EASR

Engineering and Applied Science Research

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

Application of 5D building information modeling using Cubicost in estimating construction structure work costs (Case study: Emergency Room and Hemodialysis Building at Waras Wiris Local General Hospital of Boyolali, Indonesia)

Canggih Gilang Pradana Hardi Saputra*[1)], Delista Putri Deni[1)], 'Ilma Alfianarrochmah[1)], Oktavia Kurnianingsih[1)], Ardia Tiara Rahmi[1)], Kholis Hapsari Pratiwi[1)], Tri Susanto[1)], Slamet Jauhari Legowo[1)], Fendi Hary Yanto[1)], Ramadhan Widy Pratama[2)] and Rainy Shinta Nur Halimah[2)]

[1)]Appropriate Structure Research Group, Vocational School, Universitas Sebelas Maret, Indonesia
[2)]Vocational School, Universitas Sebelas Maret, Indonesia

Received 29 August 2023
Revised 22 January 2024
Accepted 13 February 2024

Abstract

In construction projects, quantity take-off is an important process that must be considered because it will substantially impact the estimate of the overall project cost. The components that make up the structure of a building are very complex, so time inefficiencies and accuracy in calculating the volume of work often occur, which are fatal to construction costs. Therefore, in this study, an analysis of the application of 5D BIM in construction projects was carried out to identify its effectiveness, accuracy, and efficiency in determining the quantity take-off. The 5D BIM application used in this case is 5D BIM Cubicost TAS to determine the quantity take-off of concrete and formwork and 5D BIM Cubicost TRB to determine the quantity take-off of reinforcement in detail. The research method used was a comparative analysis method of the use of 5D BIM and conventional applications. The object of this research was the construction project of the Emergency Room and Hemodialysis Building at Waras Wiris Local General Hospital of Boyolali. The analysis shows that the 5D BIM Cubicost TAS and TRB efficiency in structure work was IDR 220,526,781.12 or 9.254%.

Keywords: Building information modeling, Cost estimate, Cubicost, Quantity take-off, 5D

1. Introduction

Quantity take-off (QTO) is one of the important processes that must be considered in the implementation of construction projects due to its large influence on the estimate of project costs [1]. Until now, most construction companies in Indonesia still use separate conventional applications in planning and implementing construction projects [2], such as AutoCAD 2D and 3D to create building designs, SAP2000 and ETABS to produce structural analysis, Microsoft Office Excel for volume calculations and construction costs, as well as Microsoft Project for project scheduling. This often results in non-optimal quantity take-off and information delays, resulting in cost and time inefficiencies and even inaccurate calculation results [3]. Therefore, a complete management system related to quantity take-off is needed to facilitate the calculation of cost estimates so that the control results obtained will be more accurate [4]. One of the resources that contribute significantly to project costs is material, which is equal to 40% -60% of the overall project cost [5], so inaccurate quantity take-off material will substantially impact the amount of the project cost estimate.

Building Information Modeling (BIM) Technology is a revolution in the construction industry that can be used to increase the efficiency and effectiveness of construction project implementation by reducing re-work and other construction problems [6]. BIM is able to help the planning of a building with a certain size, level, and quality according to requirements and needs, scheduling project implementation, and estimating work costs in a systematic way [4].

Table 1 BIM dimension

ID	Name of the Dimension	Description
3D	Spatial dimension	Graphic representation of the BIM model in a three dimension space
4D	Time dimension	Time model for construction activity visualization and analysis
5D	Costs dimension	Cost model for budget analysis and control during planning, construction, and operating phases
6D	Sustainability dimension	Sustainability model for evaluation of energy consumptions, environmental impact, pollution, risks, etc.
7D	Maintenance dimension	Facility management model for management and maintenance organization for the entire life-cycle
8D	Safety dimension	Safety model for checking operator's risks, preventing critical hazardous scenarios, etc.
N^{th}D	N^{th} generic dimension	Other aspects.

(Source: Changsaar et al. [7])

*Corresponding author.
Email address: canggihgilang@staff.uns.ac.id
doi: 10.14456/easr.2024.27

The BIM dimension (see Table 1) which focuses on planning to cost estimation is 5D BIM. 5D BIM is able to link planned 3D model components with the volume of project requirements and material or work unit costs to produce an estimate of the overall project cost automatically [4]. With the existence of 5D BIM technology, the overall quantity take-off process will have a higher level of accuracy and reliability than the quantity take-off process using conventional methods [1, 8-10]. However, beside the automatic quantity take-off process provided by 5D BIM, there are aspects that must be considered in detail by the user, particularly in structural work, namely defining the geometry of the 3D model of the building, such as the joints between columns, beams, and slabs that must be detailed with high precision [1, 11]. In addition, the definition of structural segments with different grades must also be considered, for example when in the joint elements there are the ones with different concrete grades [1, 12].

One of the 5D BIM applications that can be used to generate quantity take-off is Cubicost by Glodon, which uses an IFC (Industry Foundation Classes)-based BIM model. Since 2013, Cubicost has been widely used in projects in Indonesia and on a global scale (see Figure 1) [6], which means that this application has been trusted by various users. Nevertheless, to get precise and accurate results, users must still be able to understand the settings, codes, and template adjustments in the application so that a model representation is obtained according to reality in the field. This is because this application purely obtains quantity values by pure calculation based on geometric modeling [1], so research on the implementation of 5D BIM using the Cubicost application still needs to be carried out to investigate further into its use to improve the user experience. Cubicost was chosen because it has advantages over other 5D BIMs such as Revit, the calculation in Cubicost is considered more detailed because in cubicost there is a deduct feature and automatic rebar depiction which can certainly increase the efficiency value of Cubicost [13, 14]. In previous research, it was explained that Cubicost concrete calculations can also be directly implemented without having to be processed first [14]. In Cubicost, there are 4 functions that are used for quantity estimation and construction cost management, namely Takeoff for Architecture and Structure (TAS) to calculate the volume of architectural and structural work, Takeoff for ReBar (TRB) to calculate the volume of reinforcement work, Takeoff for Mechanical and Electrical (TME) to calculate the volume of mechanical and electrical work, and the Tender Series for Bill of Quantity (TBQ) to calculate the construction bill of quantity in which the four duties and functions support the overall implementation of 5D BIM [6].

Based on previous research, the results show that although the implementation of BIM in Indonesia is still a challenge, the application of 5D BIM, especially using the Cubicost application in construction work to produce quantity take-off, is able to provide advantages in the form of calculations accuracy, cost and time efficiency, as well as human errors and collisions correction in design through 3D geometry models correction with cost estimates [3, 4, 15-18]. Therefore, the application of 5D BIM will be carried out in this study to estimate the cost of structural work construction projects in the Emergency Room and Hemodialysis Building at Waras Wiris Local General Hospital of Boyolali, Indonesia using Cubicost 5D BIM with 2 main functions, TAS and TRB and its validation by calculating the quantity take-off using the conventional method. The Emergency Room and Hemodialysis Building of Waras Wiris Hospital is located on Jalan Raya Karanggede - Gemolong KM. 13, Randusari, Andong District, Boyolali Regency, Central Java Province. This building itself is a local government project where the stakeholders involved, namely the consultant and the contractor, are local business entities whose project work still uses conventional methods. The Emergency Room and Hemodialysis Intalasi building of Waras Wiris Hospital is a two-story building with reinforced concrete as the main construction material which has a steel roof construction. The construction of this building is divided into 2 main structures, namely the lower structure and the upper structure. The lower structure consists of footplates, concrete walls, and sloofs, while the upper structure consists of columns, beams, floor plates, ramps, and roofs. The purpose of this study is to analyze the comparison of cost estimates using Cubicost 5D BIM with conventional cost estimation calculations by planning consultants of the project, so that more precise results can be suggested as a guide in planning the estimated cost of the project. It is expected that with this research, The benefits of using Cubicost software in construction projects can encourage increased implementation of the use of modern BIM 5D technology and reduce human errors and optimize cost efficiency in the construction industry in Indonesia which has entered the industrial revolution 4.0.

Figure 1 Glodon Cubicost portfolio (Source: Glodon company [6])

2. Literature review

BIM (Building Information Modeling) is a method of representing integrated construction work that can save time and costs compared to conventional methods [19]. BIM has been widely adopted in the construction industry in America and European countries and even by Asian countries such as Hong Kong and Singapore as a technological basis for development. However, in Indonesia itself, the application of BIM in construction projects is still a challenge [15], especially on 5D BIM. Based on research conducted by Hatmoko et al. [15] regarding the adoption of the use of BIM in the construction industry in Indonesia, it was found that the barriers to BIM adoption in Indonesia were based on the following reasons: 1) Current technology is considered sufficient (38%); 2) Investment costs for licenses and equipment are quite high (25%); 3) Training requirement (19%); 4) There were no requests from clients because the approval documents still used conventional 2D images and Microsoft Office based reports (13%); and 5) Too advanced applications (6%). Nonetheless, there were 75% of respondents expressed interest in adopting BIM in the next few years. The reasons for interest or need for BIM adoption are as follows: 1) Integrated device management (21%); 2) Planning certainty (21%); 3) Process and collaboration efficiency (17%); 4) Detected Collision of the design (12%); 5) Well stimulated projects (12%); 6) Avoided Re-work (7%); 7) Ease of use of data (5%); and 8) Others (4%).

Several studies regarding the application of 5D BIM with the Cubicost application in construction projects which have been carried out are as follows: Research by Aini Osman et al. [20] regarding the use of BIM in quantity surveying work practices showed that Autodesk Quantity Takeoff is the most widely used application. However, Glodon Cubicost 5D BIM has the advantage of improving operations in providing a cost information database that allows users to integrate 3D model files that can generate reports and connect with cost estimates (5D), thereby providing high efficiency. Based on research by Zaini et al. [17] regarding the application of BIM to the construction industry, Cubicost 5D BIM provides an advantage over other applications, it provides continuous design performance in the design phase. Research by Husin et al. [18] on Hospital construction projects showed that the application of Cubicost 5D BIM TAS provided 6.18% of cost efficiency. The important factors of particular concern are geometry modeling and coding of material details, drawings, completeness of the bill of quantity, material specification, arrangement of activities in work breakdown, and etc. In line with this, research by Christopher Dwi et al. [4] also showed that the application of Cubicost 5D BIM TAS to a 2-storey residential construction project efficiently reduced the initial material volume of beam, column and slab elements by 7.28% and the estimated 6.79% of initial project cost, with the ability factor of the user remains the determining factor. The use of 5D BIM is able to minimize budget amendments and Contract Change Order (CCO) on projects because the entire model has been integrated so that the calculations and the collisions errors can be avoided. Research by Umam et al. [3] showed that the application of the Cubicost 5D BIM application to high-rise buildings increased the volume efficiency of concrete fc' 30 MPa, concrete fc' 35 MPa, and steel reinforcement work respectively by 7.21%, 10.87% , and 5.98%, which is far greater than the investment value of the 5D BIM application purchase. In line with the two studies above, research by Sartika et al. [16] also showed that the application of the Cubicost 5D BIM TAS application to the quantity take-off of concrete and formwork work on columns, beams, and slabs of the Maternal and Child Service Center Building Development Project, Hasan Sadikin Hospital, Bandung, gave results which were not much different from manual calculation results with a deviation of 0.00% - 32.72% and were able to provide efficiency in terms of time and work accuracy.

3. Methods

Emergency Room and Hemodialysis Building at Waras Wiris Local General Hospital Hospital of Boyolali, Indonesia was investigated during the planning stage and served as the study's research object. Reinforced concrete structures with fc' 25 MPa for slabs and fc' 30 MPa for beams, columns, and foundations are used in building construction. Planning data was obtained from the planning consultant and structural work (substructure and superstructure). This research used Glodon's Cubicost 5D BIM program. The research was conducted through the following stages:

a. *The preparation of work breakdown structure (WBS)*
The research begins with the preparation of the scope of work and its constraints. The purpose of creating a WBS is to improve project organization and help the project reach its goal. Figure 2 shows the WBS structural work on the Emergency Room and Hemodialysis Building at Waras Wiris Local General Hospital of Boyolali, Indonesia.

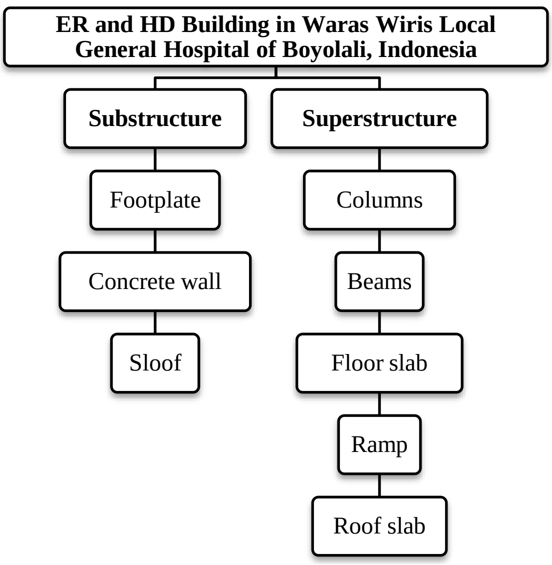

Figure 2 Work breakdown structure (WBS)

b. *Cubicost 5D BIM take-off for architecture and structure (TAS) modeling*
At this stage, BIM modeling is done using AutoCAD 2D data, which is imported and subsequently converted into a 3D image using Cubicost 5D BIM TAS. Defining materials and additional parameters is done after this stage in order to perfect the Cubicost 5D BIM TAS modeling.
c. *Cubicost 5D BIM take-off for rebar (TRB) modeling*
Modeling the Cubicost 5D BIM TRB is the following stage. This stage begins by importing the Cubicost 5D BIM TAS file into the TRB. At this stage, materials and details are now defined in accordance with standards.
d. *Cubicost 5D BIM quantity take-off validation*
After the modeling stage is completed, the output will be in the form of material volume or quantity take-off. The volume will serve as the foundation for project cost estimation calculations. Before the volume is used, it is first validated using conventional calculation parameters using Microsoft office excel by the author in detail and accurately so as to get a strong correlation value to validate the output that comes out of Cubicost.
e. *Cost estimation calculation and comparative analysis*
The validated volume of work and its calculated deviation can be used as a basis for developing cost estimates. The results of these calculations will be contrasted with the estimated costs calculated by the consultant using conventional methods and then analyzed to produce a more accurate calculation. Material and detailing are also defined according to standards at this stage.

4. Results

4.1 Cubicost 5D BIM take-off for architecture and structure (TAS) modeling

Cubicost 5D BIM Takeoff for Architecture and Structure (TAS) transforms 2D images into 3D images to obtain output quantity takeoff in the form of volume of concrete and formwork for structural work. The results of the modeling of the Emergency Room and Hemodialysis Building at Waras Wiris Local General Hospital of Boyolali, Indonesia using the Cubicost 5D BIM TAS are presented in Figures 3 and 4 as follows.

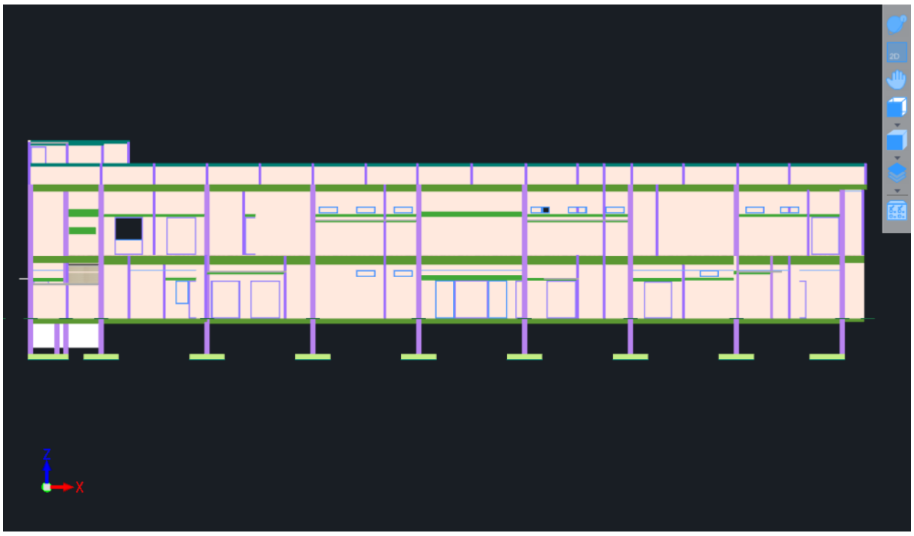

Figure 3 Cubicost 5D BIM TAS modeling result (side view)

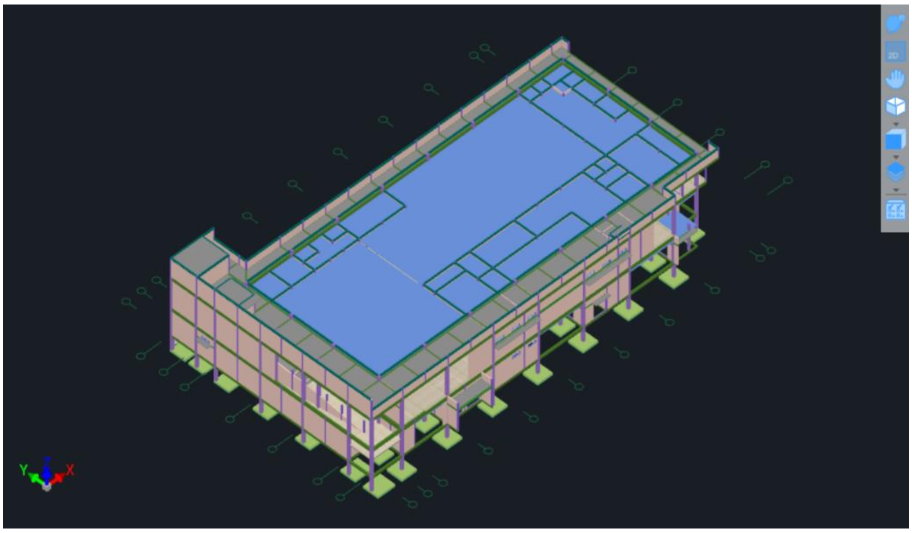

Figure 4 Cubicost 5D BIM TAS modeling result (isometric view)

4.2 Cubicost 5D BIM take-off for rebar (TRB) modeling

Modeling with Cubicost 5D BIM Takeoff for ReBar (TRB) is done by importing files from Cubicost 5D BIM TAS. Cubicost 5D BIM TRB is used to obtain quantity take-off in the form of an accurate iron volume. Figures 5 through 7 illustrate the results of the modeling of the Emergency Room and Hemodialysis Building at Waras Wiris Local General Hospital of Boyolali, Indonesia using the Cubicost 5D BIM TRB.

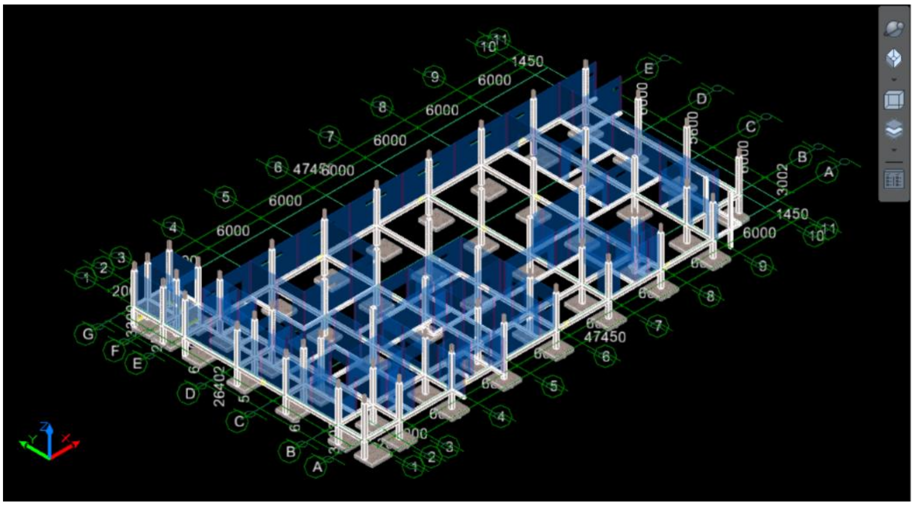

Figure 5 Cubicost 5D BIM TRB modeling result for the 1st floor (isometric view)

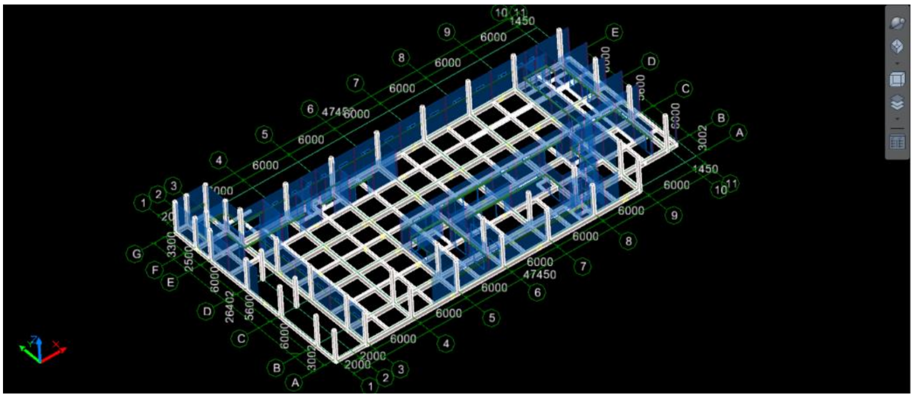

Figure 6 Cubicost 5D BIM TRB modeling result for the 2st floor (isometric view)

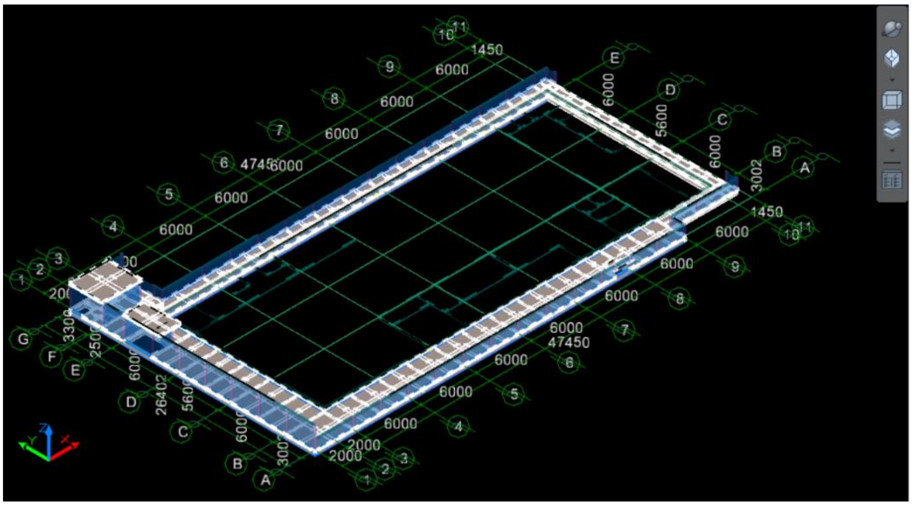

Figure 7 Cubicost 5D BIM TRB modeling result for the rooftop (isometric view)

4.3 Cubicost 5D BIM quantity take-off validation

After the modeling stage is complete, an output quantity take-off will be obtained in the form of concrete and formwork volume from Cubicost 5D BIM TAS and reinforcement volume from Cubicost 5D BIM TRB. The output must be validated first using conventional calculations carried out by the author carefully by paying attention to every detail to prove that the calculations made by Cubicost 5D BIM are correct. The quantity takeoff is validated by comparing the volume of work calculated by Cubicost 5D BIM for the second-floor structure with the results of conventional calculations and calculating the deviation.

Table 2 Cubicost 5D BIM quantity take-off validation

Work	Unit	Cubicost 5D BIM Volume	Conventional Volume	Deviation
Concrete				
Beam structure	m^3	17.416	17.327	-0.511%
Column	m^3	13.454	13.415	-0.290%
Floor slab	m^3	33.804	34.080	0.816%
Total	m^3	**64.674**	**64.822**	**0.016%**
Reinforcement				
Beam structure	kg	3,717.197	3,714.017	0.086%
Column	kg	2,834.356	2,832.727	-0.057%
Floor slab	kg	3,111.868	3,133.469	0.694%
Total	**kg**	**9,663.421**	**9,680.213**	**0.007%**
Formwork				
Beam structure	m^2	269.368	269.800	0.160%
Column	m^2	184.495	184.800	0.165%
Floor slab	m^2	271.759	272.778	0.375%
Total	m^2	**725.622**	**727.378**	**0.007%**

According to Table 2, the deviation between the results of calculating quantity take-off using Cubicost 5D BIM and conventional calculations ranges from -0.511 to 0.816%. To strengthen the results of the validation, a linear regression analysis will be conducted to determine the relationship between the takeoff quantities. Figure 8 shows the linear regression graph demonstrating the relationship between Cubicost 5D BIM volume and conventional volume.

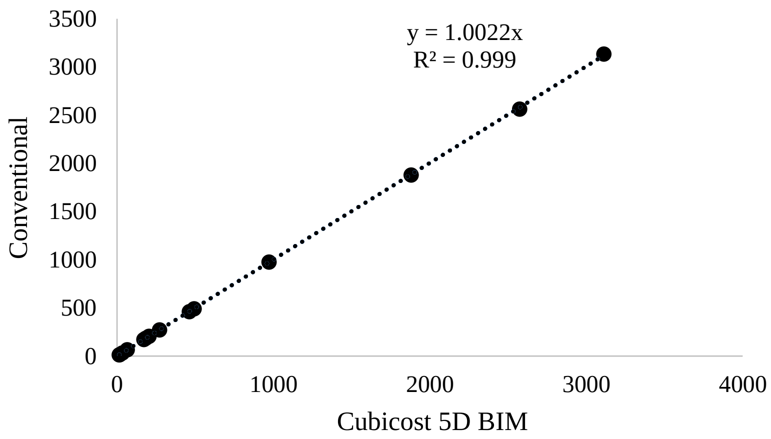

Figure 8 Relationship between Cubicost 5D BIM volume and conventional volume

Table 3 Coefficient interpretation

Coefficient Interval	Relationship Description
0.00 – 0.199	Very low
0.20 – 0.399	Low
0.40 – 0.599	Medium
0.60 – 0.799	Strong
0.80 – 1.000	Very strong

(Source: Sugiyono [21])

Based on the Figure 8 above, the correlation coefficient is 0.999, which means that the quantity take-off has been well validated. A correlation coefficient, which is close to 1, falls into the category of very strong correlation according to Table 3. The very strong correlation result is because the conventional calculation used to validate is the author's personal calculation that pays attention to every detail of the building. So, it can be concluded that the volume of Cubicost 5D BIM calculation results can represent the volume of conventional calculation results.

4.4 Cost estimation calculation and comparative analysis

The quantity take-off, represented by the volume obtained from the validated Cubicost 5D BIM calculation, which has shown a strong correlation with conventional calculations, can be processed into a cost estimation by multiplying the volume of work with the unit price of the respective tasks based on the Unit Price Analysis for the city of Boyolali, Indonesia in the fiscal year 2023. The results of the cost estimation using the volume from the Cubicost 5D BIM calculation are shown in Table 4.

Table 4 Cost estimation based on Cubicost 5D BIM quantity take-off results

Work		Volume	Unit	Amount (IDR)
Intensive Care Unit Building Floor 1				
Concrete Work				
Footplate				
a.	Concrete	58.320	m^3	75,664,825.01
b.	Working Floor	10.110	m^3	10,895,376.27
c.	Reinforcement			
-	Reinforcing Bar D16	6,739.648	kg	141,081,033.36
d.	Formwork	115.920	m^2	18,183,051.23
Total				**245,824,285.86**
Slab				
a.	Concrete	25.462	m^3	33,034,598.33
b.	Reinforcement			
-	Reinforcing Bar D13	2,920.573	kg	61,136,346.71
-	Reinforcing Bar Ø8 and Ø12	1,826.037	kg	37,562,945.68
c.	Formwork	260.953	m^2	42,856,462.54
Total				**174,590,353.26**
Column				
a.	Concrete	23.224	m^3	30,130,999.59
b.	Reinforcement			
-	Reinforcing Bar D16 and D19	5,217.409	kg	109,216,008.49
-	Reinforcing Bar Ø12 and Ø8	973.066	kg	20,016,694.79
c.	Formwork	320.091	m^2	74,676,168.24
Total				**234,039,871.10**
Ramp				
a.	Concrete	8.590	m^3	11,144,733.31
b.	Reinforcement			
-	Reinforcing Bar Ø8	772.338	kg	15,887,569.82
b.	Formwork	71.586	m^2	24,089,018.65
Total				**51,121,321.79**
Concrete Wall				
a.	Concrete	5.288	m^3	6,860,692.64
b.	Reinforcement			
-	Reinforcing Bar Ø10	393.873	kg	8,102,261.95
c.	Formwork	43.491	m^2	16,314,218.67
Total				**31,277,173.25**
Total for Floor 1				**736,853,005.26**
HD Building Floor 2				
Concrete Work				
Structural Beams				
a.	Concrete	60.056	m^3	77,917,125.01
b.	Reinforcement			-
-	Reinforcing Bar D13 and D16	11,135.52	kg	233,099,726.31
-	Reinforcing Bar Ø8, Ø10, and Ø12	3,299.111	kg	67,865,178.68
c.	Formwork	641.891	m^2	151,951,418.08
Total				**530,833,448.08**
Column				
a.	Concrete	14.345	m^3	18,611,315.41
b.	Reinforcement			-
-	Reinforcing Bar D16 and D19	2,342.154	kg	49,028,303.35
-	Reinforcing Bar Ø12 and Ø8	492.202	kg	10,124,962.96
c.	Formwork	196.495	m^2	45,841,631.53
Total				**123,606,213.25**
Foot Slab				
a.	Concrete	108.643	m^3	140,954,279.55
b.	Reinforcement			-
-	Reinforcing Bar Ø8 and Ø10	14,189.57	kg	291,890,038.13
c.	Formwork	721.802	m^2	242,889,696.90
Total				**675,734,014.58**
Total for Floor 2				**1,330,173,675.90**
Rooftop				
Concrete Work				
Structural Beams				
a.	Concrete	17.416	m^3	22,595,654.88
b.	Reinforcement			-
-	Reinforcing Bar Ø8, Ø10, and Ø12	3,717.197	kg	76,465,520.13
c.	Formwork	269.17	m^2	63,719,172.26
Total				**162,780,347.27**
Roof Slab				
a.	Concrete	36.516	m^3	47,376,144.55
b.	Reinforcement			-
-	Reinforcing Bar Ø8	3,367.03	kg	69,262,323.27
c.	Formwork	294.519	m^2	99,106,999.76
Total				**215,745,467.57**
Total for Rooftop				**378,525,814.85**
Total				**2,445,552,496.01**

Based on Table 4, the cost estimation calculated based on Cubicost 5D BIM quantity take-off amounts to IDR2,445,552,496.01. After obtaining this amount, a comparison will be made between the cost estimation of each item from Cubicost 5D BIM and the cost estimation calculated using the conventional method by the consultant. The values for the cost estimation comparison between the Cubicost 5D BIM quantity take-off results and the consultant's conventional method can be seen in Table 5.

Table 5 Comparison of cost estimation based on Cubicost 5D BIM quantity take-off with conventional cost estimation by the consultant.

Work		Cubicost 5D BIM (IDR)	Consultant (Conventional) (IDR)	Efficiency (IDR)
Intensive Care Unit Building Floor 1				
Footplate				
a.	Concrete	75,664,825.01	75,197,758.19	- 467,066.82
b.	Working Floor	10,895,376.27	11,261,788.53	366,412.26
c.	Reinforcement			
-	Reinforcing Bar D16	141,081,033.36	143,727,233.98	2,646,200.62
d.	Formwork	18,183,051.23	18,126,582.13	- 56,469.10
Slab				
a.	Concrete	33,034,598.33	32,526,014.45	- 508,583.87
b.	Reinforcement			
-	Reinforcing Bar D13	61,136,346.71	56,551,755.48	4,584,591.23
-	Reinforcing Bar Ø8 and Ø12	37,562,945.68	35,574,849.34	1,988,096.34
c.	Formwork	42,856,462.54	44,245,360.56	1,388,898.02
Column				
a.	Concrete	30,130,999.59	34,069,929.78	3,938,930.19
b.	Reinforcement			
-	Reinforcing Bar D16 and D19	109,216,008.49	98,972,689.31	10,243,319.18
-	Reinforcing Bar Ø12 and Ø8	20,016,694.79	20,689,443.23	672,748.44
c.	Formwork	74,676,168.24	82,083,104.59	7,406,936.36
Ramp				
a.	Concrete	11,144,733.31	12,117,789.19	973,055.88
b.	Reinforcement			
-	Reinforcing Bar Ø8	15,887,569.82	28,169,379.34	12,281,809.52
c.	Formwork	24,089,018.65	26,203,613.59	2,114,594.94
Concrete Wall				
a.	Concrete	6,860,692.64	6,746,520.75	- 114,171.89
b.	Reinforcement			
-	Reinforcing Bar Ø10	8,102,261.95	10,066,296.51	1,964,034.56
c.	Formwork	16,314,218.67	10,923,410.53	5,390,808.13
HD Building Floor 2				
Structural Beams				
a.	Concrete	77,917,125.01	71,110,923.50	- 6,806,201.51
b.	Reinforcement			
-	Reinforcing Bar D13 and D16	233,099,726.31	186,576,038.33	46,523,687.98
-	Reinforcing Bar Ø8, Ø10, and Ø12	67,865,178.68	87,656,902.73	19,791,724.05
c.	Formwork	151,951,418.08	149,044,202.73	2,907,215.35
Column				
a.	Concrete	18,611,315.41	20,550,940.13	1,939,624.72
b.	Reinforcement			
-	Reinforcing Bar D16 and D19	49,028,303.35	54,717,606.02	5,689,302.67
-	Reinforcing Bar Ø12 and Ø8	10,124,962.96	10,565,548.62	440,585.65
c.	Formwork	45,841,631.53	49,286,257.04	3,444,625.51
Foot Slab				
a.	Concrete	140,954,279.55	139,562,160.94	- 1,392,118.61
b.	Reinforcement			
-	Reinforcing Bar Ø8 and Ø10	291,890,038.13	284,457,885.10	7,432,153.03
c.	Formwork	242,889,696.90	254,508,527.90	11,618,831.00
Rooftop				
Structural Beams				
a.	Concrete	22,595,654.88	29,035,987.37	6,440,332.50
b.	Reinforcement			
-	Reinforcing Bar Ø8, Ø10, and Ø12	76,465,520.13	66,398,061.14	10,067,458.99
c.	Formwork	63,719,172.26	73,263,909.89	9,544,737.62
Roof Slab				
a.	Concrete	47,376,144.55	40,180,720.69	- 7,195,423.86
b.	Reinforcement			
-	Reinforcing Bar Ø8	69,262,323.27	72,118,169.60	2,855,846.33
c.	Formwork	99,106,999.76	46,696,744.04	52,410,255.72
Total		**2,445,552,496.01**	**2,382,984,105.24**	**220,526,781.12**
Efficiency Percentage				**9.254%**

Based on Table 5, even though the cost estimation values obtained from the Cubicost 5D BIM quantity take-off appear higher, the efficiency percentage of using Cubicost 5D BIM TAS and TRB in the structural work of the Emergency Room and Hemodialysis Building at Waras Wiris Local General Hospital of Boyolali, Indonesia is IDR 220,526,781.12 or 9.254%. This is due to the presence of human errors, which will be further explained in the discussion.

5. Discussion

By using Cubicost 5D BIM quantity take-off, estimating cost of the structure work of the Emergency Room and Hemodialysis Building Construction Project at Waras Wiris Local General Hospital of Boyolali, Indonesia resulted in a value of 2.626% which was higher than that calculated by the planning consultants using conventional methods. Even so, the application of 5D BIM still provided efficiency of IDR 220,526,781.12 or 9.254% overall. The efficiency value was obtained from the ability of Cubicost 5D BIM to find human errors in the calculation carried out by the consultants, among others are:

a. The main reinforcement in the channeling, hooking and bending sections was not calculated and only relied on the iron coefficient value addition in the analysis of the price of work unit.
b. The effective length of the *sloof* reinforcement was calculated only to the outer limit of the column so that the part touching the column was considered not to have reinforcement.
c. One side of the formwork on the concrete wall formwork was not calculated.
d. The height of the outer side of the 2nd floor beam formwork was considered the same as that of the inner side.
e. There was an error in the calculation of quantity take-off of the roof slab formwork.

Human errors done by the consultant caused the calculation results to appear smaller because many items were not accurately calculated and this would certainly affect the development process later. Therefore, if it occurs due to human errors, the value made by the consultant which is greater than the Cubicost 5D BIM value is still included in the efficiency. A negative efficiency value of a work occurs due to differences in calculation methods, for instance in concrete calculations the consultant includes column heads in the column calculations while Cubicost 5D BIM includes them in the beam calculations considering the fact that during work, the column heads are cast together with the beam. In addition, the quality of the column head equals that of the beam. The results show that Cubicost 5D BIM is able to increase the accuracy of calculations and help detect human errors and collisions in conventional calculations, thus providing more accurate and efficient estimated cost. It will, of course, be useful in the implementation of construction projects where inaccurate volume calculations on designs will cause re-work and contract change orders or addendums in the later construction phase. This is in line with previous studies by Umam et al. (2022) [3], Christopher Dwi et al. [4], Sartika et al. [16], Zaini et al. [17], Aini Osman et al. [20] in which, through its duties and functions, Cubicost 5D BIM is able to increase the accuracy and efficiency of quantity take-off in construction projects. However, the user factor also determines the results of the analysis. In Cubicost 5D BIM which is very dependent on the geometry of the 3D model, the definition of materials and high accuracy elements, such as joints, needs to be paid close attention because it will have a substantial impact on the value of *quantity take-off* [1].

6. Conclusions

Based on the above analysis, the following conclusions can be drawn:

a. The correlation between the calculations made by Cubicost software and conventional calculations made by the author in detail obtained a value equal to 0.999, which shows that Cubicost software calculations are very strong in truth so that they can be implemented on a project.
b. The application of Cubicost 5D BIM TAS and TRB in estimating construction structure work cost of the Emergency Room and Hemodialysis at Waras Wiris Local General Hospital of Boyolali gives a total efficiency value of IDR2,445,552,496.01 or 9.254%. The efficiency value occurs because there are human errors in the calculation of conventional cost estimates by the consultant.
c. Human errors found in this research occurred in the calculation of the volume of reinforcement work and the volume of formwork work calculated by the consultant was not detailed, causing large human errors.
d. The application of Cubicost 5D BIM in the project helps find human errors so that it can anticipate quantity take-off errors during the project and provide more accurate, effective, and efficient calculation results. However, the definition of materials and high accuracy elements in Cubicost 5D BIM needs to be paid close attention because the quantity take-off in this application depends very much on the accuracy of the 3D model geometry.

7. Acknowledgements

This work was part of Appropriate Structure Research Group which was financially supported by the Hibah Grup Riset Scheme, Universitas Sebelas Maret (Contract No. 228/UN27.22/PT.01.03/2023).

8. References

[1] Liu H, Cheng JCP, Gan VJL, Zhou S. A knowledge model-based BIM framework for automatic code-compliant quantity take-off. Autom Constr. 2022;133:104024.
[2] Kamil AA, Raflis. Comparison of quality and time cost control using conventional methods and BIM methods. Proceedings of Young Intellectuals Seminar#1, Innovations in Science, Technology, and Art in the Planning and Design of the Built Environment; 2019 Apr 11; Trisakti University, Indonesia. p. 27-33. (In Indonesian)
[3] Umam FN, Erizal, Putra H. Improving the cost efficiency of multi-storey building construction with 5D building information modeling (BIM) Application. Teras J. 2022;12(1):245-56. (In Indonesian)
[4] Christopher Dwi BA, Wasono DS, Hermawan, Dwi Hatmoko JU. Preliminary study of the efficiency of using 5D-BIM on material volume and cost estimation in construction projects (case study of 2-storey residential house). 15th National Conference on Civil Engineering; 2021 Oct 21-22; Semarang, Indonesia. p. 292-301. (In Indonesian)
[5] Perdana AS, Indrayadi M, Pratiwi R. Identification of construction material waste in building construction projects (case study: UNTAN Pontianak rector's office house). JeLAST. 2018;5(2):1-9. (In Indonesian)
[6] Glodon Company. UNS BIM Implementation Plan. Jakarta: Glodon Indonesia; 2022. (In Indonesian)
[7] Changsaar C, Abidin NI, Khoso AR, Luenhui L, Yaoli X, Hunchuen G. Optimising energy performance of an eco-home using building information modelling (BIM). Innov Infrastruct Solut. 2022;7:140.
[8] Sattineni A, Bradford RH. Estimating with BIM: a survey of US construction companies. Proceedings of the 28th ISARC; 2011 Jun 29 - Jul 2; Seoul, Korea. p. 564-9.

[9] Sacks R, Eastman C, Lee G, Teicholz P. BIM handbook: a guide to building information modeling for owners, designers, engineers, contractors, and facility managers. 3rd Ed. United States: John Wiley & Sons; 2018.
[10] Nadeem A, Wong AKD, Wong FKW. Bill of quantities with 3D views using building information modeling. Arab J Sci Eng. 2015;40:2465-77.
[11] Khosakitchalert C, Yabuki N, Fukuda T. Automated modifcation of compound elements for accurate BIM-based quantity takeoff. Autom Constr. 2020;113:103142.
[12] Choi J, Kim H, Kim I. Open BIM-based quantity take-off system for schematic estimation of building frame in early design stage. J Comput Des Eng. 2015;2(1):16-25.
[13] Herzanita A, Anggraini RP. Comparison of building structure cost estimation between autodesk revit software and Cubicost. Constr Mater J. 2023;5(1):1-11. (In Indonesian)
[14] Putro SH, Febriyuni AP. Calculation of the quantity of work to take off the structure using Glodon Cubicost and autodesk revit on the Surakarta air force hospital project (location: TA2023TKBG11-28) [thesis]. Semarang: Politeknik Pekerjaan Umum Semarang; 2023. (In Indonesian)
[15] Hatmoko JUD, Fundra Y, Wibowo MA, Zhabrinna. Investigating building information modelling (BIM) adoption in Indonesia construction industry. MATEC Web Conf. 2019;258:02006.
[16] Sartika I, Rachmat A, Sugiri T. Implementation of BIM QS in the upper structure planning of the construction project of the mother and child service center building RSUP Hasan Sadikin Bandung. Sistem Infrastruktur Teknik Sipil. 2023;3(1):59-71. (In Indonesian)
[17] Zaini N, Ahmad Zaini A, Tamjehi SD, Razali AW, Gui HC. Implementation of building information modeling (BIM) in Sarawak construction industry: a review. IOP Conf Ser: Earth Environ Sci. 2020;498:012091.
[18] Husin AE, Meisaroh M, Rahmawati DI, Kussumardianadewi BD. Improvement of cost performance based on BIM quantity take-off hospital structure work. Research Square. 2020:1-14.
[19] Lhara Sari O, Yulianto Nugroho T. Analysis of take off quantity with BIM approach and pareto diagram on structural works of prosecutor's office building in Balikpapan City. 2023;10(2):553-63. (In Indonesian)
[20] Aini Osman N, Suhaida SK, Abdul Razak N. Assessing the BIM software application in quantity surveying practice. INTI J. 2019;10:1-6.
[21] Sugiyono. Quantitative research methods. Bandung: Alfabeta; 2018. (In Indonesian)