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Integration of Laser Scanner Technology Based on Work Breakdown Structure (WBS) and Building Information Modeling (BIM) to Enhance Dam Maintenance Performance

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ABSTRACT
This research explores the integration of Laser Scanner technology with Work Breakdown Structure (WBS) and Building Information Modeling (BIM) to enhance dam maintenance performance. Dams are critical infrastructures requiring meticulous monitoring and maintenance to prevent structural failures and ensure operational safety. Traditional methods often face limitations in accuracy and accessibility, prompting the adoption of advanced technologies. The study aims to analyze the implementation of Laser Scanner for real-time dam monitoring (RQ5) and develop a relationship model between WBS, BIM, and Laser Scanner to improve maintenance efficiency (RQ6). Using a mixed-method approach, data were collected through field observations, expert interviews, and case study analysis, with statistical validation via questionnaires from 78 industry professionals. Key findings reveal that the integration of these technologies identified 52 element clusters across six dam components, enabling precise 3D modeling and real-time condition assessment. Regression analysis demonstrated a strong relationship (R^2 = 65.6%), with BIM contributing the most to performance improvement. The model highlights the synergistic effect of WBS for task organization, BIM for visualization, and Laser Scanner for accurate data capture. The research concludes that this integration significantly enhances maintenance efficiency, reduces manual errors, and supports data-driven decision-making. Practical implications include recommendations for investing in digital tools, standardizing procedures, and upskilling personnel. Future studies should address technical challenges like data acquisition in obstructed areas.

Keywords: Dam, BIM, WBS, Laser Scanner, Maintenance Performance.

INTRODUCTION

A dam is a structure made of earthworks, rockworks, and concrete, built not only to retain and contain water but also to retain and contain mine waste or accommodate mud, thereby forming a reservoir. The definition of a dam is explained in the Regulation of the Minister of Public Works and Housing of the Republic of Indonesia number 27/PRT/M/2015. Between 2014 and 2019, the Indonesian government implemented a program to build 65 new dams.

Table 1. Dam Construction Program 2014 -2019.

No.	Island	Volume (million m^3)	Benefits				Quantity (pieces)
			Irrigation (ha)	Flood Reduction (m^3/det)	Raw Water (m^3/det)	Electricity (MW)	
1	Sumatra	775,2	130.582	1.889	10	58	10
2	Java	2.188,21	198.438	5.008	30	152	24
3	Kalimantan	921,96	28.679	1.120	14	21	5
4	Bali	24,22	2.375	-	3	3	3
5	West Nusa Tenggara	149,29	13.646	1.044	1	10	5
6	East Nusa Tenggara	146,5	14.377	1.859	1	4	7
7	Sulawesi	1.292,94	80.017	1.596	11	47	9
8	Maluku	57	10.000	471	1	6	1
9	Papua	153,37	5.500	-	-	65	1
			Total Dam				65

Source: Sub-directorate of Data and Information DG Water Resources, Status 2018)

In the next few years, this new dam will require maintenance on both small and large scales. As emphasized in the Regulation of the Minister of Public Works and *Public Housing* of the Republic of Indonesia number 27/PRT/M/2015, Article 2, paragraph 2, point 4 (four), the conception of dam safety as referred to in paragraph (3) consists of three (3) pillars, namely:
a. structural safety in the form of safety against structural failure, safety against hydraulic failure, and safety against seepage failure;
b. operation, maintenance, and monitoring; and
c. emergency preparedness.

If there is no maintenance and monitoring of the state of the dam, it will cause damage that can have micro impacts, such as material losses and displacement of affected communities, including flash floods. Many factors cause dam damage, especially those that can be detected first in the part of the structure that holds water. This can be aided by the development of technology in the construction field, which has experienced rapid advances. One such technology is the Laser Scanner.

In dam maintenance, there are limitations in carrying out visual inspections, especially when accessing hard-to-reach areas, as well as the potential for human error in manual measurements (Kang et al., 2023; Prastica et al., 2022; Semrad, 2024). Laser scanning technology offers a solution to improve the effectiveness of dam maintenance by providing faster, more accurate, and comprehensive mapping. This laser technology can determine the distance to an object and produce a Digital Terrain Model (DTM) in 3D. This data can be integrated into the 3D model of the initial dam design (Maleika, 2015; Pronk et al., 2024; Tao et al., 2023; Wimmer et al., 2019). This initial 3D data of the dam design can be represented in a *Building Information*

Modeling (BIM) model (Azhar et al., 2012; Cao et al., 2022; Lu et al., 2017; Pardosi & Khatimi, 2022b; Volk et al., 2014).

Building Information Modeling (BIM) is the process of processing data with software that is able to represent the physical and intrinsic conditions of a building as an object-oriented model bound to a database (Arrafi et al., 2023; Chen et al., 2023; Fadillah, 2022; Mahamood & Fathi, 2022; Pardosi & Khatimi, 2022a). In addition, we can combine this data with *Work Breakdown Structure* (WBS) so that the structural details of the scope of work can be seen in more detail. According to the 6th edition of *PMBOK* (2018), *Work Breakdown Structure* (WBS) is a hierarchical grouping of the project scope that must be considered by project team members to achieve project objectives and meet final result requirements.

Modern technologies such as Laser Scanner, *Work Breakdown Structure* (WBS), and *Building Information Modeling* (BIM) are increasingly considered in improving the effectiveness and efficiency of real-time condition monitoring of dams. This research aims to analyze the development of Laser Scanner implementation for monitoring dam maintenance based on *Work Breakdown Structure* (WBS) and *Building Information Modeling* (BIM) (Research Question 5), and to build a relationship model between *Work Breakdown Structure* (WBS), *Building Information Modeling* (BIM), and Laser Scanner in improving dam maintenance performance (Research Question 6).

METHOD

This research uses quantitative and qualitative approaches, combining quantitative and qualitative techniques to investigate the integration of Laser Scanner, *Work Breakdown Structure* (WBS), and *Building Information Modeling* (BIM) for dam maintenance. The research design was case study-based, focusing on field observations, expert interviews, and data analysis to validate the proposed model. The target population comprised professionals in dam construction and maintenance, including engineers, project managers, and consultants. A purposive sampling technique was used to select 78 respondents with relevant expertise, ensuring representation from owners (67.95%), consultants (8.97%), and contractors (23.08%). Data were collected using structured questionnaires, validated through expert reviews, and tested for reliability using Cronbach's alpha to ensure internal consistency.

The research instruments included a Laser Scanner for 3D data capture, BIM software for modeling, and WBS templates for task organization. Field data were processed into point clouds and integrated into BIM to compare with existing maintenance records. A standardized operational procedure (SOP) guided the Laser Scanner usage, ensuring consistency in data acquisition. Validity tests, such as the content validity index (CVI), were conducted to confirm the relevance of questionnaire items, while reliability tests yielded a Cronbach's alpha above 0.7, indicating acceptable consistency. Data collection followed a systematic procedure: (1) identifying dam components for scanning, (2) executing scans and converting data into BIM models, and (3) distributing questionnaires to assess the model's impact on maintenance performance.

For data analysis, statistical techniques such as multiple regression were applied using SPSS software to examine the relationship between WBS, BIM, Laser Scanner, and maintenance performance. Descriptive statistics summarized respondent demographics, while regression coefficients quantified the contribution of each variable. The model's predictive accuracy was evaluated using R^2 and adjusted R^2 values, with a standard error of estimate (1.033) indicating robust performance. Qualitative insights from expert interviews complemented the quantitative findings, providing context for the technological integration's practical challenges and benefits. This comprehensive approach ensured methodological rigor and actionable insights for improving dam maintenance practices. The research method in this study is illustrated in the following figure.

Data was collected through literature review, case study analysis, and expert validation.

1. Development of Laser Scanner implementation for WBS and BIM-based dam maintenance monitoring (RQ5):
   a. The integration of Laser Scanner with WBS-based BIM is done by identifying components that can be monitored using 3D scanning.
   b. Data collection was carried out using a Laser Scanner tool on the dam used as a case study.
   c. The scan results were converted into a BIM model and compared with existing maintenance data.
2. Model the relationship between WBS, BIM, and Laser Scanner in dam maintenance (RQ6):
   a. Data was analyzed using multiple regression methods to determine the effect of each variable on maintenance performance.
   b. Validation was conducted through a questionnaire distributed to respondents who have experience in the field of dam maintenance.

RESULT AND DISCUSSION

Development of Laser Scanner Integration with BIM and WBS

As a result of the data validation of the components included in the Laser Scanner implementation, there were a total of 52 element clusters divided into six major components in the dam structure that could be integrated into the Laser Scanner. The Road and Bridge component has 9 element clusters, reflecting the complexity of the supporting transportation and access infrastructure. The Main Dam consists of 8 element clusters covering key parts of the dam's core structure. The Spillway has 7 element clusters, which play a role in water management and maintaining dam safety. The Intake, which regulates the inflow of water, consists of 7 element clusters. The Outlet, which controls the outflow of water, has 11 clusters of elements. Meanwhile, the Facility Building, which supports the operation and maintenance of the dam, consists of 10 element clusters.

Table 2. Dam Laser Scanner Components Expert Validation Results

Dam	Laser Scanner Components		Laser Scanner Main Elements		Cluster	Laser Scanner Element
	Code	Description	Code	Description	Code	Description
Jobs Maintenance Dam	1	Road and Bridge	1.1	Road Drainage and Bridge	1.1.1	Supporting Drainage
					1.1.2	Bridge Drainage
			1.3	Bridge Bottom Structure	1.3.1	Gabions
			1.4	Upper Structure Bridge	1.4.2	Column
					1.4.6	Barrier
			1.5	Bridge Accessories	1.5.1	Railing
					1.5.2	Roads Lamp
					1.5.3	Guard rail
					1.5.4	Directional stakes
	2	Main Dam	2.1	Concrete Structure Dam	2.1.1	Sidewalks
					2.1.2	Railing
			2.3	Peak Accessories Dam	2.3.1	Hand Rail
					2.3.2	Safety Stake
					2.3.3	Lighting Lamp
					2.3.4	Concrete Pavement
			2.4	Dam Drainage	2.4.1	Dam Peak Drainage
					2.4.2	Foot of Dam Drainage
	3	Spillway Building (Spillway)	3.1	Concrete Structure of Spillway Building	3.1.1	Spillway
			3.2	Spillway Drainage	3.2.1	Side Drainage
			3.4	Spillway Door	3.4.1	Spillway Door
					3.4.2	Lifting Equipment
			3.5	Spillway Accessories	3.5.1	Hand Rail
					3.5.2	Lighting Lamp
					3.5.3	Safety Fence
	4	Retrieval Building (Intake)	4.1	Concrete Structure of Intake Building	4.1.1	Intake Tower
					4.1.2	Inclined Retrieval Building
			4.2	Intake Drainage	4.2.1	Side Drainage
			4.4	Lidromechanical equipment	4.4.1	Auto Panel
			4.5	Drive Engine	4.5.3	Panel
					4.5.4	Genset
					4.5.5	Backup Genset
	6	Building Expenditures	6.1	Tunnel	6.1.1	Pipes
					6.1.2	Connection

Dam	Laser Scanner Components		Laser Scanner Main Elements		Cluster	Laser Scanner Element
	Code	Description	Code	Description	Code	Description
		(Outlet)	6.3	Drive Engine	6.3.1	Panel
					6.3.2	Genset
					6.3.3	Backup Genset
			6.4	Protective Building	6.4.1	Wall
					6.4.3	Ladder Inspection
					6.4.4	Protective Roof
			6.5	Gallery	6.5.1	Concrete Wall
					6.5.2	Tabffa Inspection
					6.5.3	Description
	7	Facility Building	7.1	Building	7.1.1.	Intake Operational Building
					7.1.2	Gebang Gate/Gate
					7.1.3	Management Office
					7.1.4	Office House
					7.1.6	Generator House
					7.1.7	Tank House
					7.1.8	Water Reservoir
					7.1.9	Viewpoint
					7.1.10	Guard Post
					7.1.11	Mushola

A total of 52 element clusters in the Laser Scanner were identified from various key components of the dam covering crucial aspects of infrastructure and function. Each component consists of several more detailed sub-components, which are further grouped into specific element clusters. After the validation process, the approved elements were then organized into a data collection plan using the Lasser Scanner tool. This data collection is made in a Standard Operational Procedure based on existing references.

The data obtained from the Laser Scanner can be processed into a 3D point cloud and correlated with BIM to get a picture of the real-time condition of the dam. This integration can be seen from the following figure:

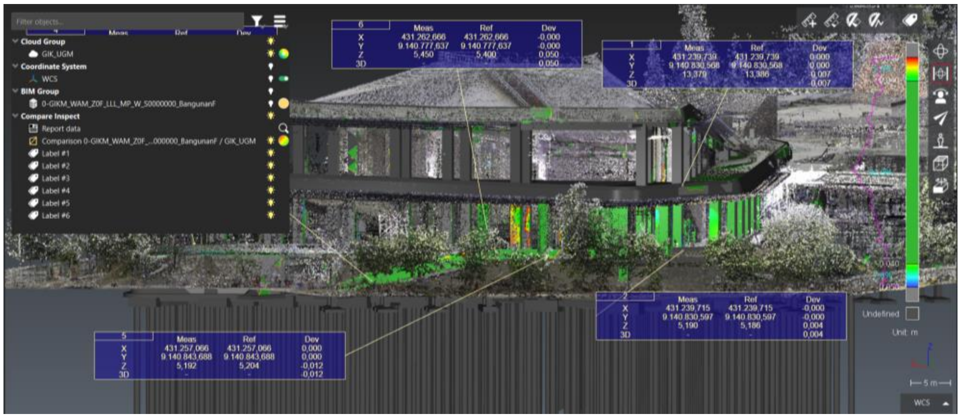

Figure 3. Illustration of the integration of Laser Scanner and BIM results on Building Facilities

Source: PT Waskita Karya

Relationship Model between WBS, BIM, and Laser Scanner

Of the 78 respondents who have filled out the questionnaire from Question RQ6 with the following respondent background data:

Educational Background

Table 3. Educational background

Education	Code	Total	
		n	%
S1	1	51	65,38%
S2	2	27	34.62%
S3	3	0	0.00
Total		78	100.00%

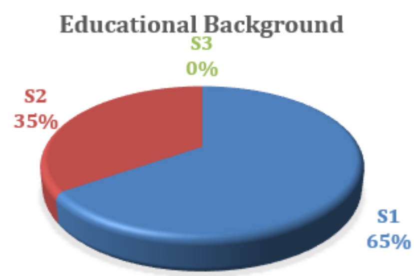

Figure 4. Educational Background Diagram

Work Experience Background

Table 4. Work Experience Background

Work Experience	Code	Total	
		n	%
2 to 5 years	1	28	35,90%
6 to 10 years	2	23	29,49%
Above 10 years	3	27	34,62%
Total		78	100.00%

Figure 5. Work Experience Background Diagram

Agency Background

Table 5. Agency background

Instance	Code	Total	
		n	%
Owner	1	53	67,95%
Consultant	2	7	8,97%
Contractor	3	18	23,08%
Total		78	100.00%

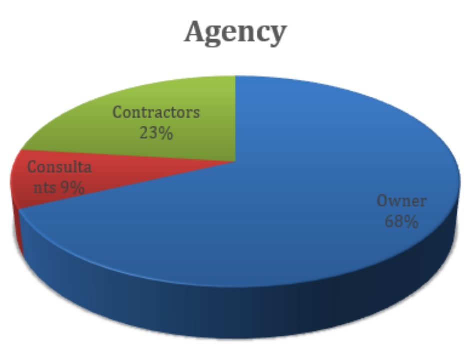

Figure 6. Agency Background Diagram

After the data is obtained, statistical tests and regression tests are carried out to answer Research Question 6 regarding the relationship model between WBS, BIM and Laser Scanner variables. The following is a summary of the results of these tests:

a. The correlation coefficient (R) of 0.810 indicates a very strong relationship between the independent variable and the dependent variable in the regression model.
b. The coefficient of determination (R^2) of 0.656 indicates that 65.6% of the variation in dam maintenance performance can be explained by the independent variables used in the model. Meanwhile, another 34.4% of the variation is influenced by other factors not included in the model.
c. The Adjusted R Square of 0.642 provides a more accurate value considering the number of independent variables in the model. This result indicates that after adjustment, 64.2% of the variability in dam maintenance performance can still be explained by the independent variables used.
d. Std. Error of the Estimate of 1.033 indicates the level of model prediction error. The smaller this value, the better the model in predicting the dependent variable.

The results of the analysis show that the independent variables consisting of Work Breakdown Structure (WBS), Building Information Modeling (BIM), and Laser Scanner have a significant contribution to dam maintenance performance. The R Square value of 65.6% confirms that this model is good enough to explain variations in dam maintenance performance. However, the lower Adjusted R Square value (64.2%) indicates a possible decrease in accuracy after adjustment, which could be due to factors such as additional less relevant independent variables or limited sample size.

Nevertheless, with a relatively low Std. Error of the Estimate is relatively low (1.033), the model still has good predictive accuracy and is reliable. Overall, the results of the analysis show that the independent variables have a significant influence on dam maintenance performance, and the regression model used has been statistically tested and is practically relevant.

$$Y=2.924+0.237\,X1+0.109\,X2+0.082\,X3$$

a. Intercept (2.924): Indicates that without the implementation of WBS, BIM, and Information Systems, Dam Maintenance Performance has a fairly high base value.
b. Coefficient X1 (0.237): The implementation of WBS makes a positive contribution, although the effect is relatively small.
c. X2 coefficient (0.109): BIM has the most influence on performance improvement, confirming the importance of this technology in supporting more efficient maintenance processes.
d. Coefficient X3 (0.082): Laser Scanner, despite its small contribution, still has a positive impact on performance.

Regression analysis shows that these three variables have a significant relationship to improving dam maintenance performance. BIM has the greatest influence in improving monitoring effectiveness, followed by WBS which plays a role in work management, and Laser Scanner which provides real-time condition data.

CONCLUSION

This research shows that the integration of *Work Breakdown Structure* (WBS)-based Laser Scanner and *Building Information Modeling* (BIM) provides a significant improvement in the effectiveness of dam maintenance. The current conventional maintenance system still relies on routine and preventive approaches without fully adopting digital technology for real-time monitoring. Through regression analysis, it was found that the combination of WBS, BIM, and Laser Scanner was able to explain 65.6% of the variation in maintenance performance, with BIM being the most contributing factor. The integration of these three technologies was shown to increase efficiency, reduce manual errors, and speed up the data-driven decision-making process. As a future contribution, this research recommends optimizing the integrated system for dam maintenance by strengthening human resource competencies, investing in digital technology tools, and standardizing operational procedures. In addition, further research is needed to overcome technical limitations, such as constraints in data acquisition in areas with reflective or obstructed objects. Periodic field trials also need to be conducted to ensure the effectiveness of this integration model and to adjust it to future technological developments and operational needs.

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