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Time Cost Trade of Analysis Using Building Information Modelling to Improve Construction Project Effectiveness

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Abstract

This research examines how the implementation of *Building Information Modelling* (BIM) can enhance time and cost efficiency in construction projects using the *Time Cost Trade-Off* (TCTO) method. It aims to explore BIM's potential in optimizing project scheduling and budgeting to improve overall effectiveness. Employing a mixed-methods approach, the study integrates qualitative and quantitative strategies to analyze BIM's role in supporting the TCTO method. Findings indicate that the TCTO method significantly improves time and cost efficiency by enabling accurate critical path identification and cost-effective acceleration strategies. Additionally, BIM enhances project effectiveness through information integration, cost-time analysis, and building simulation, supporting key TCTO processes. Expert validation and survey responses confirmed a strong correlation between BIM and TCTO. However, the research is limited to construction projects in Indonesia, which may affect the generalizability of the results. Practically, integrating BIM with TCTO provides project managers with a strategic tool to improve scheduling and budgeting accuracy. The findings offer actionable insights to enhance planning efficiency in large-scale or complex construction projects. This study presents a novel framework linking BIM capabilities directly with the technical stages of the TCTO method, combining validated indicators and empirical data to offer a new perspective on optimizing construction project performance through digital and analytical integration.

Keywords: Building Information Modelling, time cost trade off, project effectiveness

INTRODUCTION

The construction industry plays a crucial role in supporting national development and economic growth in Indonesia (Ministry of Public Works, 2024). Infrastructure development continues to increase, as reflected by Indonesia's ranking of 62 out of 140 countries in terms of infrastructure development (Adhiputra, 2016; Adhityas et al., 2023; Adi et al., 2020; Ginting S & Pontan, 2021; Juansyah et al., 2018). According to Statistics Indonesia (BPS, 2024), construction activity trends can be tracked through the Construction Value Index, which reflects the physical realization of construction work. In the first quarter of 2024, the index reached 162.16, representing an increase of 8.09% compared to the same period in 2023. However, this also marks a 3.60% decline compared to the fourth quarter of 2023, primarily due to business-related issues such as fluctuations in building material prices (BPS, 2023).

Project effectiveness in the construction sector is measured by the alignment between planning and actual performance in the field, often evaluated through the dimensions of time, cost, and quality (Liu et al., 2016). Price volatility in construction materials poses a significant challenge, leading to unexpected cost increases that disrupt project schedules and budgets. This fluctuation can reduce cost efficiency by 15–20%, extend project timelines by 10–30%, and compromise quality due to material substitution (Pratiwi, 2012). Between 2020 and 2024, 68% of contractors in Indonesia experienced unplanned cost overruns (Broto, 2017).

Project delays remain a critical issue, with substantial impacts on both budget and quality due to the interdependent nature of time, cost, and quality (Agung, Gultom, & Haryanto, 2024). The Ministry of Public Works (2024) reported that 38% of construction projects in Indonesia were delayed by more than six months, incurring cost overruns of 18–32% above the original budget. Case studies show that weak project management is a dominant cause of such delays. Project management plays a vital role throughout the project life cycle, ensuring optimal outcomes from the planning phase to post-construction maintenance (Adhityas et al., 2023; Boy et al., 2021; Latanna, 2020; LIRAWATI, 2021; Megawati, 2021; Rosdianto, 2017; Simanjuntak & Salim, 2020). A structured and systematic approach to project management is essential to maintain timelines and prevent cost increases due to delays (Salindeho, Prastasis, & Sumanti, 2022).

Moreover, imbalances between time, cost, and quality often arise when schedule acceleration (*crashing*) is implemented to recover from delays, resulting in increased costs and potential quality reductions. Conversely, excessive cost-saving measures may prolong project duration and negatively affect the final output quality (Setiono, Suryoto, & Supriyor, 2022). An effective construction project is one that adheres closely to the initial plan in terms of both schedule and budget. Improving project effectiveness would enhance the construction sector's contribution to the national economy and yield higher-quality infrastructure. The *Time Cost Trade-Off* (TCTO) method and *Building Information Modelling* (BIM) share common principles across all types of construction projects. To address these issues, strategic implementation of *Building Information Modelling* (BIM) integrated with the *Time Cost Trade-Off* (TCTO) method offers promising potential. BIM enables more accurate project planning, integration of schedules and costs, and early identification of potential delay risks. Without addressing the root causes of project inefficiencies, Indonesia's construction sector risks continued delays, cost overruns, and declining quality, all of which can hinder national growth and infrastructure development.

In the context of the construction industry, several studies have examined project delays and cost overruns, but few have integrated modern technological advancements like *Building Information Modelling* (BIM) and traditional methods such as the *Time Cost Trade-Off* (TCTO) technique. For instance, Liu et al. (2016) analyzed project effectiveness and suggested that deviations in time, cost, and quality are often attributed to poor project management. While this study provided valuable insights, it did not consider how technological innovations such as BIM could mitigate these challenges. Similarly, a study by Setiono, Suryoto, and Supriyor (2022) discussed the impact of schedule acceleration on project outcomes, emphasizing cost and quality issues. However, this research failed to explore how BIM could help prevent such imbalances, making it difficult to understand how these factors can be addressed comprehensively.

Therefore, further study on the integration of BIM and TCTO is essential to optimize implementation strategies and enhance project effectiveness across the Indonesian construction industry. The findings are valuable for policymakers, contractors, and project managers, offering practical recommendations to enhance construction project performance. By improving project outcomes, this research will contribute to the growth of Indonesia's infrastructure sector, supporting national development and economic growth.

RESEARCH METHOD

This research employs a mixed-methods approach by integrating both qualitative and quantitative strategies to comprehensively analyze the role of Building Information Modelling (BIM) in enhancing time and cost efficiency in construction projects through the Time Cost Trade-Off (TCTO) method.

Data was collected using a combination of primary and secondary sources:

a. Primary Data: experts in construction management, BIM implementation, and cost-time optimization were engaged through structured and semi-structured questionnaires. This method was used to validate the critical factors and indicators affecting project effectiveness, and to evaluate the application of BIM in TCTO. Practitioners with experience in BIM-integrated projects were surveyed to assess the actual impact of BIM on TCTO calculations, identify technical challenges, and gather expert-driven solution recommendations.
b. Secondary Data: literature review to identify established indicators and best practices related to TCTO methods, BIM functions, and effectiveness in construction projects. This data formed the foundation for initial indicator lists used in validation rounds.

Purposive sampling was employed to select both expert respondents and project case references relevant to the integration of Building Information Modelling (BIM) and Time Cost Trade-Off (TCTO) in construction projects. Experts were chosen based on their demonstrated experience in construction project management, BIM implementation, and cost-time optimization.

Tools and techniques used were:

a. Literature Review: A literature-based approach was used to identify best practices, benchmark indicators, and support the theoretical framework of the study.
b. Questionnaires: Structured and semi-structured questionnaires were developed to gather expert opinions on the influence of TCTO and BIM on construction project effectiveness.

c. Data Analysis Tools: Statistical analysis was performed using tools like Microsoft Excel to evaluate quantitative data.

Data Analysis techniques used were:

a. Qualitative data were analyzed using a thematic analysis approach to interpret expert insights and extract recurring patterns and underlying themes from open-ended responses.
b. Quantitative data obtained from expert surveys were primarily analyzed using the Relative Importance Index (RII) method and mean score calculations to quantify the level of consensus among expert respondents.

By employing this robust mixed-method approach, the study aims to generate reliable, replicable, and actionable findings that contribute to the broader discourse on the integration of Building Information Modelling (BIM) and Time Cost Trade-Off (TCTO), particularly in the context of enhancing construction project effectiveness in Indonesia.

RESULTS AND DISCUSSION

The effectiveness of a construction project can be assessed through two key dimensions: reduction in project duration and cost efficiency. The implementation of the Time Cost Trade Off (TCTO) method has demonstrated a significant influence on both variables, contributing to enhanced project performance by minimizing delays while maintaining budget discipline. TCTO consists of four critical stages: network diagram development, cost slope analysis, activity compression, and iterative process, all of which serve as indicators of its impact on project effectiveness. The effectiveness of a construction project can be assessed through two key dimensions: reduction in project duration and cost efficiency. The implementation of the Time Cost Trade Off (TCTO) method has demonstrated a significant influence on both variables, contributing to enhanced project performance by minimizing delays while maintaining budget discipline. TCTO consists of four critical stages: network diagram development, cost slope analysis, activity compression, and iterative process, all of which serve as indicators of its impact on project effectiveness.

Table 1. Research Variable

No	Variable	Code	Indicator	Expert 1	Expert 2	Expert 3	RII	Rank
1	Network Diagram Development	1.1	Accuracy of Network Diagram	5	5	4	0.93	4
		1.2	Critical Path Identification	5	5	5	1.00	1
		1.3	Accuracy of resource estimation	4	5	4	0.86	7
2	Cost Slope Analysis	2.1	Accuracy of cost slope calculation	5	4	5	0.93	5
3	Activity Compression	3.1	Prioritizing activities with the lowest cost slope	5	5	5	1.00	2
		3.2	Addition of labor	4	4	3	0.73	9

No	Variable	Code	Indicator	Expert 1	Expert 2	Expert 3	RII	Rank
		3.3	Accuracy of acceleration cost estimation	5	5	4	0.93	6
4	Iterative Process	4.1	Repetition of the TCTO process	4	4	4	0.80	8
		4.2	Evaluation of acceleration strategy effectiveness	5	5	5	1.00	3

The indicators derived from the TCTO method received Likert scores of ≥3 from expert validation, indicating that all indicators are considered relevant in measuring the influence of TCTO on project effectiveness. A Likert score of ≥4 is interpreted as "influential," based on the conventional interpretation of a 5-point scale. In this context, scores of 4 and 5 are categorized as positive responses, signifying that the indicators are appropriate for inclusion in subsequent analytical stages. Furthermore, the high consistency of scores among experts reflects a strong level of assessment homogeneity, reinforcing content validity, as evaluations were provided by professionals with relevant experience in the construction sector. Following expert validation of the indicators established from the literature review, a quantitative analysis was conducted using the Relative Importance Index (RII) method. RII was employed to measure the relative significance of each indicator based on expert ratings using the Likert scale. The RII value was calculated by aggregating the scores and normalizing them against the maximum possible score (i.e., 5) and the number of experts.

The RII analysis results show that the indicators Critical Path Identification, Prioritizing Activities with the Lowest Cost Slope, and Evaluation of Acceleration Strategy Effectiveness achieved the highest RII score of 1.00, indicating full consensus among experts that these are the most influential TCTO indicators on project effectiveness. Other indicators, such as Accuracy of Network Diagram and Cost Slope Calculation, also received high RII values of 0.93, highlighting their important role in acceleration planning and decision-making. In contrast, Addition of Labor obtained the lowest RII score of 0.73, suggesting that it is perceived to have relatively less impact on overall project effectiveness. Overall, these findings support the earlier expert validation and contribute to the prioritization of indicators in developing effective time-cost optimization strategies in construction projects using the TCTO approach.

The implementation of Building Information Modeling (BIM) significantly enhances the effectiveness of construction projects by improving both time efficiency and cost performance. Based on expert validation and recent studies, BIM's positive influence is observed through multiple integrated aspects, like 3D modeling, Information Integration, Collaboration and Coordination, Lifecycle Management, Data Analytics, Risk and Conflict Detection, Building Visualization, Building Simulation, and Regulatory Compliance. Collectively, these aspects demonstrate BIM's holistic capability to improve project effectiveness. Studies estimate potential cost savings of 20–52% and time acceleration of 15–50% across various project phases. The synergistic interaction among BIM features establishes a strong foundation for delivering high-quality, cost-efficient, and timely construction outcomes. Despite some challenges in adoption—particularly in Indonesia, such as high initial costs and limited skilled personnel—the strategic implementation of BIM offers substantial benefits that justify its integration into modern construction management practices.

Validation of the Building Information Modeling (BIM) indicators was conducted to assess the extent to which each indicator contributes to the improvement of construction project effectiveness. These indicators were initially formulated through literature review and subsequently evaluated by experts with substantial competence in construction and project management. A Likert scale was employed for scoring, ranging from 1 (very uninfluential) to 5 (very influential). In addition to quantitative assessments, experts also provided qualitative feedback to justify their ratings, thereby strengthening the content validity and contextual relevance of each indicator.

Following expert validation, the data was further analyzed using the Relative Importance Index (RII) method to determine the relative weight of each indicator. RII is calculated based on the aggregation of expert scores and normalized against the highest possible score and the number of respondents. This method enables the ranking of BIM indicators based on their level of influence on project effectiveness.

Table 2. BIM indicators

No	Indicator	Expert 1	Expert 2	Expert 3	RII	Rank
1.1	3D Modeling	5	5	4	0.93	5
1.2	Information Integration	5	5	5	1.00	1
1.3	Collaboration and Coordination	5	4	5	0.93	6
1.4	Lifecycle Management	5	5	4	0.93	7
1.5	Data Analytics	5	5	5	1.00	2
1.6	Risk and Conflict Detection	4	5	4	0.86	8
1.7	Building Visualization	5	5	5	1.00	3
1.8	Building Simulation	5	5	5	1.00	4
1.9	Regulatory Compliance	5	4	4	0.86	9

The analysis revealed that all BIM indicators achieved RII values above 0.85, indicating a generally strong influence on construction project performance. Five indicators—information integration, time analysis, cost analysis, building visualization, and building simulation—each obtained the highest possible RII score of 1.00, reflecting unanimous expert agreement on their critical importance. These indicators are thus considered top priorities in leveraging BIM to improve project outcomes. On the other hand, indicators such as risk and conflict detection and regulatory compliance received the lowest RII scores at 0.86. While still above the relevance threshold, these aspects are perceived as relatively less impactful when compared to the more integrative and analytical features of BIM. However, their inclusion remains essential, as they contribute to the overall systemic efficiency and quality assurance in project delivery. In conclusion, the RII results affirm that BIM's core functionalities—particularly those related to data integration, analytical capability, and visualization—are instrumental in enhancing the effectiveness of construction projects. These insights not only support previous theoretical frameworks but also offer practical guidance for prioritizing BIM features during project planning and execution.

The assessment of Building Information Modeling (BIM) implementation in supporting the Time Cost Trade-Off (TCTO) method was conducted through the distribution of questionnaires to 31 respondents, consisting of professionals and academics in the construction sector. Each respondent was asked to evaluate a series of indicators previously developed through literature review and expert validation. A 5-point Likert scale was used to measure the perceived relevance and effectiveness of BIM in supporting key aspects of the TCTO method. The collected data was analyzed descriptively to identify trends in respondent perceptions for each indicator. The analysis method employed was relative frequency percentage, which involved calculating the proportion of responses for each Likert rating across the total number of respondents. This approach aimed to determine the dominant opinions regarding the effectiveness of BIM implementation in enhancing the TCTO method—particularly in terms of improving project effectiveness.

The results of the questionnaire analysis revealed that all BIM indicators obtained an average score above 4.00, indicating that BIM is widely perceived as having a tangible contribution to the implementation of the TCTO method. The strongest relationships were identified between BIM indicators and the core stages of TCTO, namely network diagram development, cost slope analysis, and the iterative process.

The highest recorded score was observed for the Building Simulation indicator (BIM), which received a value of 5.25 in relation to the evaluation of acceleration strategies (TCTO). This suggests that BIM's capability to simulate various acceleration scenarios visually is extremely helpful for the evaluative processes within the TCTO method.

In addition, the accuracy of the network diagram—a fundamental component in critical path analysis—was most strongly associated with the Regulatory Compliance indicator (score: 4.52), highlighting how structured documentation and information within BIM enhance the precision of technical planning.

The Time Analysis indicator also consistently received high scores across TCTO components, particularly in supporting the identification of the critical path and the estimation of acceleration durations. This underscores the importance of BIM-based timeline visualizations in improving accuracy and mapping the sequence of critical project activities.

Cost Analysis, another key BIM feature, was also seen to play a vital role in supporting activity compression and the estimation of additional acceleration costs, both of which are critical elements of the TCTO method.

Overall, the findings indicate that BIM contributes substantially to facilitating, accelerating, and improving the accuracy of TCTO calculations, in terms of both time and cost. Therefore, Hypothesis 3 is accepted, as the empirical data from respondents support the existence of a causal relationship between BIM implementation and the increased effectiveness of the TCTO method in construction projects.

These findings demonstrate that integrating BIM into each phase of the TCTO process serves as an effective strategic approach for optimizing project planning and control holistically.

CONCLUSION

This study demonstrates the significant role of *Building Information Modelling* (BIM) in supporting the *Time Cost Trade-Off* (TCTO) method to enhance construction project effectiveness, particularly in optimizing time and cost. Key TCTO stages—critical path identification, selecting activities with the lowest cost slope, and evaluating acceleration strategies—were found to be crucial, each scoring highest in influence. BIM substantially improves project outcomes through information integration, time and cost analysis, building visualization, and simulation, all of which enhance scheduling accuracy, cost estimation, and interdisciplinary collaboration. Survey responses from 31 experts validated the strong synergy between BIM and TCTO, especially in supporting acceleration strategy evaluation and network diagram development. Moreover, BIM's shared digital platform fosters better stakeholder coordination, streamlining project workflows. The research concludes that integrating BIM into TCTO offers a strategic advantage for delivering construction projects more effectively and efficiently. Future research should explore the application of this integrated approach in diverse construction contexts and regions to assess its generalizability and identify best practices for broader implementation.

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