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Building Information Modelling for clean water and wastewater system in the medium rise school building

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Building Information Modelling for clean water and wastewater system in the medium rise school building

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Abstract. Human activities in a building are closely related to the use of clean water. At this time, the concept of a water installation is demanded to be as effective as possible by minimizing the possibility of water waste caused by leakage problems, broken pipes, blocked pipes, and others. However, some concepts still use traditional techniques by depicting 2D models and manual calculations. The method used is a hydraulic analysis with SNI 03-7065-2005 as standard and using Autodesk Revit MEP as modeling and calculating tools. Necessary data are technical specifications, design drawings, and designed plumbing facilities. The system comprises of Domestic Cold Water, Sanitary Grey Water, Sanitary Black Water, and Vent. Building Information Modelling (BIM) is applied to evaluate the effectiveness of the existing design and design its modification as well as to provide the working drawing. The analysis includes analysis of piping system completeness, system crash, flow, velocity, pressure loss. Based on the report, it can be concluded the flow velocity of Domestic Cold Water is 0.7-6.4 m/s which is out the range of standard value. For the pressure, a manual calculation is performed to validate the report results using the Darcy Weisbach equation that has the same value as the report by Building Information Modeling. The cost of the design conditions has a difference of Rp 8.363.608 or eight million three hundred sixty-three thousand rupiah or 0.4% more efficient.

1. Introduction

Water is one of the primary needs for human life which can be used for several functions, both for daily use and for energy utilization. In the construction of a building, it cannot be separated from the role of the need for clean water. The need for water in a building means water that is used either by the occupants of the building or for other purposes related to building facilities. The need for water in a building is closely related to the function of the building or the activities of building users. This is the basis that each type of building has different needs for clean water.

However, until now the planning of clean water and wastewater systems generally still use conventional methods where the depiction is still limited to 2D media, and planning and control are carried out by manual calculations. With the development of the concept of Building Information Modeling, it is hoped that all projects in Indonesia can be developed and adapt the current, more modern technological concepts in the field of construction which will be easier for all project stakeholders.

Aniendhita [1] and Volk et al. [2] studied the literature review of Building Information Modeling application. However, the application in the modeling was not performed. Further implementation for building object behavior and lean construction performance have been researched [3,4]. In this study, BIM is applied to assist the evaluation of plumbing system efficacy.

This research was conducted to simulate the clean water distribution system along with the sewerage system of the medium rise school building using the necessary hydraulic calculations and analyze the performance of the optimal distribution of clean water and sewage. To simplify the design of clean water distribution networks in buildings, design is assisted by Autodesk Revit MEP software. This is a construction design software in the form of a 3D design that provides an integrated Building Information Modeling. With this technology, the data that is managed will be more accurate and more detailed, starting from modeling, detailing, engineering, drawing, reporting, to scheduling.

2. Methods

At first, the piping system and the dimension are analyzed according to the water demand [5] and volume. The basis for calculation is Indonesian National Standard of Plumbing System Planning Procedure [6]. Afterward, the design is introduced into Building Information Modeling using for the modeling to ensure that it is appropriate, safe, and comfortable to use using Autodesk Revit MEP. The software used is Free Download Autodesk Revit 2019 for Student and Educational Version by creating an account as a student so 1-year license is obtained for free. Control that is carried out in the planning of clean water and wastewater treatment plants includes control of the laying of pipelines whether there are crosses or not. In terms of pressure and flow velocity in the pipe, it is also necessary to control using standards from Indonesian National Standard of Engineering Planning Procedures for Distribution Networks and Clean Water Supply System Service Units [7] regarding the planning procedure for the plumbing system of flow velocity in pipes mentioning that the velocity is 0.9 – 2 (m/s). Meanwhile, according to SNI 7509: 2011 that the maximum flow velocity is 3 m/s. According to PVC pipe standards, the maximum allowed pressure of AW class is 10 kg/cm^2.

Flow control is performed using Revit MEP [8], which can be directly controlled by friction and flow velocity after inputting pipeline dimension data. Control is also carried out on the layout of the pipeline network because if there is an error either in the pipe, connection or other elements, there will be an error in the layout. Flow calculations uses Plumbing Fixture Flow method where this method converts the fixture unit into the volumetric flow using the values listed in Table E103.3 (3) 2012 International Plumbing Code (IPC). The specific flow conversion method is used in the classification of the Domestic Hot/Cold Water System. The results of flow calculations can later be used to determine pipe dimensions. The calculation of pressure drop uses the Colebrook Equation method available in the application. After making sure that the model on Revit MEP matches the expected output, the resource volume calculation can be done automatically. Finally, the comparison of material quantity and budget of existing design and Building Information Modeling design results is discussed.

3. Results and discussion

Figure 1 is the 3D model of the medium rise school building being researched. To explain the colours on the model, the following is the description **Table 1**.

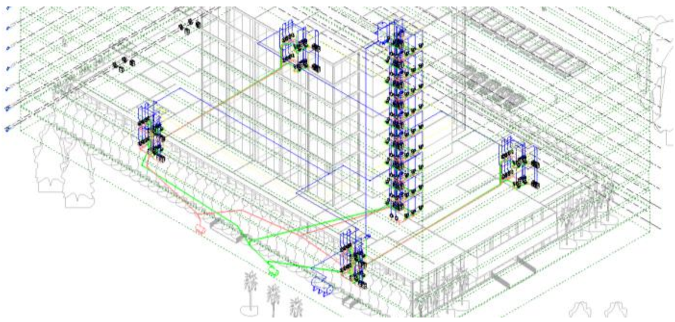

Figure 1. 3D model of the subject.

Table 1. Pipe description.

Pipe Color	Plumbing System Classification	Pipe Type	Slope
Blue	Domestic Cold Water	PVC	0
Red	Sanitary Grey Water	PVC	1%
Green	Sanitary Black Water	PVC	2%
Yellow	Vent	PVC	0

3.1. Layout assessment
Layout control is carried out to ensure that pipelines between the systems do not collide with each other. For a larger scale, usually done for control of one system to another, for example, such as plumbing systems for duct systems and other complex systems. In **Figure 2**, the example of detailed side view of plumbing system is illustrated. Green pipes have a slope of 2% so they appear as tilted line, the same thing as red pipes which have 1% slope. Meanwhile, the blue and yellow pipes appear in straight line because the slope value is 0 or does not have a slope. Because the individual pipes are easily visible, it can be seen that the pipes are not stacked on top of each other.

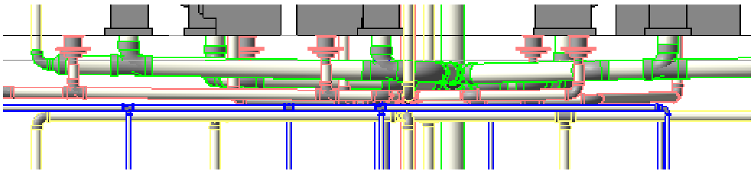

Figure 2. Detailed side view of plumbing system.

3.2. Velocity assessment
It is required to assess the flow velocity of clean water system. **Table 2** provides a summary of the report. From the table, the flow velocity from 5 Domestic Cold Water systems are in the range 0.7 m/s to 6.4 m/s. It can be concluded that for four clean water systems, except Domestic Cold Water 2 system, the velocity is higher than minimum standard, i.e. 0.9 m/s. However, in terms of maximum standard, all systems exceed permissible velocity of 2 m/s. Therefore, if the speed is too high it will cause frequent water blows which can damage plumbing equipment, cause scaly sound from the pipe and cause rapid wear of the pipe surface which later causes pipe leakage.

Table 2. Velocity report summary.

Pipe System	V (m/sec)	
	Min	max
DCW 1	1.7	5.1
DCW 2	0.7	6.4
DCW 3	1.7	5.1
DCW 4	1.7	5.1
DCW 5	1.7	5.1

3.3. Pressure assessment
Verification of the Building Information Modeling results is carried by comparison with manual calculations. Darcy-Weisbach and Bernoulli formulas are used to confirm the head loss and the pressure.

3.3.1. Calculation of head loss with the Darcy-Weisbach formula. To calculate the formula, some values that have been given in the Building Information Modeling need to be stated. **Figure 3**, **Figure 4**, and **Figure 5** show the pipeline properties and the report in Revit MEP. The data that will be used as input data calculations are marked in these figures. The calculation for section 41 on the DCW 2 system using Darcy-Weisbach Formula [9] are as follows:

$$\Delta p = f_D \frac{\rho V^2 L}{2 D_i} = 0{,}017722 \frac{998{,}9114 \; x \; 1{,}63^2 \; x \; 3{,}84}{2 \; x \; 0{,}0779} = 1158{,}4 \; N/m^2 \tag{1}$$

Domestic Cold Water 2

System Information	
System Classification	Domestic Cold Water
System Type	Domestic Cold Water
System Name	Domestic Cold Water 2
Abbreviation	
Fluid Type	Water
Fluid Temperature	16 °C
Fluid Dynamic Viscosity	0.00112 Pa-s
Fluid Density	998.9114 kg/m³

Figure 3. Data for fluid density.

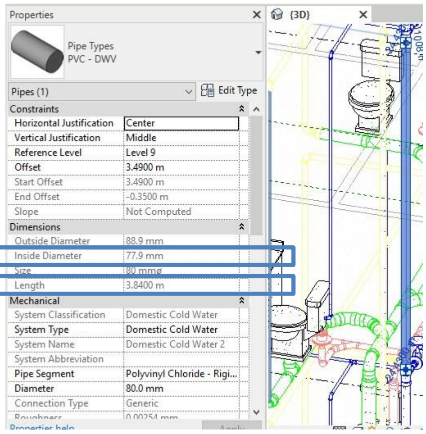

Figure 4. Data for inner diameter, and length.

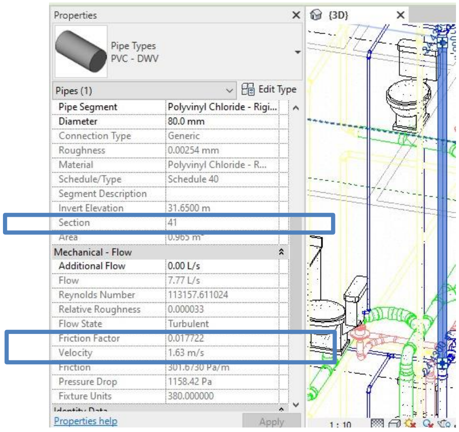

Figure 5. Data for section, Fd and v.

41	Pipe	7.8 L/s	80 mmø	1.6 m/s	-	4 m	-	301.67 Pa/m	1158.4 Pa	1158.4 Pa
	Fittings	7.8 L/s	-	1.6 m/s	1326.5 Pa	-	0	-	0.0 Pa	

Figure 6. Pipe report for section 41.

Based on the manual calculations, the compressive loss in section 41 is 1158.4 N/m^2 or equal to 1158.4 Pa. Compared with Building Information Modeling analysis report shown in **Figure 6**, the pressure provides the same value. It can be proven that the results of the report are valid because they can be proven by using manual calculations using the Darcy - Weisbach equation formula.

3.3.2. Calculation of residual pressure with the Bernoulli formula. In this discussion, the assessment will be carried out on the critical sections according to the report. Figure 7 shows the critical path of Domestic Cold Water 2 system. The critical path is the pipeline that starts from the roof water tank on the roof floor to the pipe at the urinal on the 1st floor. Cumulative Hf at the section should be the same as the static pressure value in the Building Information Modeling properties. Figure 8 is the properties of static pressure for DCW 2 system.

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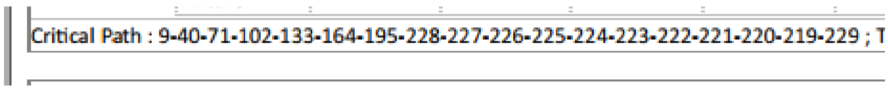

Figure 7. Critical path of Domestic Cold Water 2 system.

Table 3. Residual pressure calculation of Domestic Cold Water 2 system.

Section	Hf		Cumulative	Elevation (m)		ΔH	P		P max control	
	(Pa)	(mH_2O)	(m)	Start	End	(m)	(mH_2O)	(kg/cm²)	(kg/cm²)	OK / NO
9	45.7	0.004	0.0046	36	36	0	0.0045	0.000457	10	OK
40	1158.4	0.115	0.1204	36	32	4	4.1204	0.4120	10	OK
71	1010.1	0.101	0.2214	36	28	8	8.2214	0.8221	10	OK
102	882.2	0.088	0.3096	36	24	12	12.3096	1.2310	10	OK
133	771.0	0.077	0.3867	36	20	16	16.3867	1.6387	10	OK
164	629.4	0.062	0.4497	36	16	20	20.4497	2.0450	10	OK
195	503.8	0.050	0.5001	36	12	24	24.5001	2.4500	10	OK
228	377.0	0.037	0.5378	36	8	28	28.5378	2.8538	10	OK
227	44.7	0.005	0.5422	36	4	32	32.5422	3.2542	10	OK
226	64.7	0.007	0.5487	36	4	32	32.5487	3.2549	10	OK
225	360.4	0.036	0.5847	36	4	32	32.5847	3.2585	10	OK
224	61260.5	6.126	6.7108	36	4	32	38.7108	3.8711	10	OK
223	4616.7	0.462	7.1725	36	4	32	39.1725	3.9172	10	OK
222	16114.4	1.611	8.7839	36	4	32	40.7839	4.0784	10	OK
221	5662.2	0.566	9.3501	36	4	32	41.3501	4.1350	10	OK
220	10744.0	1.074	10.4245	36	4	32	42.4245	4.2425	10	OK
219	12260.1	1.226	11.6505	36	4	32	43.6505	4.365	10	OK
229	142694.4	14.269	25.9198	36	1	35	60.9200	6.0920	10	OK

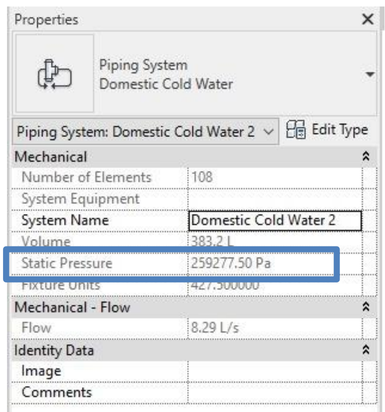

Figure 8. Static pressure of Domestic Cold Water 2 system.

The following is the example of calculation in the section 219. Hf in this section is 12260.1 mH_2O or 12260 Pa. Cumulative pressure at 219 is Hf at section 219 added by cumulative at section 220 or 1.2260 mH_2O added by 10.4245 mH_2O that equals to 11.6505 mH_2O. With start elevation of 36 and end elevation of 4, the height different is 32 m. Applying Bernoulli's formula [10], the remaining pressure in the system is elevation difference added by Hf, that is 32 added by 11.6505, that equals to 43.6506 mH_2O. In kg/cm^2 the pressure is 43.6505 mH_2O divided by 10 or 4.3651 kg/cm^2. The summary of pressure calculations for the entire system are shown in **Table 4.**

Table 4. Residual pressure calculation of Domestic Cold Water 2 system.

Classification System	P (kg/cm²)			P max control	
	min	max	static	(kg/cm²)	OK / NO
Domestic Cold Water 1	0.9972	3.1322	2.4322	10.000	OK
Domestic Cold Water 2	0.4120	6.0920	2.5920	10.000	OK
Domestic Cold Water 3	1.0062	3.1448	2.4445	10.000	OK
Domestic Cold Water 4	1.0221	3.0100	2.3100	10.000	OK
Domestic Cold Water 5	1.0217	2.5630	2.4630	10.000	OK

The analysis shows that the pressure ranges from 0.4120 kg/cm^2 to 6.0920 kg/cm^2 with static pressure ranges from 2.3 kg/cm^2 to 2.6 kg/cm^2. The pressure value is below the maximum permissible pressure value of 10 kg/cm^2. The static pressure value is also quite flat and falls into the standard category for offices, which is between 2.5 to 3.5 kg/cm^2.

3.4. Construction budget

The calculation of the budget plan is intended to determine the total cost required to install the clean water and wastewater system. Construction budget plan is analyzed from unit price and work quantity from automatic calculation by schedule/quantity tool on Revit shown in **Figure 9** as an example. **Table 5** and **Table 6** shows the work items from Building Information Modeling and it cost. The total budget cost for the redesign is IDR 2,481,776,832.00 and for the conventional design is IDR 2,490.140.439.

<Plumbing Fixture Schedule>

A	B	C
Count	Family	Type
50	Urinal - Wall Hung	1" Flush Valve
4	Toilet-Domestic-3D	Toilet-Domestic-3D
69	M_Water Closet - Fl	Public - Flushing Greater than 6.1 Lpf
78	M_Floor Drain - Rou	125 mm Strainer - 50 mm Drain
81	Lavatory - Vanity	30"x18" - Private

Figure 9. Quantity calculation on revit.

The difference is not too big because the two designs are simulated in the same way and it lies only in the dimensions of the pipe used. The redesign uses pipe dimensions that have been readjusted to the standard calculations and values, while the conventional is in accordance with the initial design. Overall, the implementation of BIM is beneficial as it allows the construction can be thoroughly analyzed, simulations performed quickly, and performance demonstrated accurately [11].

Table 5. Budget cost of the redesign.

No.	Work Item	Total Price (Rp)
A	Sanitary Tool	665.687.111
B	Clean Water Pipe	437.871.797
C	Wastewater and Vent Pipe	574.998.806
D	Hydrant	204.829.729
E	Complementary	598.389.389
	Sum	2.481.776.832

Table 6. Budget cost of the conventional design.

No.	Work Item	Total Price (Rp)
A	Sanitary Tool	665.687.111
B	Clean Water Pipe	438.592.889
C	Wastewater and Vent Pipe	582.641.322
D	Hydrant	204.829.729
E	Complementary	598.389.389
	Sum	2.490.140.439

4. Conclusions and suggestions

4.1. Conclusions

The simulation of clean water distribution system along with the sewerage system of the medium rise school building and the resources analysis has been presented. By using BIM technique, the pipelines and fixtures are visible. Therefore, it is possible to evaluate the pipe and accessories placement to avoid crash or stacked component. The application in the study building gives flow velocity that ranges from 0.7 m/s to 6.4 m/s. Analysis of the pressure using Darcy-Weisbach and Bernoulli method shows that the BIM report using Revit MEP as the software is accurate. The pressure ranges from 0.4120 kg/cm^2 to 6.0920 kg/cm^2 with static pressure values ranges from 2.3 kg/cm^2 to 2.6 kg/cm^2. The budget cost has a difference IDR 8.363.608, so the redesign is 0.4% more efficient than the conventional. BIM is recommended for plumbing design as the flow parameter as well as the resources can be easily obtained.

4.2. Suggestions
BIM software looks practical, but accuracy is needed to correct the details that potentially interfere when performing analysis and the reports, so the input data and steps used must be precise and appropriate.

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