Development of A Time and Cost Control System For The Construction of A Ø1000 Mm Pipe Bridge Based on A Work Breakdown Structure (WBS) Integrated With A 3d Model and Bim to Improve Time and Cost Performance

Ulya Ilmi Azhara[1*], Leni Sagita Riantini Supriadi[2], Yusuf Latief[3]

[1,2,3] Civil Engineering Department, Faculty of Engineering, Universitas Indonesia
[*]Corresponding Author:
Email:ulyailmi411@gmail.com

***Abstract*.**

The construction of large-diameter pipeline bridges plays a strategic role in ensuring the reliability of clean water distribution systems. Nevertheless, such infrastructure projects frequently experience cost overruns and schedule deviations caused by fragmented scope definition, limited integration between planning and cost control, and conventional quantity take-off practices that rely heavily on two-dimensional drawings. These limitations reduce the effectiveness of project monitoring and delay corrective decision-making during construction. This study develops an integrated time and cost control system by embedding a standardized Work Breakdown Structure (WBS) into a 3D and 5D Building Information Modeling (BIM) environment for a Ø1000 mm pipeline bridge project. A mixed-method research approach was adopted, combining expert validation, project document analysis, and quantitative assessment. Project performance was evaluated using Earned Value Management (EVM), while Partial Least Squares–Structural Equation Modeling (PLS-SEM) was applied to examine the causal relationships between WBS integration, 3D modeling, BIM implementation, the time and cost control system, and schedule and cost performance. The results demonstrate that BIM-derived quantities and costs are more consistent and traceable than those obtained from conventional Bill of Quantities (BOQ) calculations, particularly for steel structural and support components that exhibit the highest cost deviations. The integration of WBS with BIM 3D and BIM 5D significantly strengthens activity-level monitoring, improves cost control accuracy, and enables earlier detection of schedule and cost deviations. The proposed framework provides practical decision support for proactive time and cost management in infrastructure construction projects.

Keywords: *Work Breakdown Structure (WBS); Building Information Modeling (BIM); 3D Modeling; Time and Cost Control System; Project Performance and Pipe Bridge Construction.*

I. INTRODUCTION

Digitalization is increasingly recognized as a critical enabler for improving construction project performance, particularly in addressing persistent time delays and cost overruns [1]. Building Information Modeling (BIM) has emerged as a key digital approach that integrates geometric, schedule, and cost information to support coordination and decision-making throughout the project life cycle [2,3]. Consequently, governments and industry stakeholders worldwide have promoted BIM adoption as part of national construction digitalization strategies to enhance productivity and overall project performance [4,5].Large-diameter pipe bridge projects involve high technical complexity and strong interdependencies among structural, mechanical, and construction activities, making them highly vulnerable to schedule delays and cost overruns when control systems are inadequate [6,7]. Conventional time and cost control practices, which predominantly rely on macro-level tools such as S-curves and manual progress reporting, remain insufficient for detecting deviations at the activity-level and supporting proactive corrective actions [8,9]. Work Breakdown Structure (WBS) has long been established as a fundamental project management tool for defining project scope, decomposing work into manageable activities, and forming the basis for scheduling, resource allocation, and cost control. Kerzner [10] and PMI [11] argue that the absence of a detailed and standardized WBS often results in unclear work scopes, weak linkages between schedule and cost data, and ineffective project monitoring.

Empirical studies have demonstrated that a well-structured WBS significantly improves planning accuracy and enhances the effectiveness of time and cost control, particularly in complex construction projects [12]. However, in many infrastructure projects, including pipe bridge construction, WBS implementation remains fragmented and is rarely integrated systematically with digital modeling platforms.Previous research has shown that BIM, particularly 3D and 5D BIM, can substantially enhance design coordination, constructability analysis, and the integration of schedule and cost information. Eastman et al. [2] and Abdel-Hamid and Abdelhaleem [13] confirm that BIM-based time and cost integration improves estimation reliability and supports more effective project monitoring. In parallel, Earned Value Management (EVM) has been widely applied as a quantitative method for assessing project performance and providing early warnings of schedule and cost deviations [10,14]. Nevertheless, the effectiveness of EVM is highly dependent on the availability of accurate, consistent, and activity-level progress data, which is often unavailable in projects that lack a standardized WBS and BIM-based data integration. The state of the art in construction project control reflects a growing transition toward integrated digital frameworks that combine WBS-based planning, BIM enabled visualization, and performance based monitoring techniques.

Recent studies underline the importance of directly linking WBS structures to BIM elements in order to improve data interoperability, traceability, and control effectiveness [15,16]. Despite these advances, most BIM-based control models have been developed for buildings or generic infrastructure projects, while research focusing specifically on pipe bridge construction remains limited. Moreover, empirical investigations examining the causal relationships between WBS integration, BIM utilization, project control processes, and time and cost performance are still scarce, particularly in the context of water infrastructure projects.Although previous studies have explored the integration of BIM with scheduling, cost management, and Earned Value Management, most existing models are developed for building projects or generic infrastructure without explicitly addressing the role of a standardized, control-oriented Work Breakdown Structure. Moreover, empirical studies that investigate the causal relationships between WBS integration, BIM utilization, project control systems, and time–cost performance remain limited, particularly in the context of pipeline bridge and water infrastructure projects.This study addresses these gaps by developing a pipeline-bridge-specific WBS that is systematically embedded within a 3D model and a BIM environment to support activity-level time and cost control. Unlike prior research that positions BIM primarily as a visualization or estimation tool, this study conceptualizes BIM as a control oriented information management platform. The proposed framework empirically validates the mediating role of the time and cost control system in linking WBS, 3D modeling, and BIM to schedule and cost performance, thereby extending systems based project management theory into a BIM enabled infrastructure context.

II. METHODS

This research employed a mixed-method design to develop and validate an integrated time and cost control framework. Qualitative methods were used to evaluate existing control practices and to develop a standardized Work Breakdown Structure (WBS) through expert validation. Quantitative analysis was subsequently conducted to assess the relationships among WBS (X1), 3D modeling (X2), BIM (X3), the Time and Cost Control System (X4), and project performance variables using EVM indicators and PLS-SEM.This approach enables both the structural validation of the proposed framework and the empirical examination of causal relationships between digital integration and project performance. **Figure 1** and **Figure 2** present the overall research methodology framework and the detailed implementation stages adopted in this study.

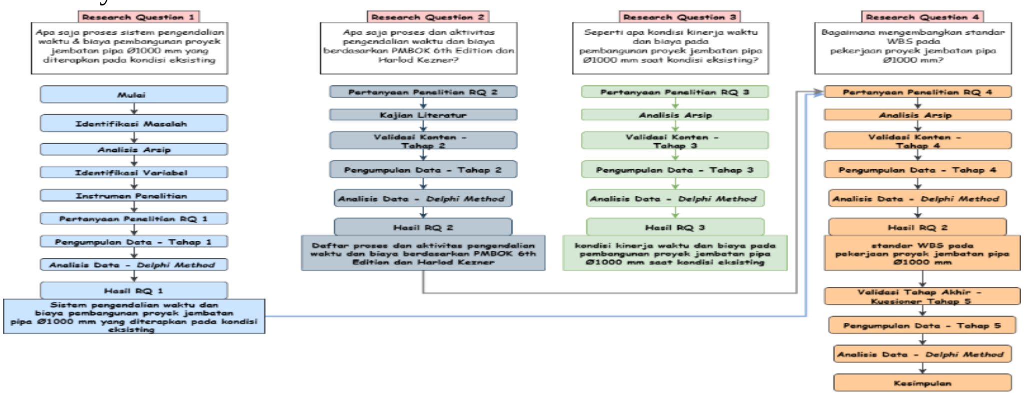


Fig 1. Research Methodology Framework

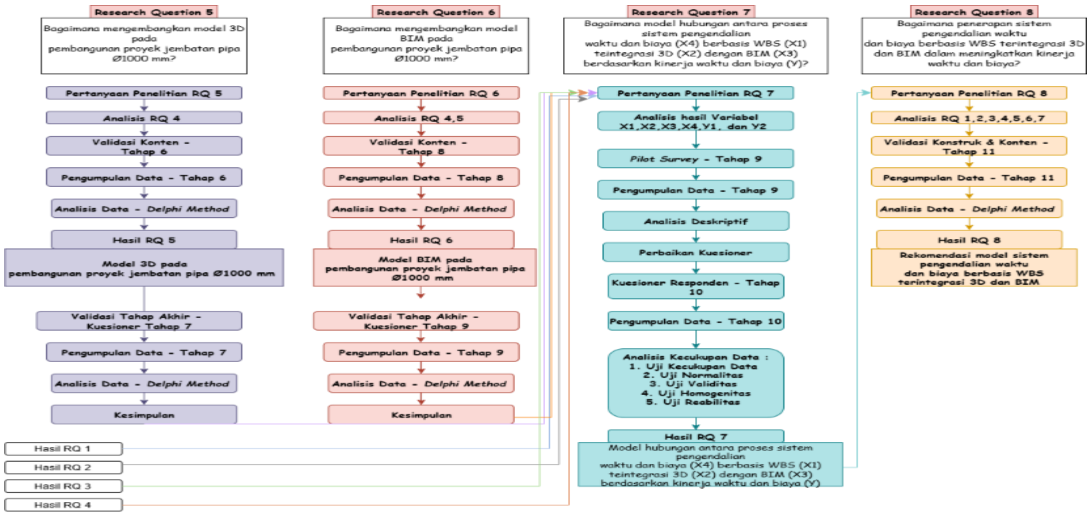


Fig 2. Research Methodology Framework

In conclusion, **Figure 1** and **Figure 2** collectively illustrate a structured and coherent research methodology designed to address the research objectives comprehensively. The framework integrates qualitative evaluation of existing time and cost control practices with quantitative empirical analysis, ensuring both conceptual rigor and analytical validity. The progressive development of a standardized Work Breakdown Structure (WBS), its integration into a 3D model, and subsequent implementation within a BIM enable activitylevel linkage between scope, schedule, and cost data. Furthermore, the application of Earned Value Management (EVM) and Partial Least Squares Structural Equation Modeling (PLS-SEM) provides robust performance measurement and causal relationship analysis. Overall, the combined frameworks confirm that a systematically integrated methodological approach is essential for developing an effective BIM based time and cost control system that enhances schedule and cost performance in Ø1000 mm pipeline bridge construction projects.

Data Collection Methods

Data collection was conducted through several stages corresponding to the research questions (RQ). For RQ1 and RQ2, which focus on evaluating the existing time and cost control system and identifying current weaknesses, document and archival analysis was carried out using project records, including schedules, cost reports, S-curves, and existing Work Breakdown Structures (WBS). This stage aimed to capture the actual condition of schedule performance (Y1) and cost performance (Y2). For RQ3 and RQ4, related to the development and validation of a standardized WBS (X1), expert validation was conducted involving construction management and BIM professionals to assess the relevance, completeness, and structure of WBS indicators. For RQ5 and RQ6, which address the roles of 3D modeling (X2) and Building Information Modeling (BIM) (X3) in project control, data were collected through expert assessment and structured questionnaires to evaluate their contribution to activity-level monitoring and control. For RQ7 and RQ8, which focus on the integrated time and cost control system (X4) and its impact on schedule performance (Y1) and cost performance (Y2), a structured questionnaire survey was distributed to construction professionals using a five-point Likert scale.

Data Analysis Methods

The data analysis consisted of two main approaches:

1. Qualitative analysis was applied for RQ1–RQ6 through literature synthesis and expert judgment to validate indicators, refine the WBS structure, and confirm the roles of 3D modeling and BIM within the control system.
2. Quantitative analysis was conducted for RQ7 and RQ8. Schedule and cost performance were measured using the Earned Value Management (EVM) method to obtain objective performance indicators. Subsequently, Partial Least Squares–Structural Equation Modeling (PLS-SEM) was used to analyze the causal relationships among WBS (X1), 3D Model (X2), BIM (X3), Time and Cost Control System (X4), and their effects on Schedule Performance (Y1) and Cost Performance (Y2).

III. RESULT AND DISCUSSION

Current Time And Cost Control Process And Activities

Addressing Research Question 1 (RQ1), this section evaluates the existing time and cost control processes and activities implemented in the Ø1000 mm pipeline bridge project. The analysis commenced with content and construct validation conducted by five construction management experts to identify relevant control activities across planning, monitoring, and evaluation phases. A total of 18 time and cost control activity indicators were examined, covering schedule planning, progress monitoring, cost tracking, deviation analysis, and reporting mechanisms. The expert validation confirmed that all indicators were valid and relevant, with agreement levels ranging from 82% to 94%, indicating strong professional consensus regarding their importance.Subsequently, a questionnaire survey was distributed to 80 construction professionals directly involved in infrastructure and pipeline projects. The results revealed that current control practices predominantly rely on macro-level monitoring tools, such as S-curve progress reports and periodic cost summaries. As a result, schedule delays and cost overruns are often identified only after deviations exceed 15–20% of the baseline, limiting the effectiveness of corrective actions. These findings indicate that the existing control process remains reactive rather than proactive.While these tools provide a general overview of project performance, they lack the capability to detect deviations at the activity-level.

Current Time And Cost Control Practices In The Literature

The review of current time and cost control practices in construction projects indicates that conventional control systems are generally characterized by fragmented scope definition, macro-level monitoring, and limited integration between schedule and cost management. Previous studies consistently report that reliance on S-curves, periodic progress reports, and manual cost tracking limits the ability to detect deviations at an early stage and reduces the effectiveness of corrective actions, particularly in complex infrastructure projects (Gebrehiwet & Luo, 2017).To contextualize these findings within the practical conditions of pipeline bridge construction, an expert and practitioner validation was conducted involving 80 construction professionals with experience in infrastructure project management. This validation focused on 15 indicators representing key activities and characteristics of existing time and cost control systems, including schedule planning, progress measurement, cost tracking, deviation analysis, reporting mechanisms, and coordination processes.

The objective of this stage was to assess the relevance and effectiveness of current control practices and to identify critical weaknesses that hinder performance improvement.The validation results demonstrate a very strong consensus among respondents regarding the limitations of existing control systems. The majority of indicators were rated at a high to very high level of agreement, confirming that current practices are predominantly reactive and lack activity-level integration. Indicators related to delayed deviation detection, limited linkage between schedule and cost data, and insufficient use of structured scope decomposition were identified as the most critical weaknesses. These findings indicate that deviations in time and cost are often recognized only after exceeding acceptable thresholds, reducing the opportunity for timely corrective action. Furthermore, the validation highlights that the absence of a standardized Work Breakdown Structure (WBS) and its integration with digital tools is a major contributing factor to weak control effectiveness. Respondents emphasized that without a clear linkage between work packages, schedules, and cost data, control processes become fragmented and heavily dependent on manual interpretation.

Development Of Work Breakdown Structure (Wbs) For Time And Cost Control Process

Addressing Research Question 3 (RQ3), this study developed a standardized Work Breakdown Structure (WBS) specifically tailored for Ø1000 mm pipeline bridge construction to enhance the effectiveness of time and cost control processes. The WBS development was conducted through an iterative expert validation process involving five domain specialists, resulting in a hierarchical structure consisting of four levels: project deliverables, structural components, construction activities, and detailed work packages.

Furthermore, this section examines the systematic development of the WBS, which commenced with Content and Construct Validation conducted by seven construction experts. The validation process confirmed the validity and relevance of 18 indicators across five WBS sub-variables, namely identifying and analyzing, structuring and organizing, decomposing, developing and assigning, and verifying. The results indicate that the proposed WBS provides a comprehensive and reliable framework for supporting time and cost control in pipeline bridge construction projects.

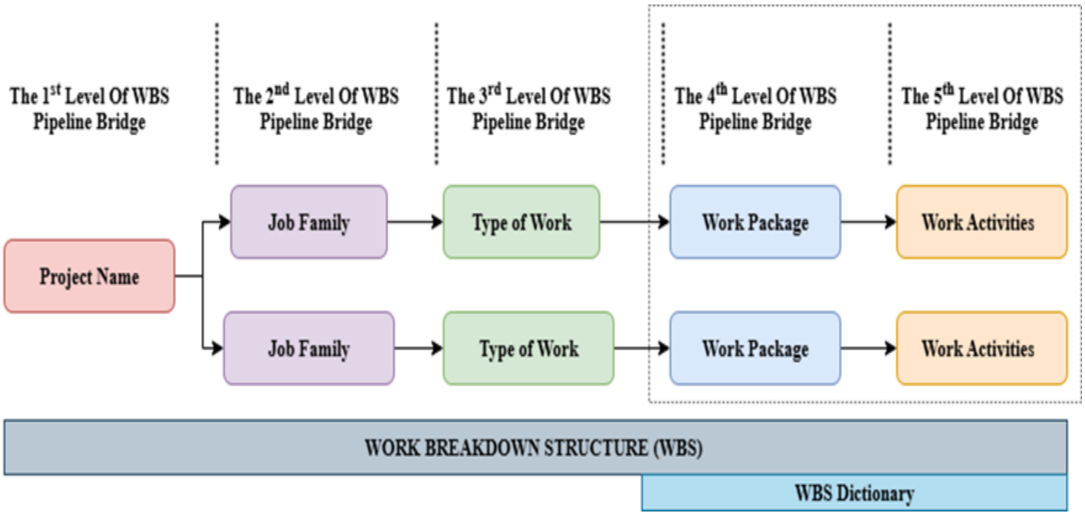


Fig 3. Level WBS Structure and WBS Dictionary Pipeline Bridge

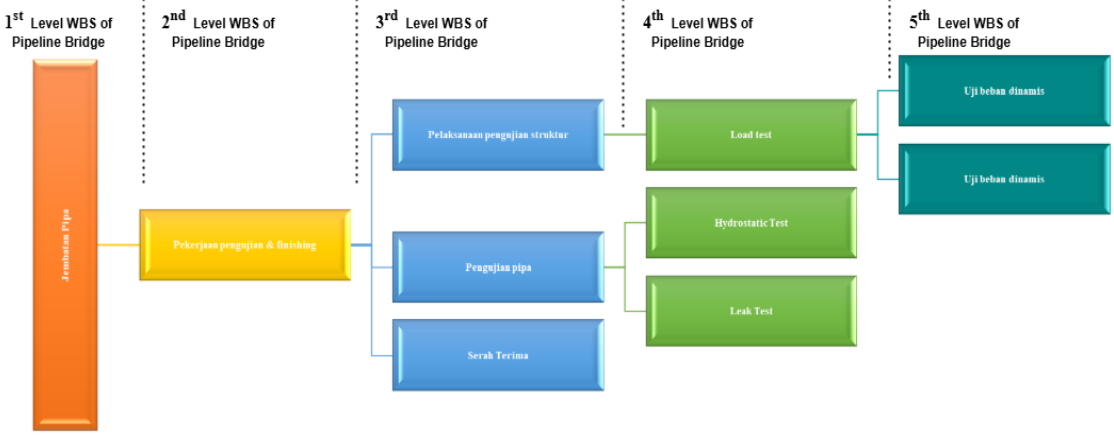


Fig 4. Standardization WBS Structure and WBS Dictionary Pipeline Bridge

The development of the WBS dictionary on the pipeline bridge was carried out after WBS pipeline bridge existing construction was validated. The WBS dictionary will describe the detail of each element contained in the work packages on the pipeline bridge. The WBS dictionary will contain more detailed information on each work package on the the pipeline bridge where the WBS dictionary contains information on:

- Code every level WBS
- WBS level color code
- Deliverable package of work
- Work package description
- Resources of each activity

Development Of 3d Model Based On Work Breakdown Structure (Wbs) For Time And Cost Control Process

Addressing Research Question 4 (RQ4), this section discusses the development of a 3D model structured in accordance with the validated Work Breakdown Structure (WBS) to support the time and cost control system in Ø1000 mm pipeline bridge construction. The primary objective of this development was to transform the hierarchical WBS into a control-oriented visual model that enables activity-level monitoring and strengthens the integration between scope definition, construction sequencing, and project control requirements.Expert validation was conducted on 10 indicators related to model accuracy, constructability representation, and integration with time and cost control processes. The subsequent survey of 80 construction professionals demonstrated a very strong consensus regarding the importance of WBS-based 3D modeling in strengthening project control systems. The indicators rated as most critical emphasized the role of the 3D model in supporting progress monitoring, identifying schedule deviations, and improving the accuracy of time and cost performance tracking. The resulting WBS-based 3D model serves as a foundational platform for activity-level time and cost control and is illustrated in **Figure 5**.

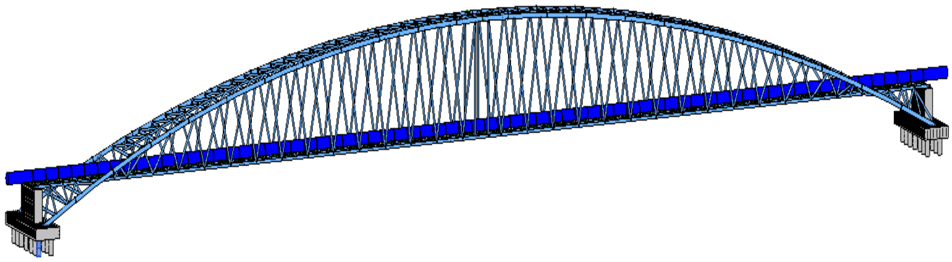


Fig 5. Simulation 3D Model on Revit

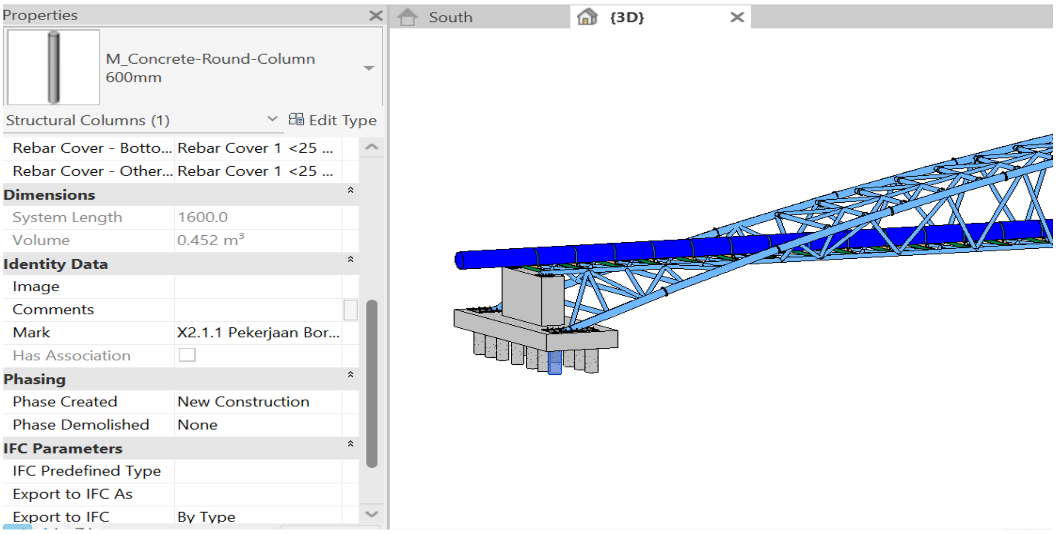


Fig 6. Simulation 3D Model on Revit based Level WBS of Pipeline Bridge

As shown in **Figure 5** and **Figure 6**, the 3D model of the Ø1000 mm pipeline bridge was developed using Autodesk Revit and structured in accordance with the validated WBS hierarchy. Each major structural component and sub-component of the pipeline bridge such as the main arch, supporting truss elements, pipe segments, bearings, and substructure was modeled as a distinct object and systematically linked to its corresponding WBS work package. This structured modeling approach enables clear traceability between physical elements and construction activities, thereby supporting detailed progress visualization and performance monitoring.Furthermore, the WBS-based 3D model facilitates the integration of construction sequencing and control data by allowing schedule and cost information to be associated directly with model elements. This capability enhances the accuracy of progress measurement, supports early identification of schedule deviations, and improves the reliability of time and cost performance tracking.

Development Of Building Information Modeling (Bim) Model Based On Work Breakdown Structure (Wbs) And 3d Model For Time And Cost Control Process.

The research addressing the development of a Building Information Modeling (BIM) based on the Work Breakdown Structure (WBS) and 3D Model as a foundation for an integrated time and cost control process in Ø1000 mm pipeline bridge construction (RQ6) began with a Content and Construct Validation conducted by seven construction management and BIM experts. This validation stage successfully confirmed the relevance and validity of 26 indicators grouped into twelve sub-variables.The subsequent questionnaire survey distributed to 80 construction professionals demonstrated a very strong consensus, indicated by a very high level of agreement regarding the urgency of these indicators. The results confirm that the structured implementation of BIM, when aligned with a standardized WBS and a detailed 3D model, constitutes a critical foundation for improving the effectiveness of time and cost control systems in infrastructure projects. This finding reinforces the view that BIM should be positioned not only as a visualization tool, but as a control-oriented information management platform.

The indicators rated as the most crucial by respondents were those related to the application of BIM dimensions 4D and 5D to support schedule monitoring, cost tracking, and performance. This indicates that, within the context of project control, practitioners primarily value BIM for its ability to integrate physical progress with time and cost information at the activity-level. Furthermore, indicators emphasizing improvements in project time and cost efficiency through BIM implementation, as well as the need to strengthen functional integration between BIM, the Work Breakdown Structure (WBS), cost, and project scheduling, also received the highest levels of agreement.These findings suggest that the main challenges in current BIM implementation are not associated with technological limitations, but rather with the need to enhance functional and procedural integration between BIM models and structured project control processes. Accordingly, the development of a BIM model based on WBS and 3D modeling provides a robust platform for more proactive, transparent, and data-driven time and cost control in pipeline bridge construction projects.

Table 1. comparison of quantities from conventional Bill of Quantities (BOQ) and BIM based take-off for the Ø1000 mm pipeline bridge project.

2	**Pekerjaan Beam Jembatan Pipa Ø 1000 mm**	**Volume (BOQ)**		**Volume (BIM)**		**Deviasi**
		Quantity	**Unit**	**Quantity**	**Unit**	
2.1	**Pekerjaan Cremona**					
	-Main Beam Pipe GIP diameter 400 mm	280,00	m	275	m	1,8%
	-Top Cross Beam Pipe GIP diameter 200 mm	222,40	m	200	m	10,1%
	-Hanging Pipe Pipe GIP diameter 250 mm	0,00	m	0,00	m	0,0%
	-Hanging Pipe Pipe GIP diameter 100 mm	359,37	m	346	m	3,7%
	-Bottom Beam Pipe Support Pipe GIP diameter 200 mm	277,72	m	260	m	6,4%
	-Bottom Cross Beam IWF 200 x 150	5746,53	Kg	4088,68	kg	28,8%
	-Pipe Support 150x150	71	Pcs	71	Pcs	0,0%
	-Clamp Pipe Plat Strip t = 5 mm	71	unit	71	unit	0,0%
	-Base Plate 1 @ 2.4x1x20	4	unit	4	unit	0,0%
	-Base Plate 2 @ 0.6x0.4x20	4	unit	4	unit	0,0%
	-Anchor Bolt M-36 L=50	128	Pcs	130	pcs	-1,6%
	-Clamp Bolt M-16 L=200	268	Pcs	270	pcs	-0,7%
	-Erection Struktur Baja	1300,29	m	1210,2	m	6,9%
2.2	**Pekerjaan Pengecatan**					
	-Sand Balast SA 2.5 Struktur Baja	686	m²	553	m2	19,4%
	-Frame Coating Struktur Baja	686	m²	553	m2	19,4%
	-Finishing Struktur Baja	686	m²	553	m2	19,4%

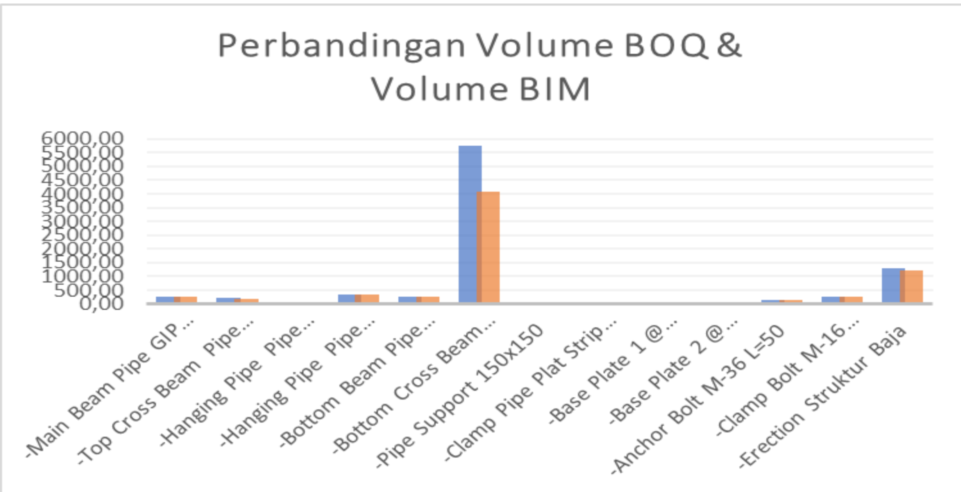


Fig 7. Comparison of quantities between conventional BOQ and BIM-based take-off

Table 1 and **Figure 7** present a detailed comparison between quantities derived from conventional Bills of Quantities (BOQ) and those obtained through BIM-based take-off. The results indicate that quantity deviations are predominantly observed in steel structural components and cross beam elements, with the highest deviation occurring in the bottom cross beam steel members. These discrepancies reflect the limitations of manual quantity take-off methods that rely on two dimensional drawings and simplified geometric assumptions.

Conceptual Framework Of Integrated Time And Cost Control Based On Work Breakdown Structure (Wbs), 3d Model, And Building Information Modeling

This research proposes a conceptual framework that integrates Work Breakdown Structure (WBS), 3D modeling, and Building Information Modeling (BIM) within a unified time and cost control system. In the framework, WBS (X1), 3D modeling (X2), and BIM (X3) function as independent variables that influence the effectiveness of the Time and Cost Control System (X4), which subsequently affects Schedule Performance (Y1) and Cost Performance (Y2). The integration of WBS with 3D and BIM ensures data consistency, interoperability, and traceability across project phases, thereby strengthening control processes.

Fig 8. presents the proposed conceptual framework

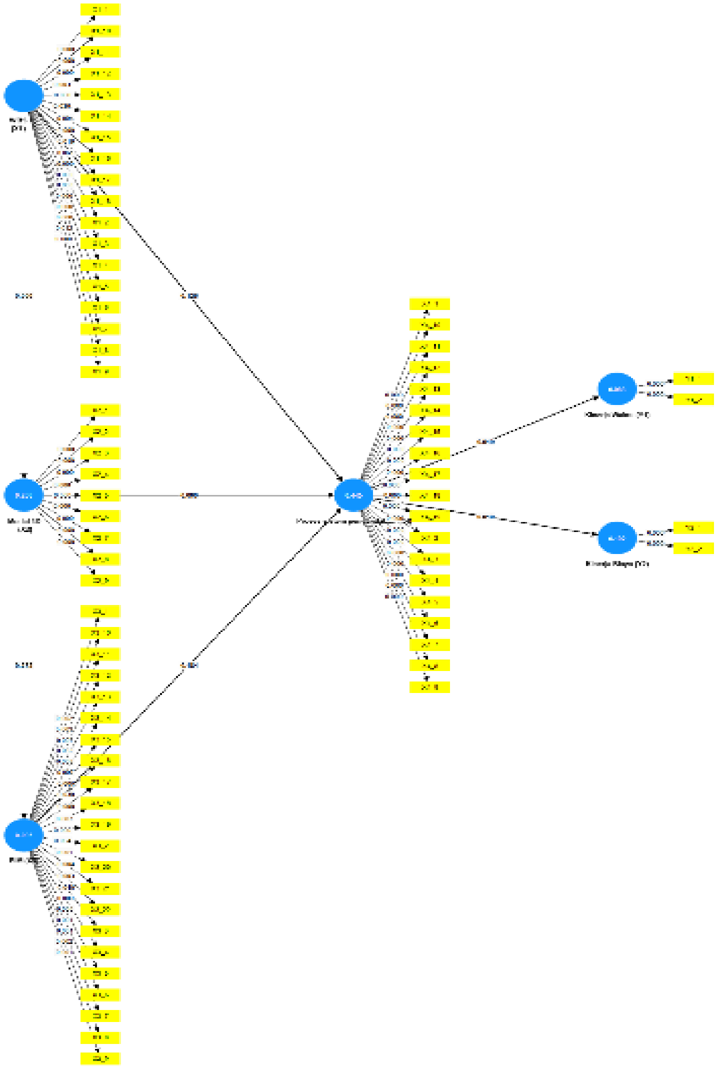


Fig 8. Result Conceptual Framework for an Integrated Time and Cost Control based on WBS, 3D Model, and BIM

Based on the proposed conceptual framework, hypothesis testing was conducted using Partial Least Squares–Structural Equation Modeling (PLS-SEM) to evaluate the relationships among Work Breakdown Structure (X1), 3D Modeling (X2), Building Information Modeling (X3), the Time and Cost Control System (X4), and project performance variables, namely Schedule Performance (Y1) and Cost Performance (Y2).

Development Integrated Time And Cost Control Based On Work Breakdown Structure (Wbs), 3d Model, And Building Information Modeling

The research addressing the development of a Building Information Modeling (BIM)-based time and cost control system for pipeline bridge construction projects (RQ5) began with a Content and Construct Validation conducted by five construction management experts. This validation stage successfully confirmed the validity and relevance of 26 indicators. These indicators were designed to assess the role of BIM as a supporting platform for integrated project time and cost control. The subsequent survey of 80 construction professionals demonstrated a very strong consensus, with a high level of agreement on the urgency of these indicators. The results confirm that the structured implementation of BIM constitutes a critical foundation for strengthening project time and cost control systems in pipeline bridge construction.

The indicators rated as most crucial by respondents were those related to the use of BIM dimensions (4D and 5D) to support progress monitoring, schedule control, and cost performance tracking, indicating that practitioners primarily value BIM for its ability to integrate physical progress with time and cost control information.Furthermore, indicators emphasizing improvements in project time and cost efficiency through BIM implementation, as well as the need to enhance integration between BIM, the Work Breakdown Structure (WBS), project schedules, and cost control data, also received the highest levels of agreement. These findings suggest that current implementation challenges are less related to technological availability and more focused on strengthening functional integration between BIM and structured project control processes. Overall, the results highlight the importance of BIM as an enabling platform for a more proactive, integrated, and data-driven time and cost control system in pipeline bridge construction projects.

Table 2. summarizes the cost comparison from conventional BOQ calculations and BIM 5D

No	Item Pekerjaan	Satuan	Kuantitas	Harga Satuan (Rp)	Biaya Pekerjaan (BOQ)	Biaya Pekerjaan (BIM)	Deviasi
2	**Pekerjaan Beam Jembatan Pipa Ø 1000 mm**						
2.1	**Pekerjaan Cremona**						
	-Main Beam Pipe GIP diameter 400 mm	m	280	Rp6.624.992,00	Rp 1.854.997.760,00	Rp 1.821.872.800,00	
	-Top Cross Beam Pipe GIP diameter 200 mm	m	222,4	Rp3.941.915,00	Rp 876.840.736,00	Rp 788.383.000,00	
	-Hanging Pipe Pipe GIP diameter 250 mm	m	359,37	Rp2.954.828,00	Rp 1.062.112.302,00	Rp -	
	-Hanging Pipe Pipe GIP diameter 100 mm	m	277,72	Rp3.941.915,00	Rp 1.094.895.064,00	Rp 1.363.902.590,00	
	-Bottom Beam Pipe Support Pipe GIP diameter 200 mm	kg	5.746,53	Rp 39.914,00	Rp 229.315.158,00	Rp 10.377.640,00	
	-Bottom Cross Beam IWF 200 x 150	pcs	71	Rp1.512.824,00	Rp 107.410.504,00	Rp 6.185.453.232,32	-17%
	-Pipe Support 150x150	unit	71	Rp 554.702,00	Rp 39.383.842,00	Rp 39.383.842,00	
	-Clamp Pipe Plat Strip t = 5 mm	pcs	128	Rp 352.992,00	Rp 45.182.976,00	Rp 25.062.432,00	
	-Base Plate 1 @ 2.4x1x20	pcs	268	Rp 85.727,00	Rp 22.975.036,00	Rp 342.908,00	
	-Base Plate 2 @ 0.6x0.4x20	m	1.300,29	Rp2.622.228,00	Rp 3.410.611.382,00	Rp 10.488.912,00	
	-Anchor Bolt M-36 L=50	pcs	128	Rp 35.299,00	Rp 4.518.272,00	Rp 4.518.272,00	
	-Clamp Bolt M-16 L=200	pcs	268	Rp 8.573,00	Rp 2.297.564,00	Rp 2.297.564,00	
	-Erection Struktur Baja	m	1300,29	Rp 262.228,00	Rp 340.972.191,03	Rp 340.972.191,03	
SUB TOTAL - PEKERJAAN CREMONA					**Rp9.091.512.787,03**	**Rp 10.593.055.383,35**	

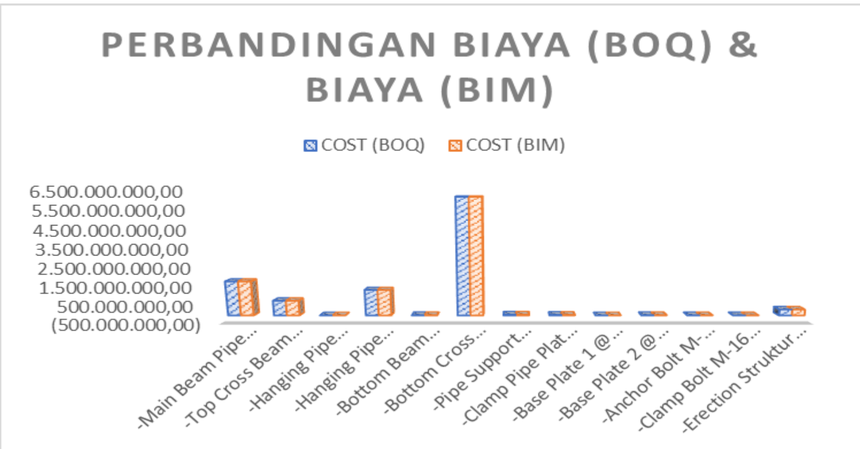
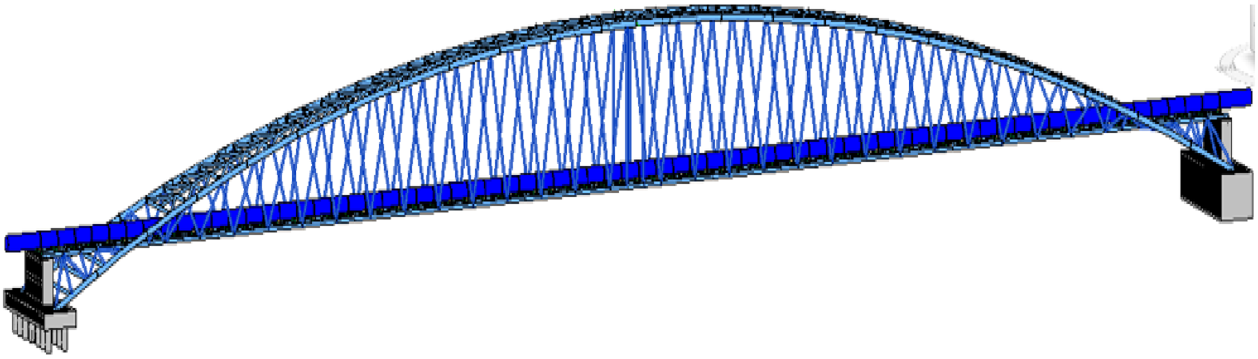


Fig 9. Graphic summarizing the cost comparison from conventional BOQ calculations and BIM 5D

Table 2 and **Figure 9** summarizes the cost comparison between conventional BOQ estimates and BIM 5D based cost calculations. The results reveal significant cost deviations for several work packages, especially steel structural and support elements, which are directly influenced by quantity discrepancies identified in Appendix A. Negative cost deviations indicate potential overestimation in BOQ calculations, while positive deviations suggest underestimation caused by incomplete representation of physical elements in conventional documentation. These findings demonstrate that BIM 5D, through its integration of 3D quantities with cost information, provides more transparent and traceable cost data at the activity and element levels. As a result, BIM-based cost estimation enhances the identification of high-risk cost items and supports more effective time and cost control compared to traditional BOQ-based approaches.



Structural Framing	0.01 m³	58.41 kg
Structural Framing	0.01 m³	58.41 kg
Structural Framing	0.01 m³	58.41 kg
Structural Framing	0.01 m³	58.41 kg
Structural Framing	0.01 m³	58.41 kg
Structural Framing	0.01 m³	58.41 kg
Structural Framing	0.01 m³	58.41 kg
Structural Framing	0.01 m³	58.41 kg
Structural Framing	0.01 m³	58.41 kg
Structural Framing	0.01 m³	58.41 kg
0.01 m³: 70	0.52 m³	4088.68 kg

Fig 10. Result Simulation BIM 5D

Figure 10 illustrates the results of the BIM 5D simulation applied to the Ø1000 mm pipeline bridge construction project, where three-dimensional geometric elements are integrated with schedule and cost information based on the validated Work Breakdown Structure (WBS). In this simulation, each structural component is linked to its corresponding work package, enabling the visualization of cost distribution and construction progress at the activity-level.This integration enhances the accuracy of cost monitoring and supports more reliable forecasting of project expenditures compared to conventional cost control approaches. Overall, the results confirm that BIM 5D serves as an effective control-oriented platform that strengthens the integration between scope definition, scheduling, and cost management. The use of BIM 5D simulation contributes significantly to improving transparency, accuracy, and decision-making in time and cost control processes for pipeline bridge construction projects.

Discussion

This study demonstrates that improving time and cost performance in Ø1000 mm pipeline bridge construction projects lies in the reliance on macro-level monitoring tools that are unable to detect deviations at the activity-level. Conventional approaches tend to be reactive, identifying schedule delays and cost overruns only after they reach significant levels. These findings confirm that effective project control requires structured integration between scope definition, scheduling, and cost management rather than isolated reporting mechanisms. The development of a standardized Work Breakdown Structure (WBS), followed by its integration into WBS-based 3D modeling, significantly strengthens project control by enabling activity-level visualization and traceability. The WBS provides a consistent structural foundation for decomposing project scope, while the 3D model functions as a control-oriented representation that improves constructability understanding, progress monitoring, and early detection of schedule deviations. This integration enhances managerial awareness and supports more proactive decision-making during project execution.Furthermore, the integration of Building Information Modeling (BIM), particularly through the 4D and 5D dimensions, consolidates physical progress, schedule, and cost data within a unified digital. The findings confirm that BIM effectiveness is highly dependent on its functional alignment with the standardized WBS and 3D model. When integrated systematically, WBS–3D–BIM-based control processes improve monitoring accuracy, forecasting capability, and overall schedule and cost performance, thereby extending system-based project management principles into a BIM enabled infrastructure context.

IV. CONCLUSION

Overall, the findings of this research summarize the answers to the research questions (RQ) related to the development of an integrated time and cost control system for Ø1000 mm pipeline bridge construction based on Work Breakdown Structure (WBS), 3D modeling, and Building Information Modeling (BIM):

1. The evaluation of existing practices indicates that current time and cost control systems are predominantly macro-oriented and reactive, resulting in delayed detection of schedule delays and cost overruns.
2. The development of a standardized and validated Work Breakdown Structure (WBS) is a critical foundation for effective project control, as it provides a structured decomposition of project scope that supports integrated scheduling and cost management.
3. WBS based 3D models are highly crucial due to their ability to automatically support activity-level visualization, constructability analysis, and progress monitoring, enabling early identification of schedule deviations.
4. The integration of BIM, particularly through 4D and 5D dimensions, significantly improves the accuracy of time and cost performance tracking by linking physical progress with schedule and cost data in a unified digital environment.
5. The effectiveness of BIM based time and cost control is strongly influenced by the level of integration between BIM, the standardized WBS, and the 3D model, indicating that technological implementation alone is insufficient without structured managerial alignment.
6. The proposed integrated control framework confirms that the time and cost control process acts as a mediating mechanism through which WBS, 3D modeling, and BIM collectively improve schedule performance and cost performance.

Overall, this study demonstrates that the systematic integration of WBS, 3D modeling, and BIM provides a practical and effective approach to enhancing time and cost performance in pipeline bridge construction projects.

V. ACKNOWLEDGMENTS

The author gratefully acknowledges that the completion of this research would not have been possible without the guidance, support, and assistance of numerous individuals. The author wishes to express the deepest gratitude and sincere appreciation to Prof. Dr. Ir. Yusuf Latief, S.T., M.T. and Leni Sagita Riantini, S.T., M.T., Ph.D., as supervisors, for their invaluable guidance, constructive feedback, and continuous encouragement throughout the research process. Their expertise and dedication have been instrumental in shaping and completing this study.The author also extends sincere appreciation to her parents and family for their unwavering moral support, motivation, and prayers, as well as for the material support that enabled the successful completion of this research. In addition, sincere thanks are conveyed to colleagues and friends who provided assistance, discussions, and encouragement during the course of this study. Their support has contributed significantly to the successful completion of this research.

REFERENCES

[1] Saputra, H., & Latief, Y. (2020). Integrating WBS with safety and cost aspects to enhance owner estimate reliability. ***Journal of Civil Engineering Forum***, 6(2), 187–196.

[2] Abanda, F. H., & Byers, L. (2016). An investigation of the impact of Building Information Modeling on project information management. ***International Journal of Project Management,*** 34(3), 422–437.

[3] Amirilaskar, E., Ervitte, R., & Sari, D. P. (2023). Comparative study of cost estimation methods in construction procurement: Data inquiry vs. cost structure. ***Journal of Construction Engineering and Management***, 149(6).

[4] Succar, B. (2009). Building information Modeling framework: A research and delivery foundation for industry stakeholders. Automation in Construction, 18(3), 357–375.

[5] Wong, J. K. W., & Zhou, J. (2015). Enhancing environmental sustainability over building life cycles through green BIM. Automation in Construction, 57, 156–165.

[6] Flyvbjerg, B. (2014). What you should know about megaprojects and why: An overview. ***Project Management Journal***, 45(2), 6–19.

[7] Love, P. E. D., Edwards, D. J., & Irani, Z. (2012). Moving beyond optimism bias and strategic misrepresentation. Construction Management and Economics, 30(6), 469–483.

[8] Gebrehiwet, T., & Luo, H. (2017). Analysis of delay impact on construction projects. ***Journal of Construction Engineering and Management***, 143(6).

[9] Kim, K., Cho, Y., & Zhang, S. (2016). Integrating BIM with Earned Value Management for effective project control. Automation in Construction, 68, 1–15.

[10] Kerzner, H. (2017). Project Management: A Systems Approach to Planning, Scheduling, and Controlling. Hoboken, NJ: John Wiley & Sons.

[11] Astana, I. N. Y., Wiryasa, N. A., & Pinakesty, S. A. P. (2023). The relationship below 80% of the owner estimate price on construction projects to project performance. ***Journal of Asian Multicultural Research for Economy and Management Study*****.**

[12] AACE International. (2020). Cost estimate classification system – As applied in engineering, procurement, and construction for the process industries *(No. 56R-08)*. Morgantown, WV: AACE International.

[13] Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2018). BIM Handbook: A Guide to Building Information Modeling. Hoboken, NJ: John Wiley & Sons.

[14] PMI. (2017). A Guide to the Project Management Body of Knowledge (PMBOK® Guide) (6th ed.). Newtown Square, PA: Project Management Institute.

[15] Abdel-Hamid, M., & Abdelhaleem, M. (2019). BIM-based cost control for infrastructure projects. Engineering, Construction and Architectural Management, 26(10), 2345–2363.

[16] Hartmann, T., van Meerveld, H., Vossebeld, N., & Adriaanse, A. (2012). Aligning building information model tools and construction management methods. Automation in Construction, 22, 605–613.