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/cm².

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.
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.](image)

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:
\[ \Delta p = f_D \frac{\rho V^2 L}{2 D_i} - 0.017722 \frac{998.9114 \times 1.63^2 \times 3.84}{2 \times 0.0779} = 1158.4 \text{ N/m}^2 \]  

(1)

**Figure 3.** Data for fluid density.

**Figure 4.** Data for inner diameter, and length.  
**Figure 5.** Data for section, Fd and v.

Based on the manual calculations, the compressive loss in section 41 is 1158.4 N/m² 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.
Figure 7. Critical path of Domestic Cold Water 2 system.

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

| Section | Hf (Pa) | Cumulative ΔH (mH₂O) | Elevation (m) | ΔH (mH₂O) | P (kg/cm²) | P max control (kg/cm²) | OK / NO |
|---------|---------|-----------------------|---------------|-----------|------------|------------------------|--------|
| 9       | 45.7    | 0.004                 | 36 36 0       | 0.0045    | 0.000457   | 10 OK                  |
| 40      | 1158.4  | 0.115                 | 36 32 4       | 4.1204    | 0.4120     | 10 OK                  |
| 71      | 1010.1  | 0.101                 | 36 28 8       | 8.2214    | 0.8221     | 10 OK                  |
| 102     | 882.2   | 0.088                 | 36 24 12      | 12.3096   | 1.2310     | 10 OK                  |
| 133     | 771.0   | 0.077                 | 36 20 16      | 16.3867   | 1.6387     | 10 OK                  |
| 164     | 629.4   | 0.062                 | 36 16 20      | 20.4497   | 2.0450     | 10 OK                  |
| 195     | 503.8   | 0.050                 | 36 12 24      | 24.5001   | 2.4500     | 10 OK                  |
| 228     | 377.0   | 0.037                 | 36 8 28       | 28.5378   | 2.8538     | 10 OK                  |
| 227     | 44.7    | 0.005                 | 36 4 32       | 32.5422   | 3.2542     | 10 OK                  |
| 226     | 64.7    | 0.007                 | 36 4 32       | 32.5487   | 3.2549     | 10 OK                  |
| 225     | 360.4   | 0.036                 | 36 4 32       | 32.5847   | 3.2585     | 10 OK                  |
| 224     | 61260.5 | 1.611                 | 36 4 32       | 32.8710   | 3.8711     | 10 OK                  |
| 223     | 4616.7  | 0.462                 | 36 4 32       | 39.1725   | 3.9172     | 10 OK                  |
| 222     | 16114.4 | 1.611                 | 36 4 32       | 40.7839   | 4.0784     | 10 OK                  |
| 221     | 5662.2  | 0.566                 | 36 4 32       | 41.3501   | 4.1350     | 10 OK                  |
| 220     | 10744.0 | 1.074                 | 36 4 32       | 42.4245   | 4.2425     | 10 OK                  |
| 219     | 12260.1 | 1.226                 | 36 4 32       | 43.6505   | 4.3656     | 10 OK                  |
| 229     | 142694.4| 14.269                | 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 mH₂O or 12260 Pa. Cumulative pressure at 219 is Hf at section 219 added by cumulative at section 220 or 1.2260 mH₂O added by 10.4245 mH₂O that equals to 11.6505 mH₂O. 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 mH₂O. In kg/cm² the pressure is 43.6505 mH₂O divided by 10 or 4.3651 kg/cm². 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 (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/cm² to 6.0920 kg/cm² with static pressure ranges from 2.3 kg/cm² to 2.6 kg/cm². The pressure value is below the maximum permissible pressure value of 10 kg/cm². 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/cm².

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.

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/cm² to 6.0920 kg/cm² with static pressure values ranges from 2.3 kg/cm² to 2.6 kg/cm². 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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