementation strategies that project managers can adopt to address external challenges such as material price fluctuations and changes in government regulations (De Marco & Narbaev, 2021; Owusu, 2024).

Population and sample

The study covers building construction projects across major Indonesian cities, including Jakarta, Surabaya, Bandung, Medan, and Makassar. A total of 204 construction projects were used to determine the research sample (Bukhori, 2023). The number of project samples was calculated using the Slovin formula to obtain a representative sample size from the population, accounting for the accepted margin of error. The sample was selected through purposive sampling, with the selected projects being medium- to large-scale projects that implemented EVM and/or BIM-based performance monitoring methods. Variations in project types, such as residential, commercial, and public facility projects, were included in this study to ensure that the research results could be applied to different types of construction projects in the context of time and cost management (Aliverdi et al., 2013).

Data collection technique

Data collection was carried out using several methods, namely:

a. Data secondary

   Secondary data is drawn from reports on ongoing and completed projects over the last 3 to 5 years. These reports include detailed information on project budgets, implementation schedules, and the use of EVM and BIM in project management. The data collected includes details of actual costs incurred, planned and realized schedules, and performance indicators such as the Cost Performance Index (CPI) and Schedule Performance Index (SPI). In addition, reports from project stakeholders are used to understand the challenges faced during project implementation and how performance monitoring methods are applied to address them (Rahimian et al., 2020).

b. Observation direct

   Direct observation was conducted at several project locations to obtain a field overview of the performance monitoring model's implementation. This observation focused on the use of BIM for detecting design errors, daily field supervision, and data collection using EVM (Golparvar-Fard et al., 2009).

c. Interview semi-structured
   Interviews were conducted with project managers, technical teams, and other stakeholders to gain practical perspectives on the application of EVM and BIM in construction projects (Kissi et al., 2019).

Research variables

a. Performance cost
   Project cost performance is measured by the Cost Performance Index (CPI), a metric in the EVM method. CPI is calculated as the ratio of the value of work completed to the actual costs incurred. A CPI greater than 1 indicates the project is under budget, while a CPI less than 1 indicates cost overruns (Aliverdi et al., 2013).
b. Performance time
   Project time performance is measured using the Schedule Performance Index (SPI), which is also an indicator in EVM (De Marco & Narbaev, 2021).
c. Influence factor external
   External variables include economic conditions, fluctuations in material prices, and government regulations (Zhao et al., 2020).

Data analysis techniques

This study uses several analysis techniques to evaluate the data collected:

a. Earned value analysis (EVA)
   EVA is used to measure a project's cost and time performance based on data collected through the EVM (Aliverdi et al., 2013).
b. Analysis correlation
   Correlation analysis is used to evaluate the relationship between BIM usage and improvements in project efficiency (Braun et al., 2015).
c. Multiple linear regression analysis
   Multiple linear regression is used to analyze the influence of internal and external factors on project cost and time performance (Zhao et al., 2020).
d. Data validation and reliability
   Validity and reliability were assessed using triangulation and Cronbach's Alpha, with values above 0.7 considered reliable (Kissi et al., 2019).

Use of analysis tools

This study uses analytical tools such as SPSS and Microsoft Excel to facilitate statistical data processing and visualization. In addition, Autodesk Revit is used to implement BIM technology for project simulation and visualization of the construction process (Owusu, 2024).

Validity and reliability

Data validity was tested through triangulation of data from various sources, including project reports, observations, and interviews with stakeholders. Reliability testing was conducted using Cronbach's Alpha, with a value above 0.7 considered reliable (Kissi et al., 2019).

RESULTS AND DISCUSSION

Results

Data analysis

The data of this study were collected through a survey distributed to project managers, contractors, and field supervisors in five major cities in Indonesia: Jakarta, Surabaya, Bandung, Medan, and Makassar. The study respondents were 204 people, including project directors, field supervisors, supervisory consultants, project managers, and site engineers, all involved in the implementation of construction projects. The selection of respondents was intended to capture a comprehensive overview of construction project execution from both managerial and operational perspectives. This diversity of respondents allows the study to reflect real-world conditions in project implementation, particularly regarding monitoring practices using Earned Value Management (EVM) and Building Information Modeling (BIM), it can see in Table 1.

Table 1. Respondents' age distribution

No.	Age Range	Number of Respondents
1.	25-30	30
2.	30-35	20
3.	35-40	30
4.	40-45	40
5.	45-50	35
6.	50-55	30
7.	55-60	25

Figure 2 the age distribution indicates that most respondents are in the productive working age range, suggesting they have sufficient field experience in construction project monitoring. This condition strengthens the validity of the responses obtained.

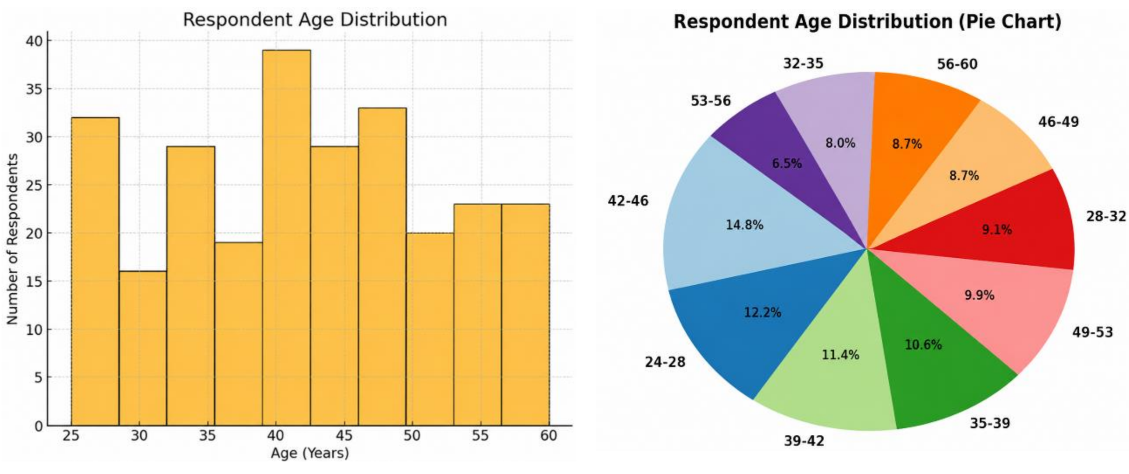

Figure 2. Respondent age distribution

Table 2. Distribution of respondents' positions

No.	Position	Number of Respondents
1.	Project Director	60
2.	Field supervisor	60
3.	Supervising Consultant	55
4.	Project Manager	50
5.	Site Engineering	45

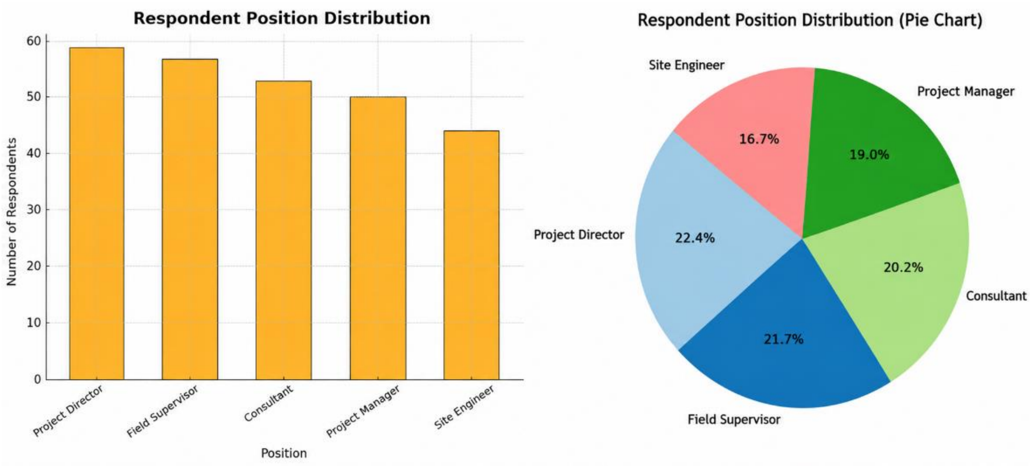

Figure 3. Distribution of respondents' positions

Table 2 and Figure 3 are the distribution of positions shows that the majority of respondents are directly involved in project execution and supervision. This ensures that the data collected represents both strategic and technical perspectives in construction project monitoring.

Table 3. Project location distribution

No.	Project Type	Number of Respondents
1.	Semarang	45
2.	Surabaya	45
3.	Bandung	40
4.	Medan	35
5.	Yogyakarta	35
6.	Macassar	30

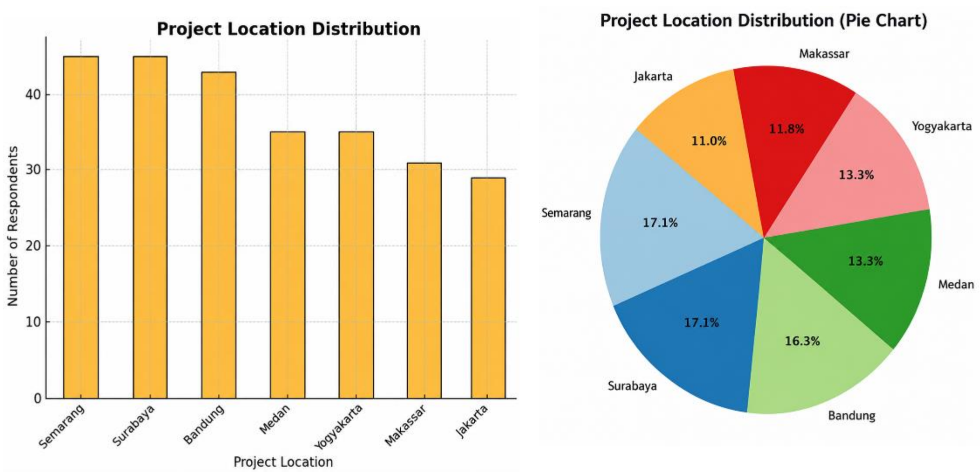

Figure 4. Project location distribution

Table 2 and Figure 4 the geographical distribution of projects indicates that the research covers a wide range of urban development areas in Indonesia. This variation provides a broader representation of construction project conditions in different regional contexts.

Table 4. Project type distribution

No.	Project Type	Number of Respondents
1.	Bridge	45
2.	Building Construction	45
3.	Road Infrastructure	40
4.	Other Projects	35

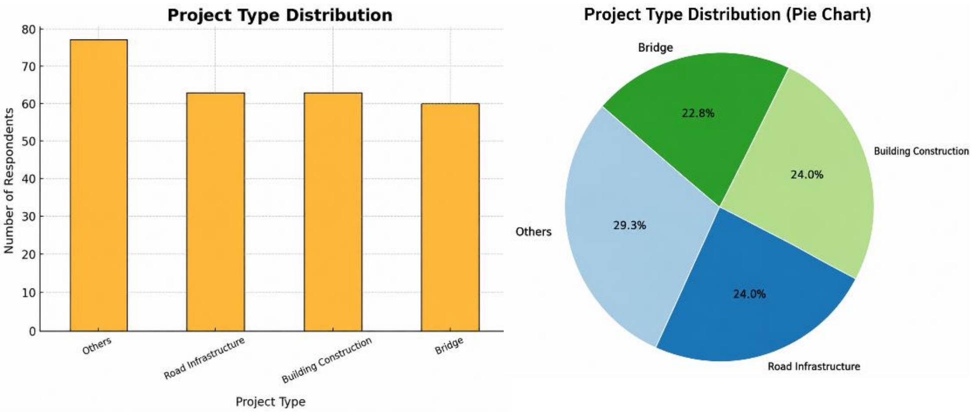

Figure 5. Distribution of project types

Table 4 and Figure 5 the dominance of building construction and infrastructure projects reflects the current trend of development activities in Indonesia, particularly in urban expansion and improvements to public infrastructure.

Table 5. Distribution of respondents based on institutions

No.	Agency	Number of Respondents
1.	Government	140
2.	Private	130

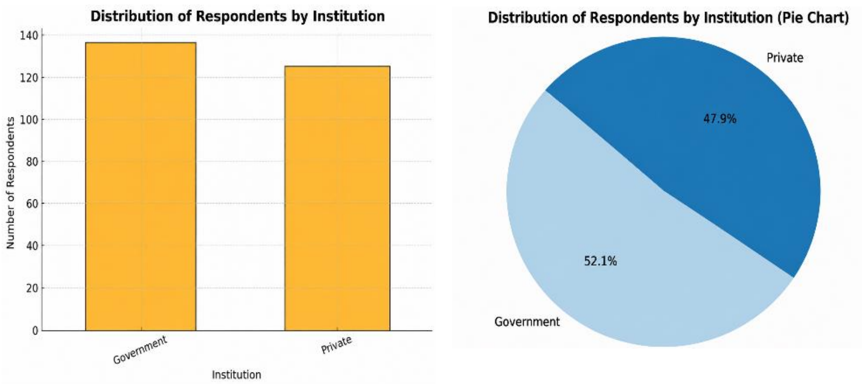

Figure 6. Distribution of respondents based on institutions

Table 5 and Figure 6 the institutional distribution shows involvement from both government and private sectors, indicating that construction project monitoring practices are implemented across different organizational environments.

Table 6. Distribution of respondents based on stakeholder status

No.	Stakeholder Status	Number of Respondents
1.	Sub Contractor	75
2.	Owner	70
3.	Contractor	65
4.	Supervision & Planning Consultant	60

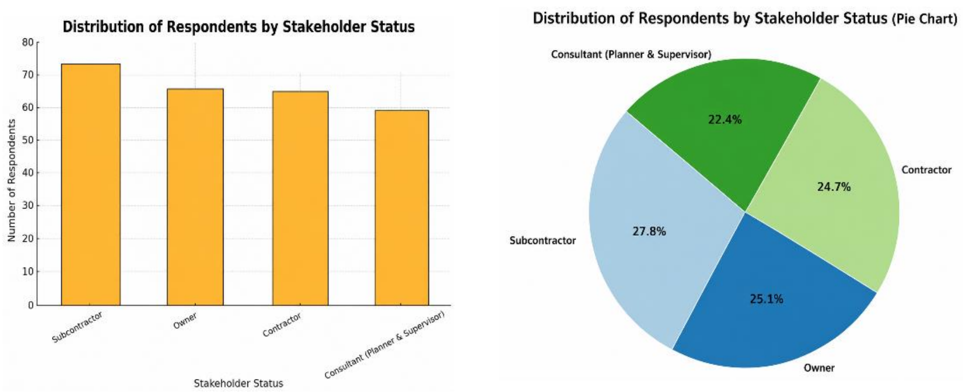

Figure 7. Distribution of respondents based on stakeholder status

Table 6 and Figure 7 the stakeholder composition highlights that project monitoring involves multiple roles, including contractors, owners, and consultants, which emphasizes the importance of coordination in construction project performance monitoring systems.

Analysis results

This study evaluates project performance using three main indicators: Cost Performance Index (CPI), Schedule Performance Index (SPI), and Quality Performance Index (QPI). These indicators provide a comprehensive measurement of cost efficiency, time efficiency, and quality achievement in construction project implementation.

Table 7. Cost Performance Index (CPI) frequency distribution

CPI Range	Frequency	Percentage (%)
< 1.0	12	30%
1.0 - 1.1	20	50%
> 1.1	8	20%

Table 7 the CPI results indicate that half of the projects operate within the expected budget efficiency range. However, a notable proportion of projects still experience cost overruns, highlighting the need for improved cost monitoring and control mechanisms during project execution.

Table 8. Quality performance index (QPI) distribution

QPI (Quality Performance Index)	Number of Projects	Percentage (%)
Meet the Standards	75%	75
Not Up to Standard	25%	25

Table 8 the QPI results show that the majority of projects meet predefined quality standards. This suggests that quality control mechanisms are generally effective, although a quarter of projects still require improvement in quality assurance processes.

Table 9. Schedule performance index (SPI) distribution

SPI Range	Frequency	Percentage (%)
< 0.9	30%	30%
0.9 - 1.1	60%	60%
> 1.1	10%	10%

Table 9 the SPI distribution demonstrates that most projects are completed within acceptable schedule performance ranges. Nevertheless, delays occur in a significant portion of projects, indicating variability in the effectiveness of time management.

DISCUSSION

The impact of performance monitoring on project costs

The analysis reveals that implementing structured performance monitoring systems significantly influences cost efficiency in construction projects. The average CPI of 1.1 indicates that, in general, projects are completed within or slightly under budget, reflecting effective cost control practices. The integration of Earned Value Management (EVM) enables project managers to track cost deviations between planned and actual expenditures continuously. This enables early detection of financial inefficiencies, reducing the likelihood of severe budget overruns. Furthermore, projects that implement systematic monitoring frameworks demonstrate better financial discipline, particularly in procurement and resource allocation stages. However, the presence of projects with CPI values below 1.0 indicates that external factors, such as material price fluctuations and inaccurate initial budgeting, still pose challenges. This highlights the need for adaptive cost control strategies that incorporate real-time monitoring data.

The impact of performance monitoring on project time

In terms of schedule performance, the results show that performance monitoring systems significantly improve time efficiency in construction projects. The SPI distribution indicates that most projects remain within acceptable schedule boundaries, while a smaller proportion experiences delays. The integration of EVM with Building Information Modeling (BIM) enhances schedule tracking by providing visual and data-driven insights into project progress. This combination allows project managers to identify delays at early stages and implement corrective actions before they escalate into major scheduling issues. Despite these advantages, delays in certain projects suggest that schedule disruptions remain influenced by external and operational factors, including labor productivity, weather conditions, and coordination inefficiencies among stakeholders. Therefore, while monitoring systems improve time control, they must be supported by strong project coordination mechanisms.

The impact of performance monitoring on project quality

The analysis of Quality Performance Index (QPI) indicates that most construction projects achieve satisfactory quality outcomes. The high percentage of projects meeting quality standards demonstrates that quality control procedures are generally well implemented. The use of BIM contributes significantly to quality assurance by enabling visualization of design conflicts and construction errors before execution. Combined with EVM-based monitoring, project teams can ensure that quality deviations are detected and corrected promptly.

However, the existence of projects that do not meet quality standards suggests that quality control implementation is not yet fully consistent across all projects. Variations in contractor capability, supervision intensity, and adherence to quality management procedures may cause this inconsistency. These findings also demonstrate the relevance of this study to SDG 9 (Industry, Innovation and Infrastructure). The integration of EVM and BIM enables more efficient and data-driven project monitoring, facilitating early detection of performance deviations and supporting timely corrective actions. By improving cost efficiency, schedule control, and quality assurance, the proposed framework may help strengthen innovation and resilience in infrastructure development and promote more sustainable construction management practices.

CONCLUSION

Fundamental Finding: This study demonstrates that integrating Earned Value Management (EVM) and Building Information Modeling (BIM) provides an effective performance-monitoring model to improve time, cost, and quality efficiency in building construction projects. The findings reveal that 50% of projects achieved a Cost Performance Index (CPI) between 1.0 and 1.1, 60% maintained a Schedule Performance Index (SPI) between 0.9 and 1.1, and 75% met the required quality standards. These results confirm that the integrated EVM–BIM framework enhances project monitoring capabilities by enabling early detection of deviations and supporting timely corrective actions. Therefore, the study emphasizes the importance of adopting data-driven and real-time monitoring systems to improve overall construction project performance. **Implication:** The results suggest that construction companies, project managers, and policymakers should consider implementing integrated EVM and BIM systems as a standard approach for project monitoring. Such integration can strengthen decision-making processes, improve resource allocation, reduce the risk of budget overruns and schedule delays, and enhance project quality. Moreover, the model provides practical support for managing external uncertainties, including fluctuations in material prices, economic changes, and regulatory requirements. These implications are aligned with SDG 9 (Industry, Innovation and Infrastructure), highlighting the importance of digital innovation in fostering resilient infrastructure development, improving project efficiency, and promoting more sustainable construction management practices. **Limitation:** This study has several limitations. First, the research focuses primarily on construction projects in Indonesia, which may limit the generalizability of the findings to other countries with different regulatory and economic environments. Second, the analysis relies on quantitative performance indicators and stakeholder responses, which may not fully capture all operational complexities encountered during project implementation. Third, external factors such as weather conditions, labor productivity, and technological readiness were not examined in depth as moderating variables affecting project performance. **Future Research:** construction projects from different countries and project scales to improve the generalizability of the findings. **Further Research:** Research may also explore integrating emerging technologies such as Artificial Intelligence (AI), Machine Learning, Internet of Things (IoT), and Digital Twin systems with EVM and BIM to enhance predictive monitoring capabilities. Additionally, longitudinal studies are needed to evaluate the long-term effectiveness of integrated monitoring frameworks in improving construction project performance under dynamic and uncertain environments.

AUTHOR CONTRIBUTIONS

Bukhori contributed to conceptualization, study design, supervision, and manuscript review. **Antonius** contributed to methodology development, experimental supervision, and manuscript revision. **Kartono Wibowo** contributed to data analysis, simulation, result interpretation, visualization, and drafting the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors state that they have no financial, personal, or professional conflicts of interest that might have influenced the research process, findings, or conclusions of this study.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors affirm that no AI tools, automated content generators, or digital writing assistants were utilized at any stage of the research, including data analysis, result interpretation, or manuscript preparation. All work was conducted independently by the authors, who assume full responsibility for the originality, accuracy, and integrity of this study.

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***Bukhori (Corresponding Author)**
Faculty of Engineering, Universitas Swadaya Gunung Jati
Jl. Pemuda No32, Cirebon City, Central Java, Indonesia
Email: bukhori@ugj.ac.id

Antonius
Faculty of Engineering, Sultan Agung Islamic University
Jl. Kaligawe Raya Km. 4, Semarang, Central Java, Indonesia
Email: antonius@unissula.ac.id

Kartono Wibowo
Faculty of Engineering, Sultan Agung Islamic University
Jl. Kaligawe Raya Km. 4, Semarang, Central Java, Indonesia
Email: kartono@unissula.ac.id