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Enhanced Accuracy in Construction Cost Estimates Using BIM

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A B S T R A C T

The Indonesian construction industry is experiencing rapid growth and increasing complexity. If done using conventional methods, this process often involves multiple manual stages that are prone to errors and inconsistencies thus requiring significant time and resources. Building Information Modeling (BIM) is a technology that provides solutions in the volume and cost estimation process. However, there have been few studies that verify the output of BIM with control calculations. This study aims to compare the volume and cost outputs from BIM with those from the Bill of Quantities (BoQ) by re-evaluating volumes identified as clashes and verifying the actual costs. Data on plan drawings, BoQ, and planned costs were obtained from a public service center building project with modeling conducted using Autodesk Revit and Naviswork. Manual volume calculations and actual cost data were used for comparison. The results showed that the BIM cost estimate was highly accurate, with a minimal difference of IDR 1,249,901.21 (0.0032%) compared to the real cost. In contrast, the BoQ estimate was higher by IDR 1,022,985,135.58 (2.63%) compared to the real cost and IDR 1,024,235,036.79 (2.57%) higher than BIM. This is because in volume calculations, BIM software has proven to be more detailed and accurate in calculating the volume of all work items and is able to eliminate human error factors. The results of this study contribute to the construction industry by highlighting the significant advantages of using BIM software that can increase efficiency and reduce the risk of calculation errors.

1. Introduction

The development of the construction in Indonesia has significant growth, this situation generate the latest technology for efficient, effective and accurate construction processes [1]. The Ministry of PUPR explains that the use of conventional methods often causes a number of problems such as a lack of accuracy in calculating the volume of work and the calculation

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process takes a long time [2]. Most construction organizers in Indonesia still use conventional methods [3]. In the work process, conventional methods are still manual using Autocad software for 2D drawings and Microsoft Excel for calculations [4]. This work is generally carried out separately so that there is no collaboration in the calculation process that causes the data to be obtained separately, which is at risk of producing miscalculations [5] or double volume calculations which can even reach 30% [6]. The use of BIM is considered capable of fixing this problem where BIM calculations provide savings of 6.03% compared to using conventional methods.

Building Information Modeling (BIM) technology is a representation in the form of digital data that provides information related to building components [6] throughout the building life cycle [7]. This technology is very useful for the construction industry [8]. BIM has several dimensions [9] namely 3D for modeling, 4D for time, 5D for costs, 6D for environmental aspects, namely green building analysis [10], and 7D for asset management. BIM has the advantages of increasing efficiency and reducing the risk of errors [11]. BIM technology can improve safety in construction areas from the results of building visualization [12]. In addition, the use of BIM can detect clash detection between building elements [14], so that it can detect errors earlier before the construction stage takes place, minimize the risk of design errors or human errors and can reduce material waste in construction projects [15]. The application of BIM provides an alternative solution when there is a revision of the drawing, the volume calculation will automatically change, so that it can speed up the volume calculation process [16] which results in the calculation of cost estimates on construction projects becoming faster, more efficient, detailed and accurate [17].

One of BIM-based software is, Autodesk Revit, which can integrate various scientific disciplines such as structural, electrical, and mechanical engineering and also architecture [13]. Autodesk Revit is a software developed by Autodesk which plays a role in the digitalization of construction [14] which produces virtual 3D construction designs [15]. In Canada, Germany, and Australia, construction companies are progressing by adopting BIM technology to complete construction projects efficiently and quickly [16]. However, the application of Autodesk Revit in calculating work volumes was still rarely done in the Indonesian construction industry, most of Indonesian still use conventional methods due to several inhibiting factors, namely large investment costs and the lack of BIM specialists in Indonesia [17]. Autodesk Revit can design 3D architectural, structural and MEP modeling and calculate work volumes [18]. Apart from Autodesk Revit, Naviswork Manage software is also BIM-based software which can combine with Autodesk Revit with purpose to check clash detection, animation and

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visualization features [19]. The clash detection feature is used to review the design of building elements that experience clashes [20], thereby reducing the risk of design errors and reducing construction costs [21].

From previous studies, the use of BIM in estimating the cost of construction projects has advantages and disadvantages, namely the advantages of producing detailed and accurate calculations [22], volume calculations can change automatically if there are design changes [18], facilitating coordination between stakeholders by accessing planning data through BIM software features and can provide revisions directly [23], saves human resources with the existence of BIM, several drawings can be produced at once by experts [16], there is a clash detection feature that can detect errors early so as to reduce rework [15], while the disadvantages of using BIM are the large initial investment costs required to purchase a BIM software license [16], requiring high computer specifications to optimise the work of BIM applications [15], requiring competent human resources in the field of BIM [22]. Based on previous research that exploits the advantages of BIM by comparing the results of its volume calculations with BOQ, there has not been much justification regarding the calculations obtained from the model produced by BIM, whether the calculations produced are correct or not.

This study aims to compare the volume and cost outputs from BIM with those from the Bill of Quantities (BoQ) by re-evaluating volumes identified as clashes and verifying the actual costs. The results of this comparison are also used to identify errors that occur in manual calculations, providing a reference for future volume calculations for construction industry players who have not fully adopted the BIM method due to limitations and readiness in its implementation. This study is expected to enhance the efficiency of cost and volume calculations while minimizing the risk of calculation errors.

2. Research Method

The method used in this study involves a comparative approach. The object of the study is a public service center building with a complex design. The research process began with collecting secondary data and its reference standards. Based on the collected data, modeling was performed using software. Project volume analysis was carried out by comparing the planned project volume data with the software output results. In addition, a manual volume calculation analysis was carried out by the author as a control. Cost analysis was carried out by comparing the planning costs and software output with real costs as a control.

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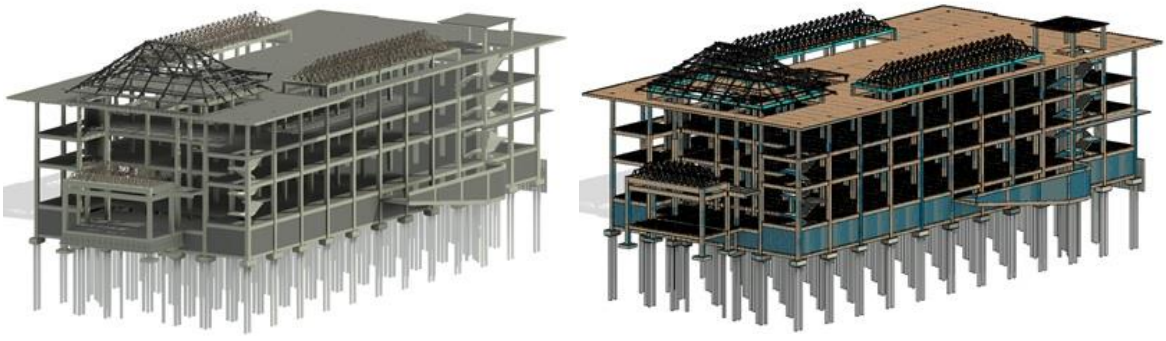
2.1 Object and Data Collected

The object for this research is a public service mall building that has several public service agencies in one building so that it has a complex design. The building project has a total of 3 floors plus basement with a total floor area of 9532.45 m^2. This research uses several data, namely plan drawings for reference to make 3D modelling in Autodesk Revit, project Bill Of Quantity (BOQ), and manual calculation data by researchers. In addition, analysis of work unit prices (AHSP) as a reference for the price of work items and SNI 2847-2019 is used as a reference for concrete work and reinforcement and SNI 1729-2020 for steel work and connections.

2.2 Modeling

The BIM method uses Autodesk Revit software to create 3D modelling and calculate the volume of work items while Naviswork to check clash detection. The calculation process using Autodesk Revit starts with setting the grid and level according to the plan reference then modelling the structure, architecture and plumbing according to the plan drawing, the next step is to import 3D modelling from Revit to Naviswork to be analysed for clash detection so as to produce a report on the results of clash detection between building elements. After checking clash detection, the next step is to provide information to 3D modelling so that volume calculations can be made using the quantity take-off feature in Autodesk Revit. After the volume calculation results are complete, then the recapitulation is then entered in accordance with the items in the BOQ.



(a) (b)

Source: Author Modeling (2024).

Figure 1. (a) 3D Concrete Modelling and (b) 3D Reinforcement Modelling

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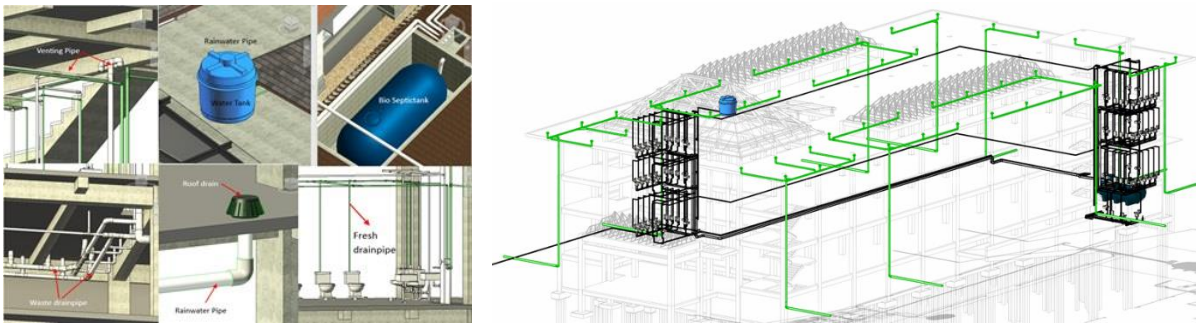
Source: Author Modeling (2024).

Figure 2. Architectural 3D Modelling Results



Source: Author Modeling (2024).

Figure 3. Plumbing 3D Modelling Results

2.3 Data Analysis

In volume analysis, the BIM volume output results will be compared with the project BoQ data with manual calculations as a control. While cost analysis, the cost output results from BIM will be compared with the project cost planning data with real cost as a control. Manual control calculations were performed using Microsoft Excel and Autocad software. The calculation process starts by using 2D CAD plan drawings with the main drawing selection being the elements detected as clash. The results of the manual control calculations obtained are used as justification for the quantity take off generated by the BIM software. To calculate the difference in volume and cost calculation results between BIM and BOQ, equation 1 is used [24].

$$\%\ \boldsymbol{Difference} = \frac{\boldsymbol{Difference}}{\boldsymbol{Total}} \times \mathbf{100}\% \quad (1)$$

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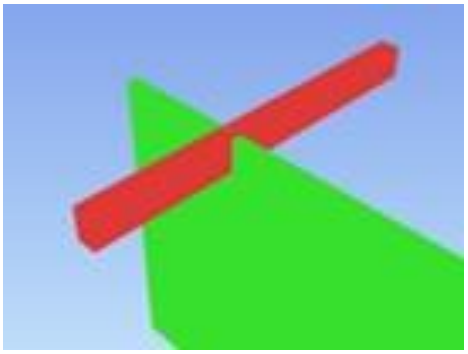
3. Results and Discussions

3.1 Clash Detection Checking

Clash detection feature can help review the design before field construction begins, so potential conflicts between structural elements can be identified and resolved early.

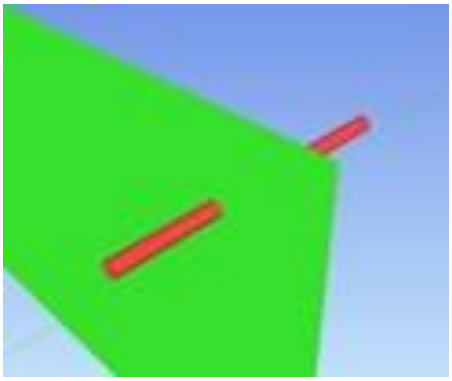


Source : Author Analysis Results (2024).

Figure 4. Clash Detection Ilustration Between Structural Beam and Wall

in **Figure 4**, it is known that there is a clash between beam and wall elements, this often results in volume calculation errors because the wall volume is not reduced by the structural beam dimensions which causes the realised wall volume to be smaller than the BoQ calculation. BIM Revit can determine the order level of each item so that when a clash occurs, BIM Revit will automatically adjust the volume based on the order level and in this case, the volume of the wall will be adjusted automatically.

Figure 5 it is known that the clash occurred in the piping work. in buildings, pipelines will generally cross from the shaft to other building grids based on the layout and function of the specified space which certainly affects the volume of the wall. Same as before, the wall volume will automatically adjusted to the diameter of the pipe that penetrating the wall.



Source : Author Analysis Results (2024).

Figure 5. Clash Detection Ilustration Between Wall and Pipe Works

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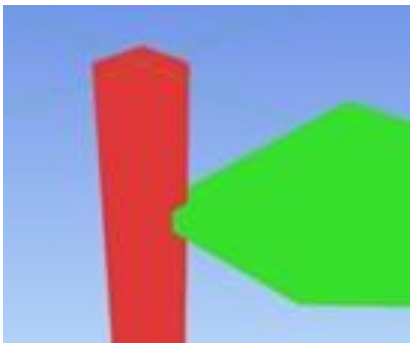

Source : Author Analysis Results (2024).

Figure 6. Clash Detection Ilustration Between Column and Floor Slab

As shown in **Figure 6**, with the clash between structural column and floor slab generates automatically adjusted floor slab volume. Volume adjustments occur not only in concrete work but also in reinforcement work, so that the clash detection that occurs in this work detects 2 types of clash at once, namely in the volume of concrete and in the volume of reinforcement.

3.2 Volume Comparison of BIM and Conventional methods

The calculation results between BoQ data and BIM results are compared with control data (recalculation of volume based on working drawings carefully). These results are shown in **Table 1**.

Table 1. Volume Calculation Comparison Between BIM Software and BoQ

Job Description	Units	BoQ	Software	Difference	Control
Land Clearing and Levelling Work	m^2	4104.00	4181.67	77.67	4181.67
Basement Excavation Work	m^3	8678.00	5492.88	-3185.12	5492.88
30x30 cm Pile Foundation Work	m	1536.00	1616.00	80.00	1616.00
1st floor Concrete Work Column K1 50/50	m^3	100.10	89.16	-10.94	89.16
1st floor Principal Reinforcement D19 K1	kg	12287.72	15947.34	3659.62	15947.15
Roof Concrete Beam B4, 20/30	m^3	31.14	17.45	-13.69	17.45
200/100 WF Structure Work	kg	4754.53	3883.58	-870.95	3882.22
Lightweight brick masonry work	m^2	1489.06	1032.81	-456.25	1032.86
Monier Roof Tile Work	m^2	1441.73	1158.43	-283.30	1158.55
Piping for Rainwater Mainline	m	261.90	77.00	-184.90	79.35
Temporary Fence Work	m	264.50	273.93	9.43	273.93

Source : Analysis Results (2024).

Based on **Table 1** the volume output for land clearing and leveling works from BIM software is larger by 77.67 m^2 or 1.89% than BoQ. BIM software calculates the volume of the cleaning and leveling area automatically based on the site modelling that has been made. The manual calculation control results are the same as the BIM calculation that showing that BIM software is more accurate than what is listed on BoQ. This occurs because of the site conditions that are not symmetrical and have more contour so it create its own challenge to accurately

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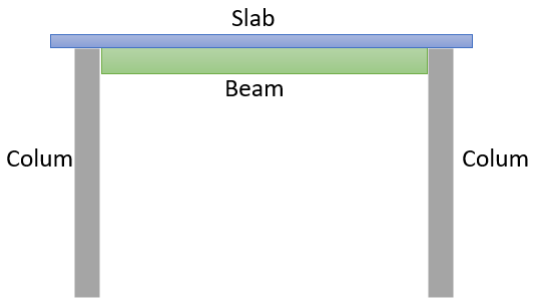
calculate the site because on each coordinate, they have different elevation. If the calculation carried out by manual process, it must go through several calculation steps such as calculate the area with coordinates and then calculate the volume based on each contour.

Basement excavation works also showing the same things that the volume output from BIM software is smaller by 3185.12 m^3 or 36.70% than BoQ. The manual calculation control results are also the same as the BIM calculation. This problem occurs also because asymmetrical site condition and different contour. The result for 30x30 cm pile foundation work is different from before, There are also differences in the calculation results, but the volume obtained from the BIM software is greater than the data listed in the BoQ by 80 m or approximately 5.21%. The manual calculation control results are the same as the BIM calculation that showing that BIM software is more accurate than what is listed on BoQ. This because the manual calculation was way more simple than the other job description where the calculation is done by simply multiplying the number of piles and the required depth because each pile for size 30x30 has the same depth.

The result from concrete works such as coloumn and beam is different too. The volume of concrete works from coloumns and beams are smaller respectively by 10.94 m^3 and 13.69 m^3 if calculated using BIM software and manual control. This occurs because of the operator that calculate for BoQ does not take into account the confluence of column, beam, and floor plate elements and the reinforcement bar that installed within so the calculation volume might be doubled when BIM software itself only calculates net volume for concrete like it shows on Figure 8. BIM is able to calculate the net volume of concrete because it has a clash detection feature, so it can identify overlapping structural elements.



Source : Author Result Analysis (2024).

Figure 7. Model Illustration of How to Calculate Concrete Volume in BIM Software

The result from principal reinforcement Work of D19 on K1 coloumn at 1st Floor calcutation shows that BIM software volume is greater by 3659.62 kg that the BoQ and the manual control calculation result is close to BIM software result itself. This happen partly because of the software has features to generate steel connection, so it can calculate the net span

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length of the steel itself automatically. The differences on volume BoQ occurs because of the calculation processed by based on length from axle to axle which is not cut with the connection so as to produce a larger volume. The result from 1st Floor lightweight wall calcutation shows that BIM software volume is smaller than BoQ by 456.25 m^2 and the manual control calculation result is close to BIM software result automatically. This differences occurs because BIM software automatically reduces the volume of the wall with the volume of doors, windows, and practical columns. The clash detection feature also minimise clashes between elements, resulting in accurate volume calculations.

The result from Monier roof tile work calcutation shows that BIM software volume is smaller than BoQ by 283.30 m2 and the manual control calculation result is close to BIM software result itself. This problem occurs mostly from human error, because the manual calculation was way more simple than the other job description where the calculation is done. BIM software itself distinguish the tile area and roof ridges so the calculation will produce more accurate result. The result from pipe working for rainwater mainline shows that BIM software volume is smaller than BoQ by 184.90 m. BIM software automatically modelling the pipe and calculates the volume of pipe length based on the net length that has been cut with pipe joints so that the volume calculation is more accurate. The results of manual calculation control also produce volume greater than the BIM Software by 2.35 m and this occurs because the calculation of the pipe length is calculated from the pipe axle. The result form temporary fence work shows that BIM software volume is greater than BoQ by 9.43 m and is the same with manual control calculation. The differences occurs because of the site conditions that are not symmetrical so it create its own challenge to accurately calculate the site. Research findings show that the volume calculation from BIM software can reduce the risk of errors during the calculation so as to produce detailed and accurate calculations.

3.3 The Comparison of BIM and Conventional Cost Estimates

The calculation of the cost difference between the conventional method and BIM is presented in **Table 2** and will be compared with the real cost.

Table 2. Cost Differences Between BIM and Conventional Methods

No	Job Descriptions	BOQ Data (IDR)	BIM (IDR.)	Cost Difference (IDR.)	Real Cost (IDR)
1	Preparation Work	153,709,839.25	157,609,175.41	3,899,336.16	156,653,500.00
2	Structural Work	20,527,638,126.63	19,836,233,513.46	-691,404,613.17	19,843,826,400.00
3	Architecture Work	17,672,910,329.63	17,464,105,524.85	-208,804,804.77	17,459,425,750.00
4	Plumbing Work	1,509,982,490.07	1,382,057,535.08	-127,924,955.00	1,381,350,000.00
	Total Cost	**39,864,240,785.58**	**38,840,005,748.79**	**-1,024,235,036.79**	**38,841,255,650.00**

Source: Analysis Results (2024).

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Based on the results above, it shows that there is a difference caused by differences in volume calculations between conventional methods and BIM methods. The conventional method gets a total cost of IDR. 39,864,240,785.58 while the BIM method produces a total cost of IDR. 38,840,005,748.79, so the cost of the BIM method is smaller by IDR. 1,024,235,036.79 or 2.57%. BoQ produces higher costs than real costs, with a total difference of IDR 1,022,985,135.58, which is 2.63% of total real costs. This shows that BoQ tends to overestimate. BIM produces costs that are very close to real costs, with a difference of only IDR 1,249,901.21 which is 0.0032% of the total real costs. This proves that BIM provides more accurate estimates than BoQ. So it can be said that by implementing BIM in calculating the volume of work, the calculation becomes more accurate and can saves up the budget so it can allocated to other work to optimizing the other function. So that the use of BIM can produce a more accurate calculation of the volume of work than conventional methods [25] which directly affects the cost estimate to be smaller which directly affects the cost estimate to be smaller than the cost stated in the BoQ [26]

More details on the preparatory work, the BIM method is greater, namely 2.54%, this is because the BIM volume calculation on cleaning work, land levelling and temporary fence installation is greater because software calculates the volume of the cleaning and land levelling work area automatically according to the model that has been made. In the temporary fence work, the volume generated by software is greater because the volume of the temporary fence length is calculated automatically based on the length of the perimeter of the land area in the project. In the structural work, the BIM method is smaller by 3.37% because software calculates the net volume of concrete automatically according to the modelling that has been made, especially in beam elements that intersect with many other elements so that the output of concrete volume and reinforcement is more accurate. In addition, the steel roof work also has a smaller volume than the BOQ data because of the steel connection features that make the volume output more accurate.

The calculation of architectural work costs is also 1.18% smaller using the BIM method, this is due to the ability of software to model architectural elements accurately and realistically, especially in wall work where the wall volume is automatically reduced by the volume of door and window holes. While the plumbing work has the most distinct costs among other work items, which is 8.47%, this is because software has features such as pipe connections and automatic pipe length calculations, resulting in accurate calculations.

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Also based on those result, the errors that occur are also known so that it can be used as a reference when doing manual calculations in the preparation of volumes in the BoQ document. The mistakes that often occurs include errors in calculating the volume of concrete, reinforcement, steel, piping, and wall installation work due too many details that overlap with each other. Another common mistakes also occurs even in simple calculation such as pile foundation, land clearing, land levelling, and temporary fences that happens largely due to human error that underestimates the calculation process. So preventive measures such as division of labour duties in volume calculation and rechecking must be carried out if the volume calculation will still be done manually.

4. Conclusion

Based on the comparison of volume and cost estimates between BIM software and BoQ, the BIM estimate was IDR 1,024,235,036.79 (2.57%) lower than the BoQ estimate, demonstrating BIM superiority in providing more precise volume and cost calculations. Additionally, the BIM cost estimate was highly accurate when compared to the real cost, with a minimal difference of only IDR 1,249,901.21 (0.0032% of the total real cost). In contrast, the BoQ method overestimated costs significantly, with a difference of IDR 1,022,985,135.58 (2.63% of the total real cost). Furthermore, This happened because in the volume calculation, BIM software proved to be more detailed in calculating the volume of all work items and eliminating human error factors, especially operator inaccuracy in calculating a work item volume. Based on those result, it is clear that the BIM method is more accurate than conventional calculations. For construction industry who have not been able to optimise BIM software in facilitating volume calculations, calculation errors occurred in several work items such as concrete, reinforcement, steel, and piping work due to the large number of overlapping details. For pile foundation, land clearing, land levelling, and temporary fences, errors occurred due to the asymmetrical site conditions and operator negligence in executing calculations that are basically easier than work items that have many details. To minimize and eliminate these errors, it is necessary to divide the tasks in volume calculation and recheck the calculation of the volume. The results of this study contribute to the construction industry by highlighting the significant advantages of using BIM software that can increase efficiency and reduce the risk of calculation errors.

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