



BIM-Integrated EVM and CPM for Foundation Design Change in a Design-Build Tower Project

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Abstract

Background: Foundation design changes triggered by differing site conditions can alter quantities, activity logic, durations, and costs in design-build projects.

Objective: This study evaluates how integrating Building Information Modeling (BIM), the Critical Path Method (CPM), and Earned Value Management (EVM) supports time- and cost-based assessment of a foundation design change in the Pelindo Office Tower project.

Methods: A descriptive case-study design was applied using contract records, working drawings, schedule and cost data, and project documentation. Autodesk Revit 2024 was used to generate three-dimensional models and perform Quantity Take-Offs (QTOs); Microsoft Project 2019 was used to identify zero-float activities and calculate performance indicators; and Autodesk Navisworks Manage 2024 was used to visualize four-dimensional and five-dimensional sequences. Contract conditions were compared with the research model.

Results: The design change increased the number of pile locations from 738 to 746 and the total pile length by 1.08%; however, the modeled duration decreased from 87 to 67.31 days, representing a 19.69-day (22.63%) reduction in duration. The research-model budget was IDR 16,919,996,110, which was IDR 570,693,850 (3.26%) below the initial contract value. This budget difference was associated with resequenced activities, optimized use of the Hydraulic Static Pile Driver, reduced waiting time, and lower time-related indirect costs. This difference should be distinguished from the EVM cost variance reported within the research model and should not be attributed to software integration alone.

Conclusion: The framework improves traceability from design quantities to critical-path logic and earned-value indicators, supporting more informed decision-making under design uncertainty.

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INTRODUCTION

Construction is a strategic sector that supports national economic growth, but project success depends on meeting budget, schedule, and quality targets rather than merely delivering physical output. Indonesian construction projects continue to face schedule delays, cost overruns, design changes, and discrepancies between actual site conditions and initial plans, all of which can affect overall project performance (Nugraheni et al., 2021; Putri, 2026).

PT Pelabuhan Indonesia III (Persero) initiated the Pelindo Office Tower project in Surabaya, with PT Wijaya Karya (Persero) serving as the contractor under Contract No. SP2.44/HK.0502/P.III-2018. The Design-Build delivery system integrates design and construction within a single contract, an arrangement that can shorten project delivery time and

simplify coordination (Yudha & Mutaqi, 2025). During foundation work, remnants of old structures caused pile driving to stop at a depth of 4.20 m, and the affected piles did not satisfy the bearing-capacity requirements established by the Static Load Test. Inspection excavations also identified damage to the lower sections of the piles.

The foundation design was therefore revised by rearranging the pile configuration and increasing the number of pile locations from 738 to 746, as recorded in the weekly meeting of April 4, 2018. The change increased the work volume and required adjustments to resources, budget, equipment utilization, and site execution. Consequently, the piling duration in the ongoing plan increased from 21 to 48 calendar days, creating a need for an integrated control approach capable of tracing how changes in design quantities affect schedule logic and cost performance.

A foundation design change affects cost and schedule simultaneously. Earned Value Management (EVM) evaluates this relationship through Planned Value (PV), Earned Value (EV), Actual Cost (AC), Schedule Performance Index (SPI), and Cost Performance Index (CPI) (Fleming & Koppelman, 2016; Li, 2023). The core calculations use Budgeted Cost for Work Scheduled (BCWS/PV), Budgeted Cost for Work Performed (BCWP/EV), and Actual Cost of Work Performed (ACWP/AC). Cost Variance (CV) and Schedule Variance (SV) are obtained using $CV = EV - AC$ and $SV = EV - PV$, respectively, while CPI and SPI are calculated as EV/AC and EV/PV , respectively (Adistana et al., 2018; Widowati, 2026). Values above 1 indicate favorable performance for the relevant index, values equal to 1 indicate performance in accordance with the plan, and values below 1 indicate unfavorable performance (Henderson, 2007; Li, 2023).

The development of construction technology has also encouraged the utilization of Building Information Modeling (BIM) as a means of integrating project information. In accordance with Minister of Public Works and Housing Regulation No. 22/PRT/M/2018, the application of BIM is mandatory for non-simple state buildings with an area exceeding 2,000 m² and more than two floors. BIM is a concept and working approach in the construction industry that utilizes an object-based digital model as an integrated representation of a building, which not only describes its physical form but also stores technical and functional information throughout the project lifecycle (Eastman, 2011; Sacks et al., 2025). Each building element is modeled as an intelligent object that is logically interconnected with other elements, so changes to one element can affect related elements, thereby minimizing errors caused by uncoordinated design changes (Burgess et al., 2026; Succar & Kassem, 2016). Integrating the BIM model with schedule and cost data makes BIM an effective tool for supporting analysis and decision-making throughout various stages of construction projects Hardin and McCool (2015) and Eldeep et al. (2022), while also improving the accuracy of design coordination and reducing errors in the interpretation of working drawings (Sacks et al., 2018, 2025). On the other hand, the Critical Path Method (CPM) is used for scheduling by identifying the critical path among project activities and determining the duration of work activities (Polii et al., 2017; Saputra et al., 2024). The critical path comprises activities with zero total float, meaning that delays in these activities can directly affect the overall project schedule. The application of CPM in project management has been shown to have a significant effect on project duration and completion effectiveness across various industrial sectors in Indonesia (Iskandar et al., 2024).

Previous research has largely examined EVM for cost and schedule performance or CPM for critical-activity identification as separate applications (Dayalan, 2025). EVM studies show that CPI and SPI can support the early detection of inefficiencies and delays (Oktriarto & Susetyo, 2020; Proaño-Narváez et al., 2022; Wahyuni & Hendrawan, 2018; Yusran et al., 2025), while CPM studies demonstrate the value of precedence relationships for identifying activities that govern project completion time (Harita et al., 2025; Ramdani et al., 2022). These approaches are useful but do not, by themselves, trace a design change from model-based quantities through critical-path logic to integrated cost and schedule indicators. Lifecycle research confirms that BIM can connect project information with management processes across delivery stages (Wang & Chen, 2023), and recent work shows that BIM data can support the early prediction of the time and cost implications of design changes (Abdulfattah et al., 2023). However, these studies do not directly examine a combined BIM-CPM-EVM workflow for a foundation design change caused by a differing site condition.

Accordingly, the research gap lies in the limited evidence of an integrated workflow that

links a foundation design change to quantity revision, critical-path rescheduling, and earned-value assessment within a Design-Build high-rise project. The study contributes a traceable decision-support sequence in which BIM supplies model-based quantities and visualization, CPM explains how revised activity logic affects project duration, and EVM evaluates the associated cost and schedule performance. This integration extends the contribution beyond the technical use of software by supporting decision-making under design uncertainty. The study therefore aims to (1) evaluate the time-performance implications of the foundation design change through the integration of BIM, CPM, and EVM and (2) evaluate its cost-performance implications in the Pelindo Office Tower project.

METHOD

This study used a descriptive case-study design to examine the foundation work of the Design-Build Pelindo Office Tower project on Jalan Tanjung Perak Timur, Surabaya, East Java. A case study was appropriate because the analysis focused on a bounded project event: remnants of old structures encountered during excavation led to a foundation design change and altered the planned configuration and execution method. The study compared the initial contract condition with the research model to assess projected completion performance using BIM, CPM, and EVM (Kuncoro, 2022; Sudaryono, 2018; Sugiyono, 2013).

Conceptually, the foundation design change was the independent condition, represented by changes in pile configuration, pile quantity, total pile length, activity sequence, resource requirements, productivity assumptions, and planned duration. The dependent outcomes were (1) schedule performance, represented by modeled duration, SV, and SPI; (2) cost performance, represented by PV, EV, AC, CV, and CPI; and (3) the critical path, represented by zero-float activities and changes in precedence relationships (Johari & Zain, 2025; Sepasgozar et al., 2022). The analytical logic was sequential: the design change modified model quantities and work logic, CPM recalculated the critical schedule, and EVM evaluated the resulting cost and schedule indicators.

The analysis used secondary project data consisting of the contract value and schedule, initial working drawings, the revised foundation configuration, pile quantities and lengths, documented site findings, and project cost and scheduling records reported in the case. No interviews, surveys, or separate primary-measurement datasets were used. Model verification was limited to cross-checking geometry and quantities against the available drawings and configuration data and checking internal consistency among Revit QTO outputs, Microsoft Project schedule logic, and Navisworks TimeLiner visualization. Because the available records did not document an independent field-validation protocol, the simulation results were interpreted as model-based estimates rather than externally validated as-built outcomes.

Autodesk Revit 2024 was used to model the initial and revised foundation elements and generate the Quantity Take-Off (QTO). Microsoft Project 2019 was used to structure the Work Breakdown Structure (WBS), assign productivity assumptions and activity relationships, identify the Critical Path Method (CPM) path based on Total Float = 0, and establish the baseline schedule. Autodesk Navisworks Manage 2024 was used to integrate the BIM model and schedule through TimeLiner to produce four-dimensional (4D) time and five-dimensional (5D) cost simulations. Software names, versions, and capitalization were stated consistently throughout the manuscript.

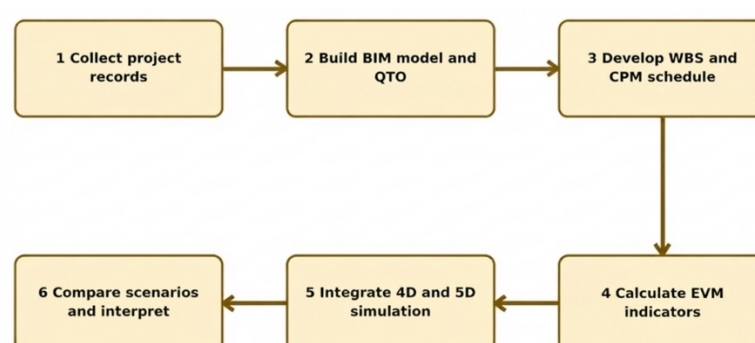


Figure 1. Research workflow from project records to result interpretation

The analytical procedure comprised six stages: collecting project records; developing the initial and revised BIM models and QTOs; constructing the WBS and schedule; identifying the CPM critical path; calculating EVM indicators; and integrating the outputs in a 4D/5D simulation before comparing and interpreting the two scenarios. The final comparison covered pile locations, total pile length, implementation duration, critical-path logic, cost performance, and projected completion time. These results were interpreted within the limitations of a single model-based case study.

The equations used were:

Cost Variance: $CV = EV - AC$ (1)

Schedule Variance: $SV = EV - PV$ (2)

Cost Performance Index: $CPI = EV / AC$ (3)

Schedule Performance Index: $SPI = EV / PV$ (4)

The Earned Schedule (ES) assessment included the Earned Schedule value, time-based Schedule Variance [SV(t)], time-based Schedule Performance Index [SPI(t)], and Estimate at Completion in time units [EAC(t)]. The final comparison covered pile locations, total pile length, implementation duration, critical-path logic, cost performance, and projected completion time. These results were then interpreted within the limitations of a single model-based case study.

RESULTS AND DISCUSSION

Results

The foundation work of the Pelindo Office Tower Project experienced a design change, and a research model was developed for comparison with the initial contract condition. The initial contract condition comprised a value of IDR 17,490,689,960, 738 pile points, and a modeled foundation-work duration of 87 calendar days. The research model comprised a value of IDR 16,919,996,110, 746 pile points, and a modeled duration of 67.31 calendar days. CPM identified the activities governing project completion, EVM assessed PV, EV, AC, SPI, and CPI, and BIM supplied model-based quantities and visualization. Thus, BIM functioned as an information and internal-verification environment rather than as a substitute for CPM or EVM.



Figure 2. Façade of the Pelindo Office Tower Building
Source: Project Data (2024)

BIM modeling was performed using Autodesk Revit, maintaining the dimensions, elevations, and coordinate positions of the foundations according to the initial contract working drawings (Figure 2a), whereas the research model shows configuration changes, including position adjustments, the addition of elements, and modifications to foundation dimensions (Figure 2b). During implementation, three pile points (223, 226, and 602) were found not to have reached the planned depth. Therefore, an alternative foundation-modeling simulation was developed that would not be potentially obstructed by the existing structure.

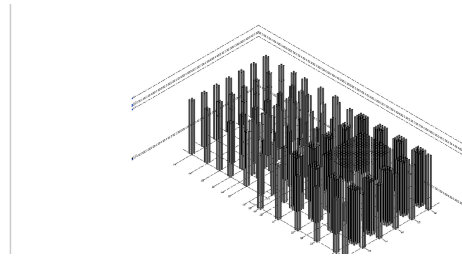


Figure 3. 3D BIM Model of the Pile Foundation under the Initial Contract
Source: Project model

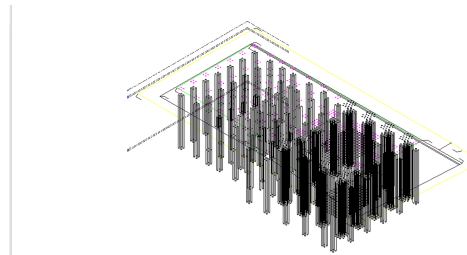


Figure 4. 3D BIM Model of the Revised Pile Foundation
Source: Research model

The modeling results show that the foundation design change increased the number of pile points from 738 to 746, representing an increase of 8 points, or 1.08%, and increased the total pile length from 22,140.00 m to 22,380.00 m, representing an increase of 240.00 m, or 1.08% (Figures 3 and 4). These changes represent adjustments to the foundation configuration in response to the documented project conditions. The Revit Quantity Takeoff provided model-linked quantity information for comparing the initial contract condition and the research model. The resulting quantity data were subsequently used to prepare the Work Breakdown Structure in Microsoft Project, which organized direct-cost activities, including procurement and piling, and indirect-cost activities, including site-office rental and personnel operating costs, for scheduling, resource allocation, and project cost and time control (Desembardi et al., 2024; Prastya et al., 2025).

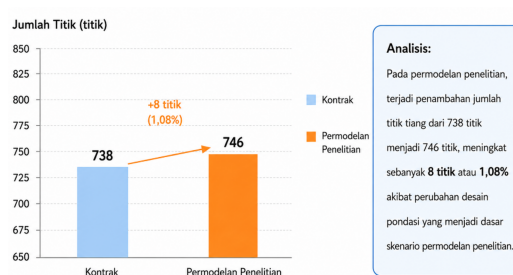


Figure 5. Comparison of Pile Points
Source: Research modeling results

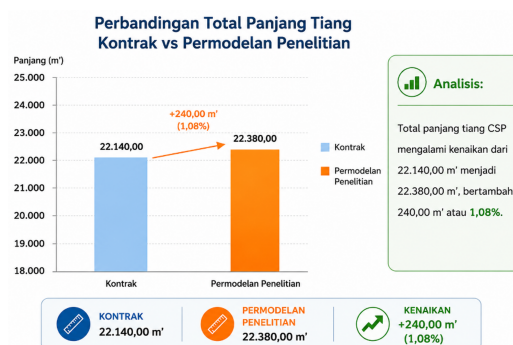


Figure 6. Comparison of Total Pile Length
Source: Research modeling results

The CPM results indicate that the modeled foundation-work duration decreased from 87 to 67.31 calendar days, equivalent to a reduction of 19.69 days, or 22.63%, even though the pile count and total pile length increased. The dominant explanation is not the increase in work volume but the revised execution logic: activities were resequenced, predecessor relationships were reorganized, Hydraulic Static Pile Driver (HSPD) use was optimized, and waiting time between handling, driving, welding, and cutting was reduced. In addition, the revised configuration avoided anticipated obstructions at pile points affected by remnants of existing structures. The acceleration therefore represents a modeled consequence of work-sequence and resource optimization, not a direct effect of increasing pile quantity.

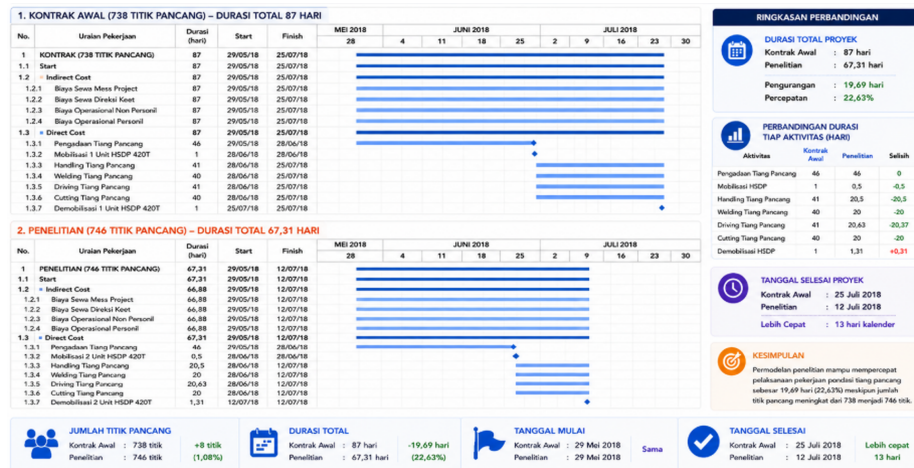
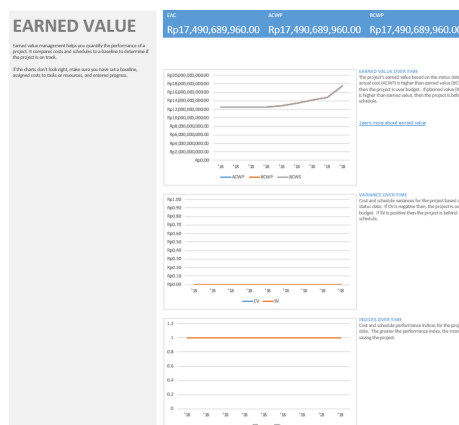


Figure 7. CPM Duration under the Initial Contract and Research Model

Source: Microsoft Project analysis

The EVM results are presented in Figures 6a and 6b and Table 1. Based on the EV and AC values reported in Table 1 and the formula $CPI = EV/AC$, the CPI values are 1.00 for direct costs, 1.11 for indirect costs, and approximately 1.00 overall when rounded to two decimal places. Direct costs show no cost variance because EV and AC are equal, whereas indirect costs show a favorable CV of IDR 19,822,922. The total EVM cost variance of IDR 19,822,922 should be distinguished from the difference between the initial contract value and the research-model budget. These indicators describe the modeled cost performance and should not be attributed to the BIM-CPM-EVM tools alone.



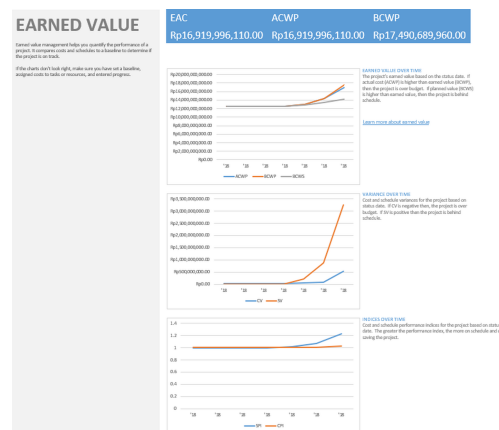


Figure 9. EVM S-Curve for the Research Model
Source: Microsoft Project analysis

Table 1

Earned Value Management Results for the Research Model

Description	PV (IDR)	EV (IDR)	AC (IDR)	CV (IDR)	CPI	SPI
Direct Cost	16,724,691,556	16,724,691,556	16,724,691,556	0	1.01	1.00
Indirect Cost	195,304,553	195,304,553	175,481,631	19,822,922	1.30	1.00
Total	16,919,996,109	16,919,996,109	16,900,173,187	19,822,922	1.03	1.00

Source: Microsoft Project Analysis Results, reprocessed by researcher (2026)

The BIM, CPM, and EVM outputs were visualized through a 5D simulation integrating Autodesk Revit, Autodesk Navisworks Manage, and Microsoft Project. The simulation provided a visual summary of model-based quantities, costs, and work schedules (Rahayu & Rezekiani, 2025). Within the modeled scenario, the visualization can support the identification of potential sequencing issues and cost-efficiency opportunities. However, because no independent field-validation protocol was documented, the simulation should not be interpreted as confirmation of actual as-built performance.

In this case, the foundation design change did not produce a longer modeled duration. Although design changes can add revision time, alter methods, and increase material requirements, the revised model reduced anticipated obstructions at affected pile points and reorganized zero-float activities into a more efficient sequence (Anadita, 2025). This finding demonstrates that the schedule effect of a design change depends on activity logic and constraint management, not only on work volume. Because the evidence comes from one project and a model-based comparison, it should not be generalized to all foundation or construction projects.

Discussion

The IDR 570,693,850 (3.26%) difference represents the comparison between the initial contract value and the research-model budget. It is distinct from the EVM cost variance of IDR 19,822,922 reported in Table 1, which was calculated from the difference between EV and AC within the research model. The difference between the contract value and the research-model budget is best interpreted as a model-based budget difference rather than as proof that software integration independently reduced costs. Within the modeled scenario, the difference was associated with the revised execution strategy, shorter exposure to time-related indirect costs, resequencing, and more effective HSPD utilization. BIM, CPM, and EVM provided the means to quantify and trace these modeled differences (Desembardi et al., 2024).

The three methods have complementary roles. BIM supplies coordinated geometry, quantities, and 4D/5D visualization; CPM tests how predecessor relationships and zero-float activities determine project completion; and EVM/ES translates the revised plan into cost and schedule indicators. This finding is consistent with evidence that BIM can integrate information with project-management processes across the project lifecycle Wang and Chen (2023) and with BIM-EVM research that emphasizes transparent, model-linked performance control (Kim et al., 2022; Salamah et al., 2023; Sepasgozar et al., 2022). It also complements predictive design-change

research Abdulfattah et al. (2023) by showing a deterministic case-study route from revised quantities to critical-path and earned-value consequences without introducing a machine-learning model.

The academic contribution is a traceable decision sequence for Design-Build projects under design uncertainty: model the change, quantify its scope, test schedule logic, evaluate cost and time performance, and visualize the alternative before implementation. This sequence can improve communication and the timing of corrective decisions. However, the current 5D model is not a digital twin because it is not continuously synchronized with field observations. A true digital-twin extension would require recurring monitoring data and closed-loop control (Ryzhakova et al., 2022; Sacks et al., 2020).

CONCLUSION

The foundation design change in the Pelindo Office Tower case increased the number of pile points from 738 to 746 and the total pile length by 1.08%, yet the research model reduced the duration from 87 to 67.31 calendar days, a reduction of 19.69 days (22.63%). The research-model budget was IDR 16,919,996,110, representing a difference of IDR 570,693,850 (3.26%) from the initial contract value. These outcomes were associated with resequenced activities, revised predecessor logic, optimized HSPD use, reduced waiting time, and lower time-related indirect costs. The integrated BIM-CPM-EVM framework contributed by linking quantity changes, critical-path logic, performance indicators, and 5D visualization within one decision process.

The findings are limited to a single Design-Build tower project and a model-based comparison; no independent real-time field-validation protocol was documented. Consequently, the results should be treated as context-specific evidence rather than as a general claim that foundation design changes improve project performance. Future research should test the framework on projects with different types and complexity levels, compare predictions with as-built field data, integrate real-time monitoring, and examine closed-loop digital-twin applications for schedule and cost control.

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AUTHOR CONTRIBUTION STATEMENT

All authors contributed to the conceptualization, methodology, data curation, formal analysis, visualization, drafting, and final approval of the manuscript. All authors are accountable for the accuracy and integrity of the work.

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