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Improving Infrastructure Performance Using BIM (Building Information Modelling): Experimental Study of Cost Reduction in Road Planning

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Abstract. The productivity of the construction sector still needs to be increased by choosing effective methods. Manual method (2D) road planning takes a long time and results are less accurate. BIM (Building Information Modelling) as a new method needs to be proven for use in road planning projects. In this study, the BIM method was applied to the case study of the new road planning of Kretek-Girijati using Autocad Civil 3D software. Planning includes vertical alignment and horizontal alignment with the 2021 Geometric Road Guidelines standards. Furthermore, the volume of excavation and landfill will emerge from the model and the total cost will be known after multiplying the unit price. Some planning alternatives use BIM models compared to the initial design. There are 3 alternative designs made, featuring a shorter road trace length, more sloping, less excavation volume and pile than existing routes. The cost of the existing design is IDR 28,920,870,000.00, the most economical cost in Alternative 3 is IDR 15,697,819,300.00 with the difference in the cost of both IDR 13,223,045,900.00. It was concluded that Alternative 3 is the most economical in terms of earthworks compared to other alternatives and existing designs. These findings provide a reinforcement to use BIM methods at the road design stage.

1 Introduction

A country's economic growth is supported by several sectors, including construction. It is proven that in 2023 Indonesia's economic growth will be at the level of 5.05 percent on an

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annual basis and the business fields with the largest contribution to the economy, namely the processing industry, trade, agriculture, mining and construction [1]

Productivity which is one of the fundamental factors affecting the performance of competitiveness in the construction industry [2]. Productivity can be increased by the efficiency of the resources that support it. As well as the use of the right construction methods and technologies, several strategies are also implemented, including the application of the use of BIM, digital construction, lean construction, augmented reality and virtual reality [3]. Rapid innovation in technology requires a critical look at existing project management processes to improve project quality and sustainability [4].

BIM is a methodology in which all information (specifications, quantity, price, stages of work, etc.) is integrated with a 3D form of building model that offers benefits such as cost and time control, coordination during efficient implementation and optimizing infrastructure asset management. One of the basic principles of the application of the BIM method based on industry 4.0 is to achieve high efficiency, timely, appropriate, and better product quality, which in infrastructure development in Indonesia began in 2017. [5]

The use of BIM makes collaboration within project teams should increase which will lead to increased profitability, reduced costs, better time management, and improved customer-client relationships [6] including increased productivity, making the significant potential of BIM [7].

The implementation of BIM will have more impact in the early stages of the project, BIM fulfills its objectives through all stages of the construction project which provides benefits in terms of better design quality, in implementation, information sharing capabilities, reduction of construction costs and design errors, faster work and shortening construction time, improving energy efficiency, supporting construction and project management, and allowing the owner more operational efficiency in the life cycle building [8].

It can then be stated that, although BIM has not yet been implemented as an active management tool in most infrastructure projects, the complete introduction of this methodology in the design of roads, highways, tunnels, or bridges is only a matter of time [9]. The presence study shows the role of BIM models and their applications in smarter and more efficient highway management during implementation [10].

The use of BIM methodologies is possible for activities such as maintenance, management, or expansion of infrastructure by implementing certain software that does not exist. That proves the need for more scientific research to address the challenge of full use of BIM in civil engineering [9]. Building Information Modeling is not only a software but also a mechanism for gathering information about construction projects during the design and pre-construction stages. BIM is not only a tool for knowledge, utilization and dissemination of knowledge but also the latest construction approach process for the latest information collected during the construction process [11]

The most immediate benefits of BIM for highway design are better design as well as increased efficiency and productivity. Because design and construction documentation are dynamically linked, the time required to evaluate more alternatives, implement design changes, and produce construction documentation is significantly reduced [12]

The Jalan Baru Kretek – Girijati section which is in Bantul Regency, has the status of a Provincial Road, this section is one of the connecting roads between beach tourism objects in Bantul Regency and Gunung Kidul Regency. New road planning will be carried out as a Provincial Road on STA 0+000 to STA 5+640 on this section, because based on the results of topographic measurements in the field, the existing situation of this station has a type of hilly terrain with a fairly steep one. So that geometric road planning is needed in accordance with applicable standards.

Technically, hilly terrain will result in a large volume of excavations and soil piles, so it is necessary to carry out several alternative planning on horizontal and vertical lines, to obtain optimal excavation and pile volume planning results with economical cost predictions while still meeting Bina Marga's safety and comfort standards.

An alternative analysis of road geometric design will be carried out on the Kretek-Girijati New Road section based on the AutoCAD Civil 3D 2025 program. The goal is to create design alternatives based on horizontal and vertical alignment, the volume of earthworks (excavation and heap) and construction costs. By using this BIM model, the design process is faster and more accurate and results are obtained that meet the set standard criteria, are economical and efficient.

2 Methods

The selection of research objects takes into account that this project is a national-scale road construction project. The hilly terrain provides an opportunity to conduct in-depth research on geometric design alternatives to optimize the volume of work. Thus, this research is expected to produce conclusions that can increase efficiency in planning and implementing road construction projects.

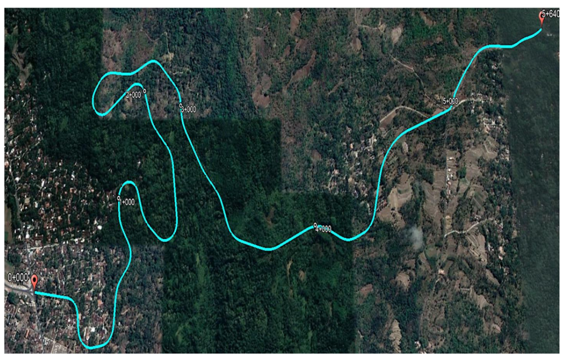

Fig. 1. Initial Plan of the Kretek-Girijati road route

The software used in road planning is AutoCAD Civil 3D. The advantage of using this software is that it uses the Dynamic Modeling concept, namely the Integrated Process Design concept where if you make changes or revisions when the design is finished, it will automatically update the entire process of the 3 related construction designs. The research flow can be seen in Figure 2.

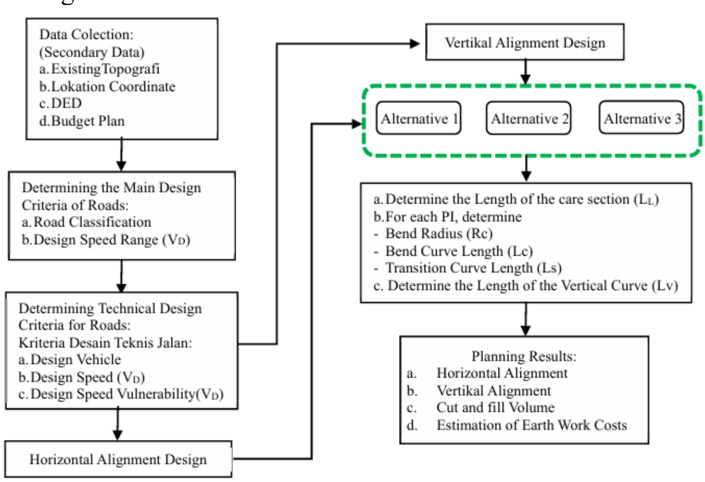

Fig. 2. Flowchart of research

Road geometric design criteria are geometric parameters whose values are set at the beginning of the design and become the basis for determining the design of other geometric elements [13]. This Road Geometric Design Guidelines are used as a basis for road geometric planning as a standard that applies in Indonesia at this time.

After data collection, among others, existing topographic data, study location coordinates, DED drawings, research locations and cost budget plans. Next is the determination of planning criteria, namely the main design criteria of the road, determining the classification of the road consisting of (road designation, road status, road network system, road function, road class, specifications of road infrastructure providers, road users, and road terrain), design speed range (VD), technical design criteria, determining design vehicles and determining design speed (VD). Next there is determining the horizontal alignment by determining the radius of the bend (R), determining the type of bend (FC/SCS), determining the parallel curve (Ls) and determining the superelevation (e). The next step is to calculate the vertical alignment which consists of setting the maximum path slope, and optimizing the vertical alignment design. Next is to display the cross section of the road, namely determining the width of the lane and the width of the shoulder of the road and determining the normal slope of the road. For the presentation of geometric designs in the form of horizontal lines, vertical lines, lines of cross-sections, and tables of volumes of excavations and stockpiles. The final step is to calculate the volume of excavation and heap and calculate the cost of earthworks in the form of excavation work and earthenware.

3 Results

The BIM software used is Autocad Civil 3D version 2025 with stages from setting drawing then import point and creating contours and creating contour labels on the existing topographic contours, then labels are given which function to provide information on the height value of each contour line. the next step is to create horizontal alignment or more commonly known as a road trace or centerline, create vertical alignment and create a longitudinal cross-section profile can be done after creating the contour and horizontal alignment.

Next, the sample line is made in advance with the aim of setting the interval for calculating cut and fill and creating a new superelevation after which the cross-section can be determined. The next step is to add superelevation to the alignment. The final step of output volume cut & fill after all the design processes have been carried out, the next step is to calculate/display the volume of excavation and embankment.

Based on calculations using the 2021 Road Geometric Design Guidelines, the following results were obtained in Table 1.

Table 1. Determination of Road Planning Classification

Road Length Section Name	Kretek – Girijati, Bantul Regency and Gunung Kidul Regency, Special Region of Yogyakarta Province
Length of the road	5,640 KM (STA. 0+000 to STA 5+640),
Road Status and Maintenance	Provincial Road
Road Network System (SJJ)	SJJ Primer (Intercity Road)
Road Function	Primary Local Roads
Street Class	Class II

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Road Infrastructure Provider Specifications (SPPJ)	Medium Road (JSD)
Road Terrain	Mountain

The next step is to determine the technical criteria for road planning to determine the cross-section that influences the use of the required road width, as shown in Table 2.

Table 2. Determination of Cross Cuts for Road Planning

Road type	Road Type 2/2–TT (2 Lanes 2 Directions Undivided)
Traffic lane width/ road pavement	2 x 3.5 m = 7.0 m
Road shoulder width	2.0 x 1.5 m
Horizontal slope of pavement (e_n)	3%
Horizontal slope of the road shoulder	5%
Maximum superelevation (e_{max})	8%

Based on this determination, it can be explained in Figure 3 of the cross-section of the road.

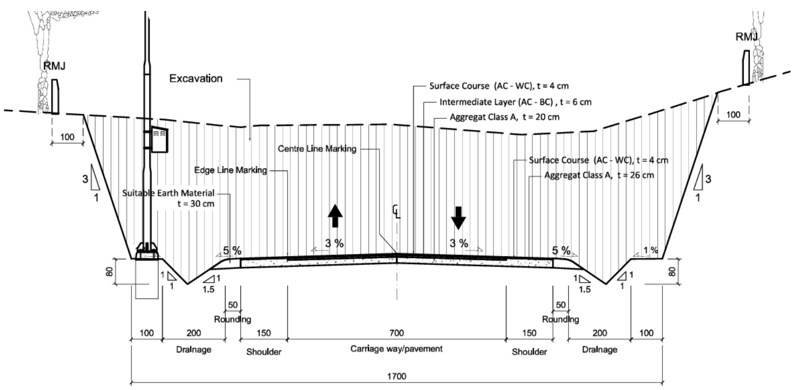

Fig. 3. Cross-section of the plan road

After being planned with AutoCAD Civil 3D 2025, the percentage of slope of the existing terrain is 28.73% and refers to the 2021 Road Geometric Design Guidelines for terrain with a slope of >25% can be categorized as Mountain Terrain.

So in this study, the design speed (VD) = 40 km/h, the Design Hour Traffic Flow (qJD) is 2400 SMP/hour. With 2 lanes of 2 undivided lanes and for shoulder width of 2 meters with a maximum transverse value of 6%, for roadside channels with a width of 1.5 meters with a safety threshold of 1 meter. Alternative design planning obtained the following results shown in Figure 4 to Figure 6 and Table 3.

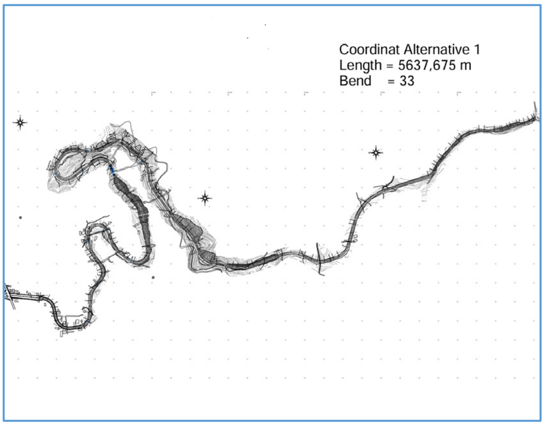

Fig. 4. Alternate Trace 1

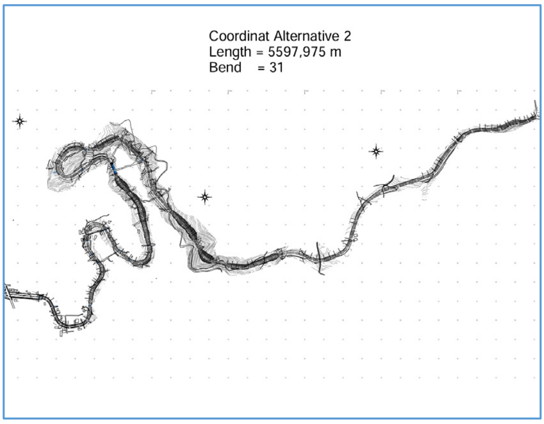

Fig. 5. Alternate Trace 2

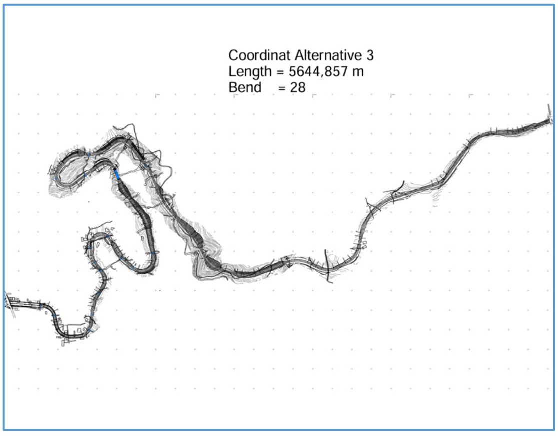

Fig. 6. Alternate Trace 3

Table 3. Alternative route planning results with Autocad Civil 3D

Criterion	Alternative 1	Alternative 2	Alternative 3
Horizontal Alignment			
- Length (m)	5637.675	5597.975	5644.857
-Bend	33	31	28
Vertical Alignment			
- Negative Slope (Derivative)	-0.78%	-	-1%
- Positive Ramp (Ramp)	18.83%	13%	12.30%
Volume of Work			
Excavation (m3)	546155.6	536880.76	533961.52
Stack (m^3)	292177.31	269736.68	289138.25
Difference (m^3)	253978.29	267144.08	244823.27

4 Discussion

The results of the planning of the three horizontal alignment alternatives obtained a final length of 5.637 km for alternative 1, 5.597 km for alternative 2 and 5.644 km for alternative 3 from the original length of 5.640 km. For the corner in alternative 1 there are 33 corners with 30 corners of the Spiral Circle type and the Full Circle type of 3 corners, while for alternative 2 there are 31 corners with the Spiral Circle Spiral type of corner totaling 29 corners and the Full Circle type of 2 corners and alternative 3 totaling 28 corners with all Spiral Circle type corners.

The vertical alignment that will be chosen has fewer bends, namely alternative 3 with 28 corners and for the optimal vertical alignment alternative, it is known to meet the safety factor because the slope value on the new road is -1% for descents and slopes of 10% so that it is categorized as safe because the slope value extends it ≤ 10% on the existing road that is overlaid or the road increase > 10% with a maximum slope of 12.30%. Because the third alternative has a more stable and lowest flexibility than others, it is said to be more optimal in meeting comfort and safety requirements

The results of vertical settlement planning are also planned using 3 design alternatives to obtain optimal land work results, namely excavation and stockpile but still meet the requirements of safety and comfort, the results of the recapitulation of the two settlement planning can be seen in table 3.

For cost estimation or cost budget plans using the analysis of work unit prices issued by Bina Marga with unit standards for wages, materials and equipment rental in accordance with Regent Regulation Number 64 of 2023, concerning the Standardization of Prices of Goods and Services of the Bantul Regency Government 2023. It is known that the cost recapitulation results from Alternative 1 amounted to Rp. 16,079,693,600.00 (Sixteen billion Seventy Nine million Six hundred Ninety Three Thousand Six hundred rupiahs), Alternative 2 amounted to Rp. 15,921,305,600.00 (Fifteen billion Nine hundred Twenty million Three Hundred Five Thousand Six hundred rupiah) and Alternative 3 amounted to Rp. 15,697,819,300.00 (Fifteen billion Six hundred Ninety Seven million Eight hundred and ninety thousand Three hundred rupiah). A comparison of volume and price can be presented in the form of a graph, shown in Figure 7.

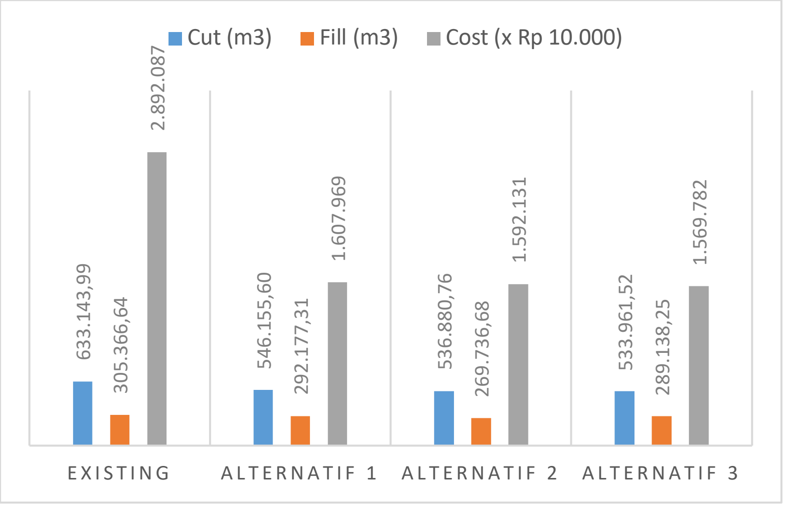

Fig. 7. Alternative design price comparison

Based on Figure 7, the difference between the excavation and the pile of Alternative 1 is 253,978.29 m^3 and for Alternative 2 is 267,144.08 m^3 while for Alternative 3 there is a difference of 244,823.27 m^3. Based on the volume of excavations and heaps, Alternative 3 was chosen which is more optimal because it has a excavation volume of 533,961.52 and a heap of 289,138.25 m^3 and has the smallest volume difference compared to other alternatives of 244,823.27 m^3. In the estimated cost of Alternative 3 of Rp. 15,697,819,300.00 with the largest difference in existing design, which is Rp. 13,223,045,900.00.

From the results of the three cost estimates, it can be concluded that Alternative 3 is the most economical or efficient design alternative in terms of earthworks compared to other alternatives.

5 Conclusion

New road planning using BIM models using Autocad Civil 3D software provides significant benefits to construction projects. The time spent in the design stage is more efficient with the alternatives offered more economically. The earlier the use of this method, the greater the positive impact on the project, the variables affected include cost and time. As stated earlier, the BIM method can increase efficiency and productivity in construction projects, this will have an impact on increasing the competitiveness of benefit users.

However, the thing to note is that the use of BIM requires large resources that are therefore less effective for projects with small budget. More serious efforts are needed from stakeholders related to the use of BIM in infrastructure projects. The government also needs to take strategic steps as a regulator.

It is very possible that the use of BIM methods is integrated with other methods such as Value Engineering to further improve efficiency, which can start from the planning stage to the operational and maintenance stage.

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