Study Of Model Design Changes On Volume And Superposition Using Building Information Modelling – Based Technology

M A T Utomo, A B Putra, Farrel, Novandy
Civil Engineering Department, Faculty of Engineering, Bina Nusantara University
Jakarta, Indonesia 11480

Corresponding author: andi.putra004@binus.ac.id

Abstract. The rapid development of the construction world in Indonesia raises the need for more effective supporting technologies. One example of technology support in the construction world is the application of Building Information Modelling. With this background, the research was made using the implementation of BIM on a project, in order to increase the digitization of the construction world in the future. By using various BIM software such as Allplan engineer, Allplan Bridge, Openroads Bentley, and Synchro. The result is that the alternative bridge design is declared feasible because there are no conflicts in the superposition analysis with the BIM software approach, interviews with experts and BINA MARGA criteria. After the application of the BIM Software, the results show there is an increase of for the volume of concrete material, volume of reinforcement weight, and the cost, this is caused by a more accurate design for the model.

Keywords: Building Information Modelling, Allplan Engineer, Allplan Bridge, Openroads, Synchro.

1. Introduction
With advances in technology, building materials and mathematics, the design process in the construction industry is undergoing rapid changes. BIM has been highlighted by the Architecture, Engineering, and Construction (AEC) industry as a design and management tool that has significant advantages over the building, design and management lifecycle.[1]

A definition of BIM put forward by Van Nederveen is "An information model about a building that consists of complete and sufficient information to support all life cycle processes and can be interpreted directly by computer applications. It consists of information about the building itself and its components, and consists of information about properties such as function, form, materials and processes for the project life cycle.” [2]. Another source also said that Building Information Modelling is a shared knowledge resource for facility information that forms the basis for decision making throughout the life cycle from concept to demolition [3]. BIM itself includes the functions of the three-dimensional model, with the object of the three-dimensional model being 'smart' because it has data that is useful for different stakeholders [4]. The most important part of BIM is the 'information' not the 'model'. This is because this information can be shared and communicated to all parties and the benefits are only created once but can be reused over the entire life cycle of the building [5]. BIM implementation
is not an easy thing because of the large number of people involved in this process so it is not easy to manage and coordinate everyone involved [6].

The purpose for the research in this paper is to: create alternative three-dimensional model based on BIM, Analysing the superposition on a three-dimensional (3D) bridge design model based on the results of interviews with experts; calculate the volume for the early design and compare with the newly created alternative design, and compare the difference of cost between the early design cost and alternative model cost

2. Research Methodology
The Figure 1 and Figure 2 below shows the flowchart of this research.

![Flow Chart of Research](image)
Figure 2. The Use of Software for the Research
The steps of this research are the following: start by collecting secondary data; then use BIM software Allplan Bridge, to model the main structure of the bridge such as abutment, pile cap, bored pile, pier, pierhead, girder, parapet, and slab; at the data collection stage, there are two kinds of data that will be obtained, they are related to the initial design and alternative designs. Includes Shop drawings, scheduling, as well as interviews with experts (required experience 5 – 10 years in the field of roads and bridges); then the model is exported into IFC file. This IFC file will be used for future analysis; then using Openroads Design Connect the superposition of the model was done by placing the bridge modelling, on the original map (interchange) according to the planned coordinates; this superposition analysis greatly contributes to the work in the field, because the results of the superposition analysis can determine whether the ramp 2 bridge work can be carried out or not; this requires importing the previously created bridge IFC file, added with the interchange mapping file; Then, volume analysis can be carried out after the detailed structural modelling is modelled on the Allplan Engineer software. The structural details in question are modelling the reinforcement requirements for each of the main components of the bridge. Such as, modelling of pilecap reinforcement, abutments, piers, pierheads, slabs and parapets; for the detail work of the I-girder structure itself, it is done using coding software, such as Python and Visual Studio code. The use of this software was carried out, due to the inability to create a three-dimensional I-Girder model which was too complicated when done using the allplan engineer and allplan bridge software; Python is a modern software-oriented programming language. Even so, python can be used as a three-dimensional bridge modelling tool in BIM (Allplan Engineer) software. According to the official website allplan.com, the Allplan python interface can offer freeform structural elements to be modelled, and with its use can help make work much more efficient and accurate; while the use of the Synchro software is carried out to visualize the construction work of the ramp 2 bridge. By importing the master schedule file (.mpp) and the bridge modelling file (.ifc); after the modelling work is done, the data will be collected for comparison and analysis using Microsoft Excel software; After comparing the volume and costs, the conclusions from this study can be drawn

3. Data and Analysis

3.1. General
This research used various building information modelling (BIM) software, such as: BIM 360 Docs, Allplan Bridge, Allplan Engineer, Synchro, Open Roads and Microsoft Excel. This research also uses Autodesk AutoCAD, Python, MS Project, and MS Excel as facilitator for the implementation of BIM Software.

The bridge being designed and modelled is the ramp 2 bridge of a project that went across across 37 villages and sub-districts located in Bekasi City, Bekasi Regency, Bogor Regency, Karawang Regency, and Purwakarta Regency as shown in Figure 3.
As for the bridge design criteria, according to the Directorate General, BINA MARGA, can add references to this research in carrying out superposition analysis. There are several aspects that are required by the following conditions:

- **Vertical clearance**
  First, the vertical free space of the bridge above the road is at least 5.1 meters

- **Horizontal clearance**
  Second, according to the US Guide Specification, the minimum horizontal clearance is 2-3 times the design ship length.

### 3.2. Implementation of BIM 4 Dimension for Visualization

The implementation of BIM in this research is to visualize the bridge work of each bridge design. By understanding the number of days needed to do bridge work, visualization can be done well. The visualization is done using the Synchro Pro software. By using this software, the progress of each bridge structure work item in each design can be seen in real time at each stage. It is hoped that by using this software, understanding the construction stages of the many work items on the schedule (Microsoft Project) can be easily understood by visualizing the bridge modelling in each of these designs, as you can see the from the design in table 1.

| No | Alternative Design | Initial Design |
|----|-------------------|----------------|
| 1  | ![Alternative Design](image1) | ![Initial Design](image2) |

*Figure 3. Ramp 2 Bridge Overview. (a) alternative design (b) early design*
3.3. Bridge Structure Superposition Analysis with Openroads Connect
Superposition analysis is one of the most important stages in planning. By placing the bridge structure on the original mapping of the design area, it can be analysed whether the bridge structure has a conflict or not. The analysis is carried out by investigating the bridge structure on the existing interchange road. This analysis can determine whether a planned design is appropriate or not and whether a design can be done in the field or not. With the parameters of the findings of bridge structure clashes on the existing interchange roads of each design, superposition analysis can be carried out.

3.3.1. Parameters of superposition analysis according to Expert
In this superposition analysis, the research is supported by related parameters which were carried out by means of interviews with bridge experts and the engineering division. There are two interviewees with at least 5 to 10 years of experience in the field of roads and bridges.

Through the interviews carried out, it is hoped that the answers from the respondents can form an input on research that discusses further about superposition analysis.

The interviews were conducted face-to-face with respondents and via online means, depending on the conditions at the time the research was conducted. The following are the results of the interview from several respondents. Table 2 below are the results of the interviews.

Table 2. Results of interviews with respondents

| No | Condition                          |
|----|------------------------------------|
| 1  | Clashes with buildings/offices     |
| 2  | Clashes with residents’ houses     |
| 3  | Vertical clearing does not meet    |
| 4  | The span of the bridge does not meet the road design |
Respondent 2

| No | Condition                                      |
|----|-----------------------------------------------|
| 1  | Clashes with existing buildings or roads      |
| 2  | Clashes with residents' houses                |
| 3  | The dimensions of the pillars are too flat in the water area |
| 4  | Land acquisition problem                      |

Respondent 3

| No | Stakeholder                             | Contractor        | Environment                  |
|----|-----------------------------------------|-------------------|------------------------------|
| 1  | Owner                                   | Easiest working method | Environmental Impact Analysis Issues |
| 2  | Contractor                               | Availability of fabrication materials | Air or noise pollution |
| 3  | Environment                              | Clash with buildings | Land problems               |
| 4  | Durable design                           | -                 | -                            |

Table 2 above, shows the response of respondent 1 and 2 that says those condition they listed are the causes of why the bridge design changes. According to the third respondent, changes in the design of a bridge design can be divided by three stakeholder aspects. Where each stakeholder has matters concerning their respective interests in a project. That way, changes to a bridge design can be influenced by each individual interest of the parties involved in a project.

3.3.2. Results of preliminary design bridge analysis

Based on the results of the integration of three-dimensional bridge modelling carried out in the Openroads software, it shows that there are design errors that occur in the structure. There are 2 factors that cause bridge structure design errors in the initial design. First, there was a clash between the bridge pillars and the existing road underneath. With the position of the bridge pillar in the middle of the existing road below, it is certain that the design cannot be done in the field because it will interfere with the traffic of motorists on the lane. The second one, with the long design of the bridge, the position of the abutment structure cannot reach the existing road on its own path. These 2 factors can be seen on Figure 4 and Figure 5. The difference in the position of the bridge abutment with the track embankment soil can result in construction failure, which is a condition of a building/infrastructure that is not functioning, either in whole or in part, from a technical point of view, benefits, work safety and general safety as the fault of the service provider or service user after the final submission of the construction work [7].

![Figure 4](image1.png)

**Figure 4.** The position of the abutment of the bridge cannot reach the existing road

![Figure 5](image2.png)

**Figure 5.** The bridge pillar collides with the existing road below it
3.3.3. Result of analysis of alternative design bridge
After the initial design superposition analysis has been carried out, it can be concluded that the design cannot be used. So, an alternative design is needed for the ramp 2 bridge. When viewed from the cause of the initial design error of the bridge, it is the bridge span and the position of the pillars. So, the solution for the design of the bridge is to change the span of the bridge and the position of the bridge pillars. With the original bridge length is 61.4 meters, changed to 94 meters. With the change in the span of the bridge, the position of the alternative design bridge abutment can reach the existing road. Then for the position of the pillars, the alternative design changes the position of the bridge pillars to the outer side of the existing road underneath. By changing the position of the pillars, clashes between the pillars and the existing road below can be avoided.

After the two factors causing the design error can be overcome, the next step is to perform a superposition analysis on alternative designs as you can see on Figure 6 and Figure 7. With the aim of cross-checking the bridge design into the interchange mapping. With the hope that the design will not clash with existing roads.

![Figure 6](image)

**Figure 6.** The position of the bridge abutment can reach the existing road

![Figure 7](image)

**Figure 7.** Alternative design bridge pillar position

3.3.4. Design results comparison using the results of interviews with experts and BINA MARGA criteria
After the data validation collection process is carried out to support the superposition analysis process such as interviews with experts and others. The next process is to analyse the results of the interview with the modelling carried out by BIM. With the help of software Openroads and Allplan Software. Below in Table 3 and 4 is the results:

| No | Interview result         | Initial design | Alternative design |
|----|--------------------------|----------------|--------------------|
| 1  | Clashing with building   | No             | No                 |
| 2  | Clashing with road existing | Yes            | No                 |
| 3  | The span of the bridge does not meet the road design | Yes           | No                 |
Table 4. Comparison based on BINA MARGA criteria

| No | Criteria         | Term       | Alternative design | Description |
|----|------------------|------------|--------------------|-------------|
| 1  | Vertical Clearance | 5,1 meters  | 6,98 meters        | Fulfilled   |
| 2  | Pier dimension   | 5-25 meters | 5,292 meters       | Fulfilled   |

With the results of the BIM comparison based on the Bina Marga criteria and the results of interviews, it can be concluded that the design can be declared feasible. The process of superposition analysis results is supported by BIM software to obtain solutions for design errors that occur.

3.4. Quantity Take-off Analysis

This segment will explain the comparative analysis of the total volume of concrete and reinforcement. After collecting data regarding the volume of concrete and also the weight of reinforcement for each bridge structure in the initial design and alternative designs. Then the next step is to compare the two data, so it can be concluded that there is an addition or subtraction of the quantity of material volume that has been calculated previously in this change in the design of the ramp 2 bridge.

For the comparison of the concrete volume between the initial design ramp 2 bridge and also this final design, it is the cumulative concrete volume of the abutment, pier and slab concrete volumes in each design. The following results in Table 5 is a cumulative table for the ratio of the concrete volume of the ramp 2 bridge, with Figure 8 is a direct comparison between the two.

Table 5. Cumulative volume of initial design concrete and alternative designs

|              | Initial design (m³) | Alternative design (m³) |
|--------------|---------------------|-------------------------|
| Abutment     | 771.64              | 699.96                  |
| Pier         | 400.31              | 1068.71                 |
| Slab         | 233.58              | 411.64                  |
| Total        | 1405.53             | 2180.31                 |

Figure 8. Graph of concrete volume comparison between bridge designs

The same thing was done to compare the weight of the ramp 2 bridge reinforcement in the initial design and the alternative design. By doing cumulative reinforcement weight on each main structure of the bridge such as abutments, piers, and slabs. The following data in Table 6 is the total weight of the ramp 2 bridge reinforcement in the initial design and alternative designs, with Figure 9 is the visual comparison.
Table 6. Cumulative weight of initial design reinforcement and alternative designs

| Element   | Initial design (kg) | Alternative design (kg) |
|-----------|---------------------|-------------------------|
| Abutment  | 70002               | 74696                   |
| Pier      | 40861               | 139610                  |
| Slab      | 26092               | 40109                   |
| Total     | 136955.66           | 254415.5                |

Figure 9. Reinforcement comparison graph between bridge designs

3.5. Comparison of Conventional Material Volume Calculation with BIM

It was said that in general, paper-based 2D systems are often time-consuming, inaccurate, incomplete, inconsistent and contain many errors [8]. The need for consistency of documents produced by a 2D system cannot be met, because document sets, such as floor plans, views, and pieces have different contents. Even though these documents are related [9]. It was also said that there are four weakness of 2D paper based which are: incorrect use of symbol and lines that caused misunderstanding, difficulty to make sure the truth of a document, the true nature of interconnected documents, and difficulty in making sure the completeness of documents [10]. After calculating the volume using the help of the BIM implementation, the calculation of the material volume is also calculated in the conventional way. By doing this conventional calculation, as a comparison with the BIM volume output later. The following is a comparison of the results of the calculation of the volume of concrete material using the conventional method using BIM.

3.5.1. Volume Abutment

The following Table 7 is the result of the comparison of the volume of concrete material from BIM calculations and conventional calculations based on the shop drawing. The conventional calculation was done using MS Excel based on the shop drawing gathered during data collection.

Table 7. Comparison of volumes with conventional approaches and BIM

| Element | BIM Calculation | Conventional Calculation |
|---------|-----------------|--------------------------|
|         | Initial design  | Alternative design       | Initial design  | Alternative design |
| Abutment| 771.64          | 699.96                   | 757.75          | 676.38             |
| Pier    | 771.64          | 699.96                   | 757.75          | 676.38             |
| Slab    | 233.58          | 411.64                   | 250.44          | 456.33             |

Between the calculation, the difference is about 5%.
3.6. Cost Change Analysis

3.6.1. Structure concrete class B-1-1a
Based on the results of the analysis of the unit prices of materials and work based on PU regulations and using a reference to the Journal book to get the unit price. So, the figure obtained for this work per unit cubic meter (m$^3$) is Rp. 1,411,642.00. With a daily production capacity of 7 hours is 75 m$^3$. The following Table 8 is a description of the calculation.

| No | Component of Work          | Unit | Volume | Unit price (Rp) | Total (Rp)   |
|----|----------------------------|------|--------|-----------------|--------------|
| A  | Manpower                   |      |        |                 |              |
|    | Worker                     | Hour | 1.62651| 19.700.00      | 32,042.17    |
|    | Handyman                   | Hour | 0.36145| 14.800.00      | 5,349.40     |
|    | Foreman                    | Hour | 0.18072| 19.800.00      | 3,578.31     |
|    | Operator                   | Hour | 21.0000| 23.600.00      | 495,600.00   |
|    | Operator assistant         | Hour | 21.0000| 16.700.00      | 350,700.00   |
|    | Sub Total                  |      |        |                 | 887,269.88   |
| B  | Material                   |      |        |                 |              |
|    | Concrete class B-1         | m$^3$| 1.05000| 850.689.00     | 66,991,758.75|
|    | Formwork Type 1            | m$^2$| 3.50000| 452.672.00     | 27,160,320.00|
|    | Sub Total                  |      |        |                 | 94,152,078.75|
| C  | Equipment                  |      |        |                 |              |
|    | Concrete Vibrator          | Hour | 14.0000| 1.411.79       | 19,765.10    |
|    | Concrete Pump              | Hour | 7.00000| 159.169.17     | 1,114,184.17 |
|    | Device                     | Ls   | 1.00000| 75.000.00      | 75,000.00    |
|    | Sub Total                  |      |        |                 | 1,208,949.27 |
| D  | Total Price of Labor, Materials and Equipment | (D=A+B+C) | 96,248,297.90 |
| E  | Overhead & Profit          |      |        |                 | 9.624,829.79 |
| F  | Total                      |      |        | (D+E) For 75m$^3$ | 105,873,127.69 |
| H  | Grand Total Unit Price      |      |        | F/75            | 1,411,642.00 |

Once the preceding analysis is done for all concrete class along with the reinforcements, results are then compared for each material volume and BIM outputs of initial design and alternative design of the structure, as seen on Table 9.

| Item                        | Unit | Volume initial design | Volume alternative design | Unit Price (Rp) | Total Cost Initial Design (Rp) | Total Cost Alternative Design (Rp) |
|-----------------------------|------|-----------------------|---------------------------|-----------------|-------------------------------|-----------------------------------|
| Structure concrete class B-1-1a | m$^3$ | 182.581               | 294.177                   | 1.411.642     | 257.739.008                   | 415.272.608.63                    |
| Structure concrete class B-1-1f | m$^3$ | 28.146                | 61.248                    | 2.382.217     | 67.049.879.68                 | 145.906.026.82                    |
| Structure concrete class B-1-3 | m$^3$ | 63.14                 | 63.14                     | 2.705.078     | 170.798.642.9                 | 170.798.642.9                     |
| Structure concrete class B-1-1f | m$^3$ | 533.25                | 942.276                   | 1.536.127     | 819.139.722.7                 | 1.447.455.605                     |
Based on the data obtained in the table above, the costs for the construction of the ramp 2 bridge in the initial design and alternative designs can be found. The detailed calculations from the table above can be seen in the attachment sheet. For the initial design it costs Rp. 5,312,677,419, while the cost required for the alternative design is Rp. 8,713,945,118. From these data it can be concluded that the cost has increased due to this design change by 64.02%.

3.7. Comparison of Unit Price Analysis Results based on ministerial regulation number 28 of 2016
The following is a comparison of the Unit Price Analysis based on ministerial regulation number 28 of 2016 against price from the actual data, as seen on Table 10.

| Item | Unit | Volume initial design | Volume alternative design | Unit Price (Rp) | Total Cost Initial Design (Rp) | Total Cost Alternative Design (Rp) |
|------|------|-----------------------|--------------------------|----------------|-------------------------------|----------------------------------|
| B-1-2 | Structure concrete class B-1-6 | m³ | 301.66 | 248.96 | 1.394.342 | 402.617.207.7 | 347.135.384.32 |
| C-1 | Structure concrete class C-1 | m³ | 288.305 | 486.853 | 1.807.762 | 592.186.823.4 | 880.114.352.9 |
| C-2 | Structure concrete class C-2 | m³ | 20.593 | 29.34 | 984.179 | 20.267.198.15 | 28.875.811.86 |
| E | Reinforcement BJTD-40 | kg | 136.955 | 254415.5 | 17.783 | 2.435.482.501 | 4.524.270.836.5 |
| PC-I Girder nominal 30m to 32m, H-1,7m | unit | 12 | 12 | 40.202.65 | 482.431.872 | 482.431.872 |

| Total | 5.312.677.419 | 8.713.945.118 |

| Item | Unit | Unit price PUPR (Rp) | Unit price from project (Rp) |
|------|------|----------------------|-----------------------------|
| Structure concrete class B-1-1a | m³ | 1.411.642 | 1.630.729 |
| Structure concrete class B-1-3 | m³ | 2.705.078 | 2.686.154 |
| Structure concrete class B-1-1f | m³ | 2.382.217 | 2.453.563 |
| Structure concrete class B-1-2 | m³ | 1.536.127 | 1.896.980 |
| Structure concrete class B-1-6 | m³ | 2.313.031 | 2.064.973 |
| Structure concrete class C-1 | m³ | 1.394.342 | 1.127.745 |
| Structure concrete class C-2 | m³ | 1.807.762 | 1.270.091 |
| Structure concrete class E | m³ | 984.179 | 1.027.061 |
| Reinforcement BJTD-40 | kg | 17.783 | 11.991 |
| PC-I Girder nominal 30m to 32m, H-1,7m | Pcs | 40.202.656.12 | 42.793.665 |
The price difference contained in each work item may occur because the material prices used are not the same because the difference in the developer and the wage price that follows the area of origin also affects the difference in the figures.

4. Conclusion

4.1. Conclusion
Based on the results of the research that has been done, the following conclusions can be drawn:
1. Based on the modelling of the 3D model using BIM and the Integration of three-dimensional modeling it can be concluded that it provides many and additional information about the modeling that is made, such as preventing clashes because it can be super positioned on BIM, arrange construction time planning to financing planning;
2. Using superposition analysis using BIM and from the parameter gathered from the interview with experts, no clashes were detected on the existing road below the structure. Hence, the structure in the position of the coordinates is declared safe, and other bad risks can be avoided before the construction period begins.
3. Changes in the main structural specifications of the bridge due to design changes are the addition of the number of pillars and the length of the bridge span. The initial design had one pillar, while the alternative design had two. Then, the bridge span in the initial design has a length of 61.4 meters and 94 meters for alternative designs. So, it can be concluded that the design changes affect the number of bridge pillars. That is, increased by 1 pillar for alternative designs, and the bridge span is increased by 32.4 m. Thus, the ramp 2 bridge structure in this alternative design can be declared feasible or safe to work on.
4. There are changes to the volume of material in the concrete structural component, of which the alternate design is higher than the initial design. This shows that having an accurate design from the initial planning phase is important to make sure that the project doesn’t add any high cost, and longer schedule. The concrete structural components said before are 55.12% more than the initial design and has a volume of reinforcement weight of 85.76%, with the change for cost of this ramp 2 bridge, there is a difference of Rp. 3,401,267,699.

4.2. Suggestion
In this study, several notes were obtained that can be used as input for further research, including:
1. For bridge modeling based on building information modeling, it is recommended not only to focus on concrete and reinforcement. Can include more detailed materials such as, prestressed steel, anchors, pipes, and others.
2. The application of building information modeling software specifically for superposition needs to be done, so that design errors can be found at the beginning of planning.

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