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THE EFFECT OF BIM 4D-5D IMPLEMENTATION AND VISUALIZATION ON IMPROVING PRODUCT QUALITY AND TOLL ROAD INFRASTRUCTURE PROJECT TIME

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ABSTRACT

The toll road construction project is inherently complex and prone to delays due to its multi-phase implementation process. In the era of the Industrial Revolution 4.0, the adoption of digital construction technologies is increasingly emphasized to enhance project efficiency and outcomes. One such technology is Building Information Modeling (BIM), which serves as a vital digital asset supporting data integration and informed decision-making throughout the construction lifecycle. This study aims to analyze the influence of BIM implementation on the quality of engineering products and how engineering product quality subsequently affects implementation time performance. Employing a quantitative approach with linear regression analysis, data were collected from toll road construction projects that have adopted BIM practices. The findings reveal a significant influence of BIM implementation on the quality of engineering products by 71.00%, and a further influence of engineering product quality on the performance of implementation time by 77.10%. These results demonstrate that BIM plays a critical role in improving construction quality and accelerating project completion. The study concludes that the structured and integrated nature of BIM enhances engineering output and time efficiency, making it a strategic tool for national infrastructure projects. It is recommended that stakeholders in the construction sector adopt BIM more comprehensively to optimize quality assurance and reduce the risk of project delays.

KEYWORDS	BIM 4D, BIM 5D, Visualization, Quality Product & Time Performance.

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INTRODUCTION

Infrastructure according to expert Neil S. Grigg (2018) is a physical system that provides drainage, irrigation, transportation, buildings and other public facilities needed to be able to meet various basic human needs, both social and economic needs. Another definition of infrastructure is the type of facilities needed by the community to support the life of community activities. In other words, infrastructure is all facilities, in the form of physical and non-physical, built by the government and individuals in meeting the basic needs of the community in social and economic aspects. Based on Presidential Regulation (Perpres) No. 56/2018 concerning the Second Amendment to Presidential Regulation 3/2016 concerning the Acceleration of the Implementation of National Strategic Projects (PSN) instructs the Ministry of Public Works and Public Housing (PUPR) to continue the construction of a number of National Strategic Projects (PSN), one of the targets is the construction of a 3,500 km toll road until 2024. The toll road project is a construction project where each stage is quite complex and there is a potential for delays in the implementation of construction. Along with the magnitude of the target and the high expectations of the public for the targeted infrastructure, it is necessary to carry out careful planning, strict supervision and the most appropriate decision-making possible so that the finished infrastructure products can be carried out on time, efficiently and with the best quality. The construction world is currently entering the era of the Industrial Revolution 4.0, where in SE Number 25.1/SE/Db/2023 concerning Implementation Guidelines *Building Information Modelling* (BIM) In the Scope of Road and Bridge Construction Work, BIM is said to be a digital asset for decision-making and as data in the next phase, so that there is no shortage and data loss that can hinder decision-making. According to the PUPR BIM Protocol, Building Information Modeling is BIM (Building Information Modeling) is a digital representation (digital asset) of the physical character and functional character of a building (physical asset). Therefore, it contains all information about these building elements that are used as a basis for decision-making in the planning process, construction implementation, and building operation period. In its implementation, BIM is divided into 8 Dimensions, the explanation for 3D is the model, 4D is 3D combined with the schedule time, 5D is 4D combined with cost, 6D is 5D combined with energy analysis, 7D is 6D combined with facility management and 8D namely 7D combined with safety aspects and until now the BIM dimension continues to be developed and new dimensions with other functions will appear.

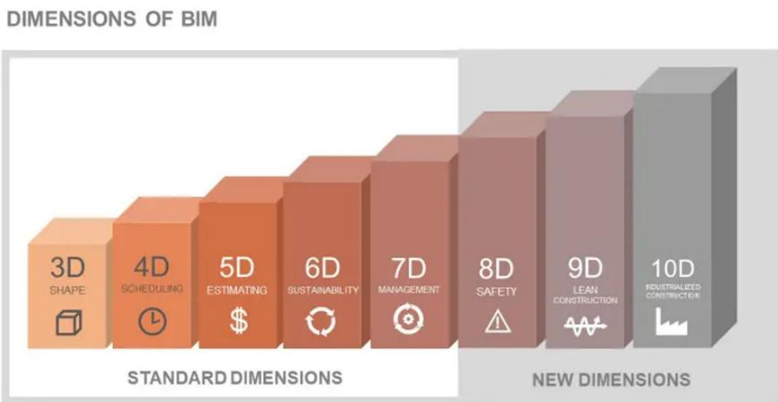

Figure 1. Level of Dimensions BIM

Based on his previous research, Research One (C.A. Berlian P, et al, 2016) obtained the results that from the comparison of the BIM method with conventional methods, it is known that the BIM method can save planning time by 50% and other previous research as well, Research Two (Raflis, et al, 2018) stated that the use of BIM provides benefits as a medium of communication in effective stakeholder collaboration.

Previous studies have shown the strategic role of Building Information Modeling (BIM) in improving efficiency and communication in construction projects. Berlian et al. (2016) revealed that BIM could reduce planning time by up to 50% compared to conventional methods. Similarly, Raflis et al. (2018) emphasized BIM's value as a collaborative communication medium among stakeholders in project implementation. However, these studies primarily focused on the planning and collaboration benefits of BIM without delving into its implementation in the context of national strategic infrastructure projects, especially toll road construction, which involves complex, multi-phase workflows and high public expectations. The novelty of this research lies in exploring how BIM—especially in its multi-dimensional capabilities (3D to 8D)—can be optimized to support planning, scheduling, cost estimation, sustainability analysis, facility management, and safety assurance in national toll road development projects. This research aims to provide a comprehensive framework for applying BIM as a digital asset in national strategic toll road construction, addressing practical implementation challenges and maximizing decision-making accuracy. The results are expected to offer actionable insights for the Ministry of Public Works and Public Housing (PUPR) and private contractors to optimize BIM integration, increase efficiency, and reduce the potential for project delays or budget overruns. Additionally, this research will contribute to the academic discourse on digital transformation in infrastructure development, especially in developing countries.

This study aims to analyze the influence of BIM implementation on the quality of engineering products and how engineering product quality subsequently affects implementation time performance

RESEARCH METHOD

Research is an effort to develop knowledge, develop and test theories. In relation to knowledge development efforts, Welberg (2016) proposed five steps to develop knowledge through research, namely: (1) identifying research problems, (2) conducting empirical studies, (3) replicating or repeating, (4) synthesizing and reviewing, and (5) using and evaluating (McMillan and Schumacher, 2011: 6). According to Sarwono (2016), research design is like a roadmap for researchers that guides and determines the direction of the research process correctly and appropriately in accordance with the goals that have been set. This research plan will use a survei method with descriptive survei and exploratory survei types, thus this research will target a certain number of populations with the aim of investigating and taking references by relating variables related to the problem to be investigated. In this study, the questionnaire variables were verified to experts who are experts in the field of BIM implementation. This verification is carried out before the questionnaire is distributed to the general respondents with the aim of ensuring the relevance of the variables to the research objectives. After verification, the questionnaire was distributed to the general respondents where in this study there were 37 general respondents consisting of engineering managers, construction engineers, BIM modelers and drafters from five toll road infrastructure construction projects. The research design in the study is described as follows:

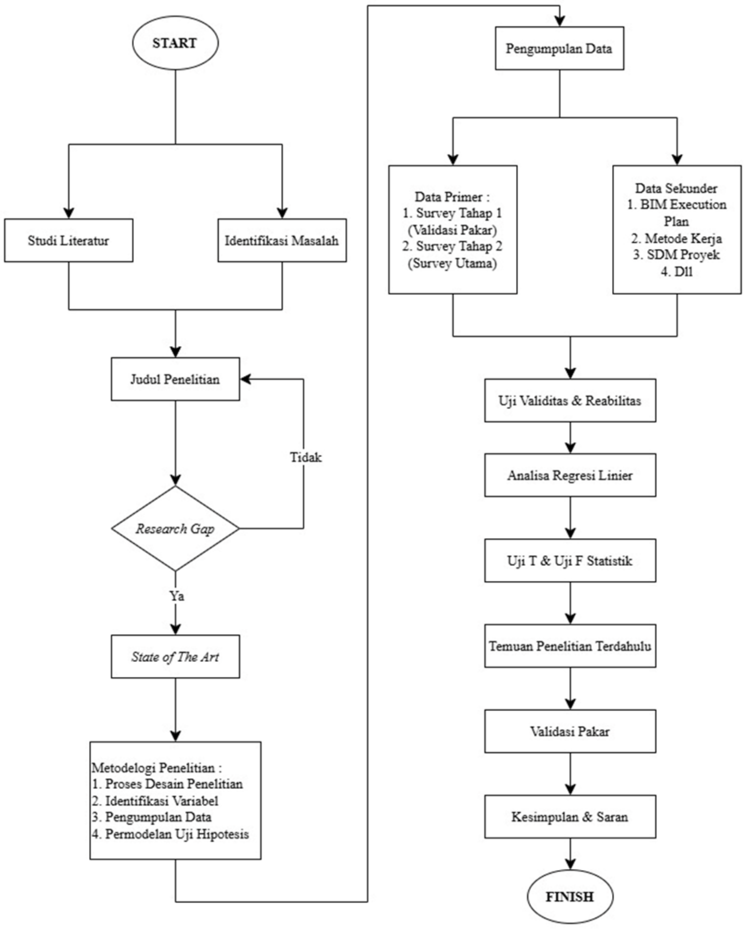

Figure 2. Research Design

In this study, two variables will be used, namely the dependent variable and the independent variable. According to Sugiyono (2019:69), the independent variable is "the variable that affects or causes the change or the occurrence of the dependent variable (bound)", while the dependent variable is "the variable that is influenced or the result, due to the existence of the independent variable". Here's a regression equation model

$$Y1 = a + b.X1 + c.X2 + d.X3$$
$$Z1 = a + b.Y1$$

Information:

Y1 = Product Quality Planning

Z1 = Project Implementation Time Performance

X1 = Implementasi BIM 4D Schedule

X2 = Implementasi BIM 5D Cost

X3 = Walktrough Visualization

a = Constan

RESULT AND DISCUSSION

The regression analysis process in this study uses the JASP program in the process. The first data analysis process is the validity test and reliability test. The output results of the JASP program using questionnaire data are obtained as follows:

Table 1. Validity Test

Variable	Pearson's r		r table	Conclusion
X1	0,671	>	0,324	Valid
X2	0,707	>	0,324	Valid
X3	0,798	>	0,324	Valid
Y1	0,878	>	0,324	Valid

Table 2. Reliability Test

Variable	Cronbach's s α		Reliability Standards	Conclusion
X1	0,849	>	0,600	Reliable
X2	0,812	>	0,600	Reliable
X3	0,965	>	0,600	Reliable
Y1	0,944	>	0,600	Reliable

After the instrumentation test was carried out and then continued with the multiple linear regression analysis of Equation 1, the output results of the process were obtained as follows:

$$Y1 = a + b.X1 + c.X2 + d.X3$$
$$= -0.589 + 0,021.X1 + 0,310.X2 + 0,464.X3$$

From the output results of the following mathematical model, the value of the determination coefficient (R2) of Equation 1 is 0.710 or in a percentage of 71.00%, meaning that the output of this mathematical model means that the independent variable (x) simultaneously or simultaneously affects the bound variable (y1) by 71.00%, in the statistical sense that the value has a truth level of 71.00%, then the remaining value of 29.00% is the influence of other variables that are not studied in The following research. Meanwhile, after Equation 1 is followed by Equation 2, the following process outputs are obtained:

$$Z1 = a + b.Y1$$
$$= 0.955 + 0.899.Y1$$

From the output results of the following mathematical model, the value of the determination coefficient (R2) of Equation 2 is 0.771 or in a percentage of 77.10%, meaning that the output of this mathematical model means that the independent variable (y1) simultaneously or simultaneously affects the bound variable (z1) of 77.10%, in the statistical sense that the value has a truth level of 77.10%, then the remaining value of 22.90% is the influence of other variables that are not studied in The following research.

The next process after the regression analysis of Equation 1 & Equation 2 is continued with a multicollinearity analysis which has the function of testing whether the regression model is found to have a high or perfect correlation between independent variables. . On the condition that the tolerance value is seen, if the tolerance value is greater than > 0.10, it means that there is no multicollinearity. Or looking at the VIF value, if the VIF value is less than < 10.00, it means that there is no multicollinearity. Based on the results of the analysis, the analysis of multicollinearity was obtained as follows:

Table 3. Multicollinearity Testing Equation 1 (Y1)

Model		Tolerance	BRIGHT	Conclusion
H0				
H1				
	X1	0,378	2,648	There is no multicollinearity.
	X2	0,581	1,721	There is no multicollinearity.
	X3	0,359	2,782	There is no multicollinearity.

Table 4. Equation Multicollinearity Testing 2 (Z1)

Type		Tolerance	VIF	Conclusion
H0				
H1				
	Y1	1,000	1,000	There is no multicollinearity.

The next analysis is the T-test and the F-test, the T-test is carried out to determine the influence of the x variable partially on the y variable while the F-test is carried out to find out the simultaneous influence of the x variable on the y variable.$_{count}$ must be greater than the value of t_{table} and ρ_{count} must be less than 0.05 (5% significance level). In Equation 1 (Y1), the value of the table coordinates = t (a/2; n-k-1) is obtained from the table of t values$_{table}$ = 2,034. As for the value of t_{count} and ρ_{count} Based on the output results, it was concluded that the variables X2 (BIM 5D Cost Implementation) and X3 (Walktrough Visualization) had a significant effect, the summary of the conclusions is as follows:

Table 5. T-Test Equation 1 (Y1)

Type		t	R	Conclusion
H0				
H1				
	X1	0,224	0,824	Insignificant Effect
	X2	2,743	0,010	Significant Influence
	X3	3,592	0,001	Significant Influence

As for Equation 2 (Z1) with table coordinates, the t-value$_{\text{of the table}}$ is 2.030. As for the value of $t_{calculation}$ and $\rho_{calculation}$ based on the output of the analysis results, the following values were obtained:

Table 6. Equation 2 (Z1) T-Test

Type	t	R	Conclusion
H0 H1			
Y1	10,848	$9{,}662 \times 10^{-13}$	Significant Influence

The F-Value test is carried out by comparing the F-value$_{\text{of the calculation}}$ must be greater than the F-value of the$_{\text{table}}$ and the $\rho_{\text{calculation}}$ must be less than 0.05. In equation 1 (Y1) with the coordinate value of the F_{table} is obtained the F value$_{\text{of the table}}$ is 2.883. As for the value of $F_{\text{calculation}}$ and $\rho_{\text{calculation}}$ based on the output results, the following values are obtained:

Table 7. F-Test Equation 1 (Y1)

Model	F	R	Conclusion
H1			
Y1	26,915	$5{,}420 \times 10^{-9}$	Significant Influence

As for Equation 2 (Z1) with the coordinate value of the table, the F value of $_{\text{the table}}$ is 4.113. As for the values of $F_{\text{calculation}}$ and $\rho_{\text{calculation}}$ based on the output of the analysis results, the following values are obtained:

Table 8. F-Test Equation 2 (Z1)

Type	F	R	Conclusion
H1			
Z1	117,677	$9{,}662 \times ^{10-13}$	Significant Influence

Based on the results of the validity and reliability testing conducted using the JASP program, it is evident that all research variables—X1 (BIM 3D Modeling), X2 (BIM 5D Cost), X3 (Walkthrough Visualization), and Y1 (Engineering Product Quality)—have passed the minimum thresholds. The Pearson correlation coefficients for the validity test all exceed the r-table value of 0.324, indicating that the questionnaire items are valid. Similarly, the Cronbach's Alpha values for all variables exceed 0.600, confirming high internal consistency and reliability of the instruments used in this study.

The multiple linear regression analysis for Equation 1 (Y1) demonstrates that the independent variables jointly influence the quality of engineering products significantly, as indicated by the determination coefficient (R^2) of 71.00%. This implies that the implementation of BIM across its various dimensions contributes substantially to the improvement of engineering output. However, when analyzed partially using the T-test, only X2 (BIM 5D Cost Implementation) and X3 (Walkthrough Visualization) show a significant impact, with t-values of 2.743 and 3.592 respectively, and significance levels below 0.05. On the other hand, X1 (BIM 3D Modeling) shows an insignificant effect ($t = 0.224$, $\rho = 0.824$), suggesting that while 3D modeling is foundational, it may not be sufficient alone to improve the quality of engineering products without being supported by cost estimation and visualization aspects.

For Equation 2 (Z1), which examines the impact of engineering product quality (Y1) on implementation time performance (Z1), the regression equation reveals a strong positive relationship. The R^2 value of 77.10% indicates that a significant portion of the variation in implementation time performance is influenced by the quality of engineering products. The T-test result ($t = 10.848$, $\rho < 0.001$) confirms this variable has a highly significant effect, affirming that better quality engineering output leads to more efficient and timely project execution.

Multicollinearity testing for both regression equations (Tables 3 and 4) confirms the absence of multicollinearity among the independent variables, as all Tolerance values exceed 0.10 and VIF values remain below 10. This reinforces the robustness of the regression model.

Further, the F-test results for both regression equations indicate a simultaneous significant influence of the predictor variables on their respective outcomes ($F = 26.915$ for Y1 and $F = 117.677$ for Z1, both with $\rho < 0.05$). These findings suggest that BIM implementation, particularly when integrating cost estimation and visualization tools, contributes significantly to both the quality of engineering products and the timeliness of project execution.

Thus, the findings support the integration of advanced BIM dimensions, especially BIM 5D and visualization, as essential components for optimizing project outcomes in infrastructure development. These results can inform policymakers and construction professionals about prioritizing BIM feature implementation to enhance quality and performance. Future research is encouraged to explore additional BIM dimensions (e.g., 6D, 7D, and 8D) and investigate their impact on sustainability, safety, and facility management in infrastructure projects.

CONCLUSION

The results and conclusions of the following study entitled The Effect of 4D-5D BIM Implementation and Visualization on Improving Product Quality and Time of Toll Road Infrastructure Projects were obtained from Equation 1, namely the effect of BIM 4D (Schedule) and BIM 5D (Cost) implementation and Visualization on the quality of engineering products such as work drawings, scheduling, quantity calculation and reporting have a regression coefficient with a positive value with a regression analysis model, namely $Y1 = -0.589 + 0.021.X1 + 0.310.X2 + 0.464.X3$ and the truth level value is 71.00%. The results of this study explain that the three variables simultaneously have a significant effect on improving the quality of engineering products and support previous research that the implementation of BIM has a positive influence. Meanwhile, in Equation 2, the effect of improving the quality of engineering products on the performance of implementation time has a regression coefficient with a positive value with a regression analysis model, namely $Z1 = 0.955 + 0.899.Y1$ and a truth level value of 77.10%. The results of this study explain that the improvement of the quality or quality of engineering products such as more detailed, more effective and more time-efficient results will have an effect on improving the performance of project implementation time.

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