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The Implementation of Building Information Modelling for Cut and Fill Quantity Takeoff in Toll Road Project

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KEYWORDS
Building Information Modeling; Cut And Fill; Quantity Take Off

ABSTRACT
Technology has been going rapidly through the years, and BIM is one of the massive developments that offer some benefits for the construction industry. BIM is widely used in building projects and has started to be used in infrastructure projects such as toll roads. In a toll road project, cut and fill is one of the massive volumes, which consumes a lot of time to calculate the quantity and has a high chance of human error. This research aims to determine the implementation of BIM in cut and fill quantity take-off in Toll Road Project. The methodology for this research is qualitative descriptive with in-depth interviews with the expert. The study shows that implementing quantity take-off with BIM increases accuracy, reduces time, and minimizes human error and efficiency. Nevertheless, still have some lacks, such as expensive cost of software, hardware and training, needs a long time adaptation to the organization, and also needs collaboration with all of the stakeholders to successfully implement BIM.

1. Introduction

The construction industry is one of the significant contributors to the economic growth of a country (Costin et al., 2018; Nguyen et al., 2022). The process involves various stakeholders (Samimpay & Saghatforoush, 2020). Due to the complexity of a project's scheduling, design, construction, and maintenance, professionals must improve project integration between stages. Especially in big projects usually require more intense interaction between stakeholders and intense cooperation during the design, construction, repair, and maintenance (Samimpay & Saghatforoush, 2020). In this challenging situation, one rapidly emerging technology, Building Information Modelling (BIM), offers some alternatives (Samimpay & Saghatforoush, 2020; Zhou et al., 2019). Because of Its advantages, scientific journals and publications have frequently discussed the adoption of BIM for the construction sector (Vitásek & Zak, 2018). The benefits of using BIM are visualizing three-dimensional (3D) models and incorporating more information for design, construction, and maintenance phases (Bazán et al., 2020; Costin et al., 2018). If connected to the database, BIM can store any information about the project through the life cycle of the project. The use of BIM as a shared source of information between design and implementation teams. Results in information integration, coordination enhancement, error reduction, and constructability improvement (Samimpay & Saghatforoush, 2020).

BIM has been widely used for a long time. Although it is used mainly in high-rise buildings (Bazán et al., 2020; Costin et al., 2018; Xing et al., 2020). However, BIM has been implemented in the infrastructure sector. It offers similar benefits to construction projects regarding project visualization (Vitásek & Zak, 2018; Xing et al., 2020), clash detection (Elyano & Yuliastuti, 2021; Xing et al., 2020), traffic analysis (Castañeda et al., 2021), road

& pavement design (Tang et al., 2020), existing road analysis (Vignali et al., 2021), quantity takeoff (Chen et al., 2022; Nguyen et al., 2022; Taghaddos et al., 2019), cost estimating (Vitásek & Zak, 2018), and information management (Lin et al., 2020). Over the last two years, there has been significant growth in BIM adoption for transportation infrastructure projects, and this trend is projected to continue. Several studies on the civil and infrastructure sectors have recently been conducted (Lin et al., 2020). In Indonesia increase the use of BIM in infrastructure, especially in Infrastructure Transportation, Direktorat Jenderal Bina Marga, through circular letter No. 11/SE/Db/2021, intends to increase the use of BIM technology Direktorat Jenderal Bina Marga to support the effective and efficient construction of roads, freeways, toll roads, tunnels, and unique bridges. Also, implementing the principle of one digital data at Direktorat Jenderal Bina Marga, implementing digital transformation in the construction industry, and enhancing the quality of planning for constructing roads, freeways, toll roads, road tunnels, and unique bridges (Direktorat Jenderal Bina Marga, 2021).

In the construction sector, a quantity calculation of the work sometimes becomes a source of several claims and disputes due to its relation to invoices (Ahmed et al., 2018). The inaccuracy of the BOQ estimation calculation will raise various problems in a project, both overestimating and underestimating (Mahmoud & Tomaizeh, 2016). The current cost calculation approach involves many people and is prone to errors (Vitásek & Zak, 2018). Compared to traditional techniques, project control with BIM is deemed more effective and efficient in cost savings, easier quality control, and faster implementation time (Kamil & Raflis, 2019). It is undesirable to hold off on creating a cost estimate until the end of the design phase. If the project goes over budget once the design is finished, there are only two options: cancel the project or use value engineering to reduce costs — and possibly quality (Eastman et al., 2008). As the design evolves, interim estimates allow for the early identification of difficulties and the consideration of potential solutions. This procedure enables the designer and owner to make more informed decisions, resulting in a construction project of better quality and within allocated budgets. (Eastman et al., 2008). However, the model's accuracy is critical for using BIM 5D because it is a digital representation and must incorporate graphic and non-graphic information from the elements/objects being assessed (Vitásek & Zak, 2018).

The conventional calculation for earthwork especially cut and fill, using cross sections in 2D drawings as a reference with Excel as platform software (Travis et al., 2021). This calculation has many steps and increases the human error risk. The distance of the data survey affects the accuracy of the calculation, the closer, the better. The most common method used for volume calculation is the average end area. It calculates two cross sections in a certain distance with the average of their area times the distance. The disadvantages of this method are that the calculation has many steps, there is a chance of high human error risk, level of accuracy depends on the distance of survey data. Cut and fill work items in toll road projects have the most significant potential for discrepancies due to their massive volume. Of the five toll road project data in Indonesia, earthwork has an average percentage of 30.73% of the total project value. Cut and fill work for usual soil has an average rate of 22.73%, as shown in the figure below.

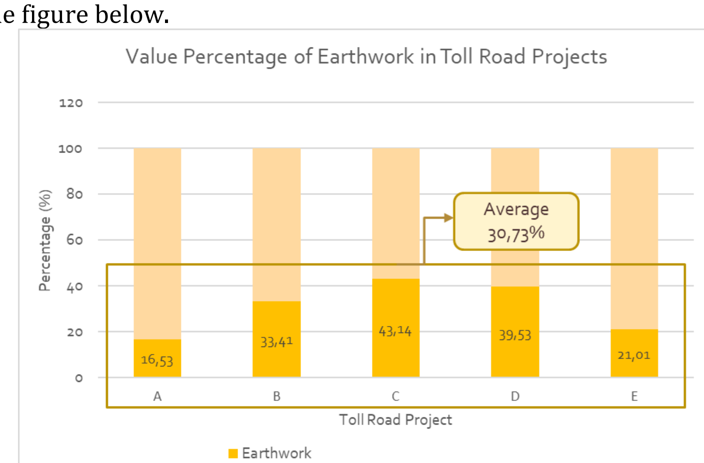

Figure 1 Value Percentage of Earthwork in Toll Road Project
Source: Research Data Collection, 2022

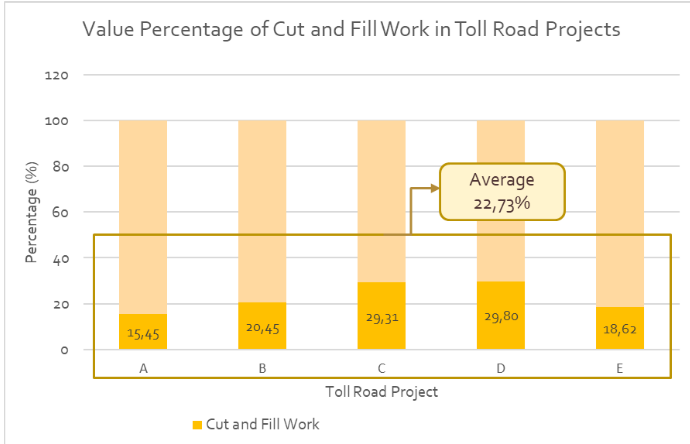

Figure 2 Value Percentage of Cut and Fill Work in Toll Road Project
Source: Research Data Collection, 2022

The figure above shows that earthwork significantly cut and fill work has a significant volume, considering that many road projects pass through hills, causing a cut and fill work to have a reasonably large volume compared to other work items. Autodesk Civil 3D (Costin et al., 2018; Vignali et al., 2021) and Open Roads Designer from Bentley Software (Vignali et al., 2021) are frequently used for modeling and quantity takeoff in road projects. According to other research, using Autodesk Civil 3D and Autodesk Revit can also simplify and improve the accuracy of quantity takeoffs. A comparison of BIM and manual quantity calculations from 2D drawings reveal a substantial difference in the three works, 4.37 percent for cut and fill, 1.7% for structural excavation, and 4.4% for concrete structure work (Travis et al., 2021). Therefore, this research aims to find the BIM implementation in Toll Road Project, particularly for quantity take-off cut and fill work.

Literature Review

Professor Charles M. Eastman invented the term BIM in the 1970s, and it essentially means digital modeling of typical building construction. It is based on a procedure that organizes all information about accomplishments (Vignali et al., 2021). National Building Information Modelling Standard (NBIMS) defines BIM as "A BIM is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward" (National Institute of Building Sciences., 2007). Meanwhile, Bina Marga defines BIM as the process of creating digital datasets that represent a three-dimensional model and the information associated with the model, as well as road/bridge data (Direktorat Jenderal Bina Marga, 2020). Compared to 3D design CAD, BIM is a three-dimensional representation and a model in which each entity has a specific role and information in the project (Vignali et al., 2021).

BIM is not simply a piece of software but also a mechanism for gathering information about a construction project during the design and pre-construction stages. BIM is not only a tool for knowledge utilization and dissemination but also the process of the most recent construction approaches for information collected during the construction process (Samimpay & Saghatforoush, 2020), and it consists of:

- 3D: Three dimensions, including length, width, and height parameters
- 4D: Three dimensions with the construction schedule
- 5D: Four dimensions with estimating construction cost
- 6D: Five dimensions of the site, which require the integration of geographical information systems and BIM.
- With GIS integration, all of the cases available in the project
- The site presents detailed information about the location.
- 7D: Facilities management in the project lifecycle

BIM 5D presents another natural step to widen the utilization of information modeling for cost management and which puts BIM into practice (Eastman et al., 2008). The following fields are of primary concern:

- Creation of quantity takeoff;
- Creation of budget for construction works;
- Planning/cost management.

BIM 5D relies on the accuracy of the model. LOD establishes the level of detail within the information model for various phases of project documentation. LOD determines accordingly which structures and their components are to be included in the model and which are not. In addition to graphic processing information, the model defines non-graphical processes. In information modeling, non-graphical information is an element's parameters, such as data used to identify an element, material, volume, or area. The detail level scale ranges from LOD 100 (lowest detail) to LOD 500 (maximum detail) (the highest detail).

The design of the infrastructure is more complex than the design of the building. The main difference is that infrastructure project frequently extends over many kilometers and causes wide environmental disruptions. Therefore, a correct geo reference is essential and can be accomplished by coordinating Geographical Information Systems (GIS) (Costin et al., 2018; Vignali et al., 2021). In addition, infrastructure projects are often public projects owned and run by government agencies with specific financing and legal constraints (Costin et al., 2018). One of the tests we use to get GIS data is LiDAR. However, its expensive cost becomes the primary barrier to its development in the small-scale project. In these instances, photogrammetry is a good alternative because it is affordable, saves time, and can scan broad regions with reasonable precision. It is possible to develop a model with geometry, data on particular relationships, geographical information, quantities and qualities of construction elements, and cost and inventory of materials (Bazán et al., 2020). The use of BIM for Building and Infrastructure is quite different, as summarized in the table below.

Table 1 Differences between BIM for Building and Infrastructure

	BIM for Building	**BIM for Infrastructure**
Project scale	Smaller	Larger
Complexity of model	Higher	Lower
Importance of clash detection	Higher	Lower
Owner	Public and private companies mainly	Government mainly
Associated applications		Combined with GIS

Source: Xing et al., 2020

In addition, the visualization and informatization features of BIM for Infrastructure help in calculating the quantity takeoff of construction materials and simulating the construction process, thus contributing to the AECO industry's technological improvement (Xing et al., 2020). In reality, by modeling construction processes, BIM contributes significantly to constructability. It is also critical to note that all BIM advantages are interconnected, with each directly or indirectly affecting others (Samimpay & Saghatforoush, 2020).

Traditionally, 2D designs approved for construction are checked manually for discrepancies. This process takes much time, especially for complex designs. BIM enables the sharing of information in a digital format among a construction project team members through developing and implementing 3D parametric computer-aided design (CAD) technology for design (Vitásek & Zak, 2018). For the application of BIM 5D, the actual information model is essential. It must be created in a way that includes all essential graphic and non-graphic details. Typically, the level of specificity provided in this information is specified in the standard document or as amendments to the contract agreement (Vitásek & Zak, 2018).

2. Materials and Methods

A qualitative methodology is employed to fully explain this study's purpose. Qualitative research mainly uses descriptive or narrative statements as the units of measurement. Also, emphasize on describing, understanding, and exploring phenomena (Kumar, 2011). Collecting data from a literature review and in-depth interview with the expert who has the knowledge and experience about BIM in Toll Road Projects.

This research processes begin with identifying the problem or phenomenon surrounding the topic that interests the researcher, then developing the research question and conducting a literature review on the related subject from a journal, articles, books, and other sources. Then, create an interview guide with open questions for the expert to answer as a data instrument for this research. The researcher will assess the responses from the experts; if the feedback is clear and understandable, the research will conclude; otherwise, a second interview with the expert will be conducted. The following figure is a flowchart of the research methodology as described previously.

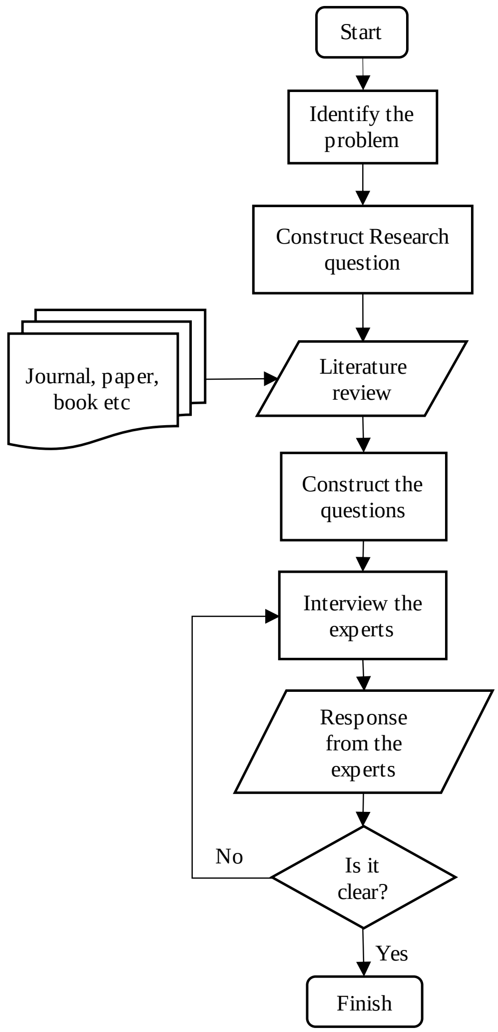

Figure 3 Flowchart of the Research Methodology

The qualification of the expert is a Bachelor's Degree or equivalent, work experience of more than five years and three years of experience in Toll Road BIM. The following table is the data of the expert in this research.

Table 2 Data of the Expert

Code	Education	Position	Work Experience (Years)	Experience with BIM (Years)
R1	Bachelor Degree	Manager, Head of BIM Operation	9	4
R2	Bachelor Degree	BIM Productivity Analyst	6	4
R3	Bachelor Degree	Manager (BIM/VDC/CDE)	7	6
R4	Master Degree	BIM Manager	11	7
R5	Bachelor Degree	BIM Coordinator	5	3

Most experts work in State Own Enterprise (SOE) in Indonesia, except R3 works at BIM Consultant Company based in Singapore. The semi-structured interview implies that questions have been prepared but are not rigid because we want a comprehensive understanding (Mieslenna & Wibowo, 2019). The instrument used in this research is an interview guideline to ask open questions to the experts consisting of eight main questions that can be added if required. For analyzing this research's results, the Delphi method is a versatile strategy suitable for resolving unresolved phenomena/problems and may be applied to both quantitative and qualitative research (Okoli & Pawlowski, 2004).

Results should be clear and concise. Discussion should explore the significance of the results of the work. Avoid extensive citations and discussion of published literature, the Results section reports what was found in the study, and the Discussions section explains the meaning and significance of the results and provides suggestions for future directions of research. In this section, The results of the research and discussion contain tabulations research data carried out accordingly with the methods and variables used. Analysis and evaluation of the data according to the formula of the theoretical study results have been done. Discussion of analysis results and evaluation can apply the comparative method, use of equations, graphs, pictures, and table. Each table and graph must be numbered and names and placed as close together as possible with paragraphs where the tables and graphs are discussed. Interpretation of analysis results to obtain answers, added value, and benefits relevant to the problem and objectives study. The discussion can be made in several sub-chapters.

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R5	Bachelor Degree	BIM Coordinator	5	3

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3. Result and DIscussion

1. Step of Cut and Fill Work Calculation Using BIM

There are numerous approaches for measuring data using BIM; one example is the largest Highway project in Southeast Asia utilizing BIM + GIS. Survey data were obtained using LiDAR; this tool has a sensor that produces XYZ data (easting, northing, zenith) with an accuracy of up to 98%. The data obtained can be used for DSM and DTM purposes.

- The use of this LiDAR will be carried out many times to retrieve data on MC0 (OGL Original Ground Level), MC1, MC2, and so on to see the progress obtained.
- Captured LiDAR data can produce several files, such as Photogrammetry, Point Cloud, RTK, etc. For earthwork calculation purposes, this can be done by extracting point cloud data such as.LAS to.XYZ / PNZ and others. This depends on the type of software used, but it is recommended to simplify data so that the data to be used complies with standards and is not too heavy.
- After extracting the survey data into data that can be used in the software, the next step is that the software will connect millions of existing points to become a surface. Do the same for the next progress like MC0, MC01, MC02 and so on,
- Many methods can be used to calculate the earthwork at this stage, such as Mass Haul Diagram, Superimpose, Tin Volume Surface, etc. An example using Superimpose, by overwriting surfaces 1 and 2, the software could calculate the cut and fill volume in great detail.
- Usually, 2-3 samples of the results of software calculations are taken, and manual analyses are carried out for Provability.
- Each software has its format for presenting data. Still, this data can be exported to Excel to be converted according to the QMS that uses detailed and clear boundaries regarding the area considered when in contact with a building.

2. Stakeholder Involved in the Process of BIM

This depends on the EIR (Exchange Information Requirement) and the actual implementation of the BEP (BIM Execution Plan). Still, almost all stakeholders are involved in the measurement process, from surveyors, contractors, and consultants, to project management—also work partners of contractors such as vendors or sub-contractors. For the precise position, the parties involved closely are the surveyor team related to the data survey, the engineering team for verification, modeling by the BIM team, and volume cut & fill cross-check calculation with the QS team.

3. Standard for Guidance to Implement the BIM

The implementation of BIM has several guidelines in its implementation such as ISO BIM 19650, which has been owned by BUMN Karya companies (SOE), Letter from Direktorat Jenderal Bina Marga Ministry of Public Works and Housing, SE No 11/SE/Db/ 2021 concerning the application of BIM in technical planning, construction and maintenance of roads and bridges. For exceptional work, it will usually be listed in the EIR and BEP when the construction project is obtained or during the auction or construction tender process.

For specifics regarding the calculation and measurement of land using BIM, there is no standard used, conventional SMM is still used, and calculations with BIM are carried out with a particular approach. In the project, one of the resource persons abroad, the measurement process for surveys for Infrastructure standards adheres to Infra-BIM by Building SMART. However, this only explains standard formats, files, zoning, naming, and others for infrastructure projects, especially surveying.

4. Software Related to BIM Implementation

This depends on the EIR (Exchange Information Requirement), but the following is the software primarily used by the interviewees for cutting and filling work using BIM.

Table 4 Software Related to BIM Implementation in Cut and Fill Work in Toll Road Project

No.	Activity	Software	Notes
1.	Processing Data Survey	ESRI ArcGIS	Processing data from LiDAR
		CoPre, Cube 3D, dan Global Mapper	
		pix4d mapper	Processing data from photogrammetry
2.	BIM Modelling	Autodesk Civil 3D and Bentley Open Road	
3.	Volume Calculation	Autodesk Recap, Autodesk Civil 3D dan Bentley Open Road	

Computation in BIM is done automatically so that calculations are calculated down to the smallest part, while conventional ones are still interpolated. In comparing these 2 data, there is a significant discrepancy, especially for earthworks. The software is part of the tool in accelerating BIM data calculation/data processing; The software results minimize the risk of human error and data transparency and speed up the data processing process.

5. The advantages of BIM implementation

Here are some BIM benefits related to quantity takeoff:

- Data can be processed very quickly and efficiently;
- The data results can be projected into other formats such as 3D Models, Elevation Banding, Slope Arrow Analysis, Watershed Analysis, and others for analysis and presentation purposes;
- More detailed data accuracy so that the resulting volume is more detailed. The results of calculations per cross-section are more accurate than manual calculations using Excel because the existing surface used uses the original value obtained from the results of the topographic survey per cross, not the average value;
- Reduce human resources, and minimize human error;

- Able to provide an analysis of potential job risks;
- Provide an overview of the effectiveness of the implementation method;
- Speed up the decision-making process.

6. The Challenges for BIM Implementation

People, process, policy, and technology (PPPT) are the critical challenges in implementing BIM (Akob et al., 2019)as mentioned below by the respondent.

- People: For 2023, the development of BIM has been very rapid; several universities have even included BIM in their curricula. But many people still don't understand what BIM is in general.
- Process: Existing standards for cut and fill work exist, but technological developments do not update these standards. So that sometimes the results of the BIM process still have to be converted to conventional methods. Furthermore, the weather should not be gloomy or too hot when using BIM in cut and fill while data collecting (aerial photography) because this generates unclear results. The tools and software required are then quite expensive; if the device is broken, further costs may arise; repair time is long, and the data processing procedure is quite long. Furthermore, the quality of the model has a considerable influence on the results of BIM calculations. Therefore accuracy and adequate resources are required.
- Policy: For overseas, each country has made its regulations for the use of BIM; for example, Singapore and Malaysia are countries in ASEAN that already have official standards for the benefit of BIM for the construction industry issued by the Ministry there. For some countries, it may be challenging to make regulations quickly, hindering the implementation of BIM locally.
- Technology: related to the high cost of implementing BIM, including the hardware, the software, and BIM training (Akob et al., 2019)

7. The role of the BIM in increasing the accuracy of the calculation

Using BIM for earthworks on road projects greatly improves data accuracy, speed, and presentation. This positive thing will result in very reliable data integrity because the error rate can be minimized. But in reality, the use of BIM still has gaps for manipulating data; therefore, to produce accurate calculation results, it is necessary to pay attention when collecting measurement data in the field, making models, processing data, calculating the volume of work using the same and proper reference data. So that the BIM results/output issued also have a high accuracy value. Based on the trial of R2's projects, the role of BIM in increasing the accuracy of calculations is quite significant because, compared to conventional calculations, the results of BIM calculations are more accurate by approximately 2% per 100 meters. The subsection should be written without a bold type. The result and analysis are presented in present form. Please avoid too many paragraphs in this section.

4. Conclusion

Cut and fill work is associated with GIS because crossing a wide area of terrain [2]. Also, have a large volume compared to other work items. BIM implementation for quantity take-off in Indonesia has already started since 2021. Most respondents agree that BIM has the advantage of increasing productivity, calculation accuracy, reduced time, more effective use of resources, better coordination, and better management. The stakeholders participating in the project are responsible for successfully implementing the BIM. The government also plays a vital role in driving the implementation of BIM in the local construction industry; cooperation between parties is also essential to develop a standardized BIM guideline to be used by construction players in the country [21]. Besides the benefits, some challenges have to be faced related to people, processes, policy, and technology (PPPT). Apart from the qualitative research methodology utilized in this study, it is advised that quantitative approaches can also be applied to analyze the outcomes of BIM implementation and offer more convincing evidence for supporting BIM.

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