BIM Implementation On Design Phase Toward Low Embodied Energy Apartment: Comparative Study On 3 Alternatives Architectural Wall Materials

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Abstract. One of the efforts to decrease environmental impact due to construction activities is by reducing Embodied Energy in design phase. In the design phase, EE can be associated with the usage of construction materials. On the other hand, the Building Information Modeling (BIM) can be an alternative approach in improving the effectiveness and efficiency material usage. The aim of this paper is to explain how to implement BIM in calculating and reducing the value of EE. The research methodology is a mix qualitative-quantitative method that conducted by using a case study and utilized BIM model of low-cost public apartment. The EE calculation is based on material properties of the BIM model and it also depends on the unit price analysis of each construction works. Furthermore, the Life Cycle Analysis (LCA) method is used to calculate the EE of materials properties value. In order to find the best EE reduction value, a comparison analysis is conducted that it compared the use of conventional materials (as alternative 1) and 2 types of substitution materials there are prefabricated wall panels and concrete masonry unit. Thus, the EE reduction value can be seen and the best low EE material will be used as a reference in the next phase of the construction process.

Keywords: BIM, Design Phase, Apartment, Embodied Energy, LCA.

1. Introduction

Disruption of Information Technology is increasingly developing in the world and in Indonesia, then spread to many industrial fields so that now a phenomenon is starting to emerge, namely the industrial revolution 4.0. Industry 4.0 requires a workforce who has skills in digital literacy, technological literacy, and human literacy [1]. The construction industry was also affected so that the term of Construction Industry 4.0 is now developed. Building Information Modeling (BIM) has been widely recognized as an approach used in the current era of construction industry disruption 4.0 to solve problems. One thing that can be done by BIM is to integrate the design process with the calculation of building embodied energy which is the basis for calculating the embodied carbon in buildings. The use of BIM will make it easier and properly for construction industry stakeholders to achieve energy efficiency so that it will achieve the goals of sustainable construction industry in this industrial era 4.0.

Building Information Modeling (BIM) is a concept of working using digital 3D modeling which contains various kinds of information related to buildings that serve for visualization, simulation, and coordination that can help owners and service providers to plan, build, and manage buildings [2]. In a specific definition, BIM is a concept for modeling various kinds of information related to buildings so that one information with other information is integrated with each other. BIM provides a system of integrity for the whole design and construction and are able to digitally coordinate the process from the
pre-construction to the construction stage [3]. In principle, BIM can work and integrate in all phases of the building life cycle, which is described in the graphic below:

![Figure 1: Integration of the whole level of the construction life cycle](image)

Reference: Bormann, 2018 [4]

In addition, the function of BIM is to provide accurate design, dense information, less construction waste, less risk management, being able to manage material management, and being able to optimize building performance, so that this function will be have a great benefit to building stakeholders [5]. BIM is also able to connect stakeholders, including building owners, architects and engineers, contractors, and building management so that they can carry out a series of construction activities properly and with integrity.

One of the most important processes in a building's life cycle is the design phase, because it is able to provide decisions and strategies about sustainable buildings [6]. So it requires an appropriate strategy in order to achieve these goals. BIM can be a solution. BIM can be an added aspect in sustainable design because it can:

- Reducing material requirements and using recycled materials
- Make an analysis of daylighting lighting
- Conduct building shape analysis and optimize the building envelope
- Make the right selection of alternative building design which has the lowest energy costs
- Reducing water use in buildings
- Reducing energy use and analyzing the use of renewable energy such as solar energy

Thus, the integration of BIM and Embodied energy in the design phase can be carried out. Embodied energy is the energy that is contained as a result of the manufacturing process [9]. Embodied energy is one of the most important parts of energy that can determine the overall energy footprint of the building’s life cycle. Embodied energy analysis at the design stage is a crucial stage. According to Wahyuni, 2016 [10] the calculation of embodied energy in the house design planning process can be an energy mitigation process that is able to reduce the overall amount of embodied energy material so that it can make it a strategy in planning sustainable home development. Calculation of building embodied energy can be done by looking at the material data stored in the BIM so that the material data can be used as the basis for calculating the building's EE in the design phase. BIM contains a lot of material data and in the process of implementing it, replacing material data to find the best alternative in EE calculations. The process is very fast so it can save time designing a building.

The process that can be carried out in the implementation of BIM to calculate Embodied Energy is to create a building component schedule table which includes Unit Weight of materials, component volume, entering EE coefficient data contained in ICE (Inventory of Carbon and Energy) [11] and Total Weight data. These variables will be needed to analyze the overall Embodied Energy calculation for each building component. According to Schwartz, 2016 [12] research on BIM and embodied energy is developing towards research on the collection of material EE inventory data that is entered into BIM data to facilitate EE calculations. In addition, BIM and EE research is also developing towards semantic
BIM, which is to enter EE parameters into the BIM programming language to then automatically calculate the EE value. This method is known as using a BIM add-in or a BIM plugin.

The vertical housing or apartment building is one of the buildings that needs attention in the issue of Embodied Energy. The development of the housing industry, especially vertical housing or medium-sized apartments or flats, is increasingly developing, especially in big cities in Indonesia, in order to become one of the solutions to solving the backlog of housing needs for Indonesians which reached 13.5 million units in 2015 according to the Ministry of PUPR. Meanwhile, the Ministry of Public Works and Housing (PUPR) can only realize it is 43,170 units of apartments.

If the development of vertical housing is increasingly encouraged and simultaneously, the carbon emissions caused by construction activity will have a significant environmental impact. For this reason, it is necessary to have control over the construction of vertical housing in order to minimize environmental impacts that will occur in the future. In addition, the process of building an apartment is a long development process because it is a high rise building with a high level of complexity so it would be the right step if you use BIM in the planning process. The benefit provided is that the planning time process will be faster because it can carry out various kinds of design alternatives while being able to process design documentation ranging from 3D to construction drawings which were originally carried out in a long coordination process between architect and drafter, can project the efficiency of material and energy use, and can reduce construction costs. Reduction in terms of coordination will increase work productivity [13].

This paper aims to show how to apply BIM in analyzing embodied energy calculations. In this case, a calculation simulation was performed in the case of a 5-storey vertical housing with 3 alternative material uses. The focus of the material discussed is on the architectural component, namely the wall. The material used for the first alternative design uses conventional brick wall material and for the material used in the second alternative is a substitution material, namely prefabricated panel walls using alternative materials, namely cement composite material and recycled plastic. Meanwhile, the third alternative material uses lightweight concrete brick material. The application of BIM to assess embodied energy in Indonesia has not developed much. It is hoped that this research will provide a stimulus and contribution to further research so that it can be developed in a more adherent direction, especially in the design of housing designs that are low in embodied energy.

2. Method
The method in this research is a mixed method Qualitative-Quantitative which is done by:

1. Using a design model using the existing BIM model. The model used is a model from the results of previous studies [14] that have done the design exploration with the concept of low carbon buildings. The component for which the EE value is calculated is the wall material component only.

2. Material data used are 3 alternative material data, namely the common brick 9 cm as the main material; material Concrete PCP (concrete panel which is combined with plastic polyethylene recycled materials) panels 7 cm and concrete masonry unit 10 cm as an alternative material for substitution, however the model and building area were not changed.

3. Make a material schedule sheet for the wall components on the three alternatives to see the volume and area values that are the basis for the analysis of embodied energy calculations. Then the total volume of the walls used is then summarized.

4. Enter the EE coefficient and unit weight data into the calculation schedule. Embodied energy calculation is done by referring to the basic energy coefficient which is found in the ICE (Inventory of Carbon and Energy) table.

5. Conduct a comparative analysis between the first alternative design, the second and the third alternative that uses substitution materials to then see the difference in embodied energy materials and the decrease of embodied energy materials.

6. See the EE reduction value of the 2 substitution materials
The following flowchart is the workflow of the method used in this study:

![Flowchart](image)

**Figure 2.** Flowchart method that is conducted in this research

3. **Discussion**

The first step to do the research is make the experiment on the wall material on the BIM model that has been designed from previous research [14]. This BIM model was chosen because it was the result of design exploration of a vertical housing design for 5 floors with an area per unit of 30 m2 with a low carbon housing concept that uses recycled material, namely using PCP (Plastic Concrete Panel) wall material which is a mixture of recycled concrete and plastic made from PET (Polyethylene). This material is the result of the development of previous research [15]. In addition, this vertical housing design uses the single-loaded passive design principle with a cross-ventilation system and natural lighting which has an indication of energy-efficient buildings. Previous research has not conducted an analysis of EE values and has not seen the EE value contained if the conventional wall material used is red brick. This study will test the comparison of the EE value in the model with 3 alternative wall materials, namely 9 cm common brick material, and 2 substitution materials, namely 7 cm PCP material and 10 cm unit masonry concrete material. The picture below describes the design perspective and 3 alternatives materials in this research:
Each material has a different specific unit weight and a different EE coefficient value. The specific unit weight (that is contained in BIM material data) and the EE coefficient value (found in ICE table data) are the values that affect the total EE value of the building material. The comparison of the unit weight values for the three materials is as follows:

| No | Wall Component Type                      | Unit Weight (kN/m³) | EE Coefficient (MJ/Kg) |
|----|-----------------------------------------|---------------------|-----------------------|
| 1  | Common Brick 9 cm                        | 19.1                | 9.58                  |
| 2  | Wall Prefabricated Concrete Panel PCP 7 cm| 23.6                | 2.6                   |
| 3  | Concrete Masonry Unit 10 cm              | 6.4                 | 1.95                  |

The unit weight and EE coefficient values mentioned above are then entered into the Schedule-Material Take-off table, which is the next step in the analysis of EE calculations. Apart from the aforementioned data, the data from the components included in the schedule are volume, area, and material description data as markers of the three alternative materials used. The Schedule-Material Take-off steps carried out on the three alternative wall materials are described in the chart below:
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Figure 4. Material-Take off Schedule step of the 3 materials

From the schedule-material take-off step, the EE total is then conducted and it used to make a comparative analysis of the overall calculation of the EE value. The results of the comparison of the overall EE value of each material are described in the table below:

**Table 2. Comparison table of the overall EE value of each material**

| No | Wall Type       | Component                | Area (m2) | Volume (m3) | Unit Weight (kN/m3) | EE Coefficient (MJ/Kg) | EE Total (MJ)  |
|----|-----------------|--------------------------|-----------|-------------|--------------------|------------------------|----------------|
| 1  | Common Brick 9 cm | 1298                     | 116.03    | 19.1        | 9.58               |                        | 2,168,147.14    |
| 2  | Prefabricated Concrete Panel PCP 7 cm | 1302                     | 90.31     | 23.6        | 2.6                |                        | 564,879.71      |
| 3  | Concrete Masonry Unit 10 cm | 1298                     | 128.72    | 6.4         | 1.95               |                        | 163,234.80      |

The results of the table analysis will be the basis of a distribution graphic in which compare each EE total value all of the alternative wall (graphic below). It shows that the EE value of the 9 cm common brick wall material is the highest with an EE value of 2,168,147.14 MJ. While the lowest value is concrete masonry unit 10 cm with EE value 163,234.80 MJ.

**Figure 5. Distribution analysis of the EE total comparison for each materials**
The comparison of volume and area values, the wall volume of Prefabricated Concrete Panel PCP 7 cm is the largest, which is 1302 m2 but has the smallest component volume, which is 90.31 m3. The comparison of the distribution of the volume and area ratio of each wall is described in the distribution graphic below:

![Wall Volume (m3) Total Comparison](image1)

![Wall Area Total (m2) Comparison](image2)

**Figure 6.** wall volume and area comparison

In other hand, the comparison of EE coefficient and unit weight value, the 10 cm unit masonry concrete wall component is the smallest value of the three alternative walls used as experimental simulation material, which is 6.4 kN/m3 and 1.95 MJ/Kg. This result shows that the EE Coefficient value and unit weight value have a greatly impact to the EE total material value. The comparison of the EE coefficient value and the unit weight is described in the chart below:

![Unit Weight Comparison](image3)

![EE Coefficient (MJ/Kg) Comparison](image4)

**Figure 7.** Distribution graphic of the comparison of the EE coefficient value and the unit weight

After performing all distribution comparison analysis, an analysis is carried out to calculate the decrease in EE total value between the conventional red brick material, 7 cm PCP prefabricated concrete substitution material, and 10 cm concrete masonry unit. The calculation for the decline in the value of EE is described in the table below.
Table 3. Percentage of EE reduction for each substitution material

| No | Substitution Materials                  | Percentage of EE Reduction |
|----|----------------------------------------|---------------------------|
| 1  | Prefabricated Concrete Panel PCP 7 cm  | 74%                       |
| 2  | Concrete Masonry Unit 10 cm            | 92%                       |

The result of the largest decrease in EE value is in the concrete masonry unit of 10 cm, which is up to 92%. Meanwhile, the 7 cm PCP prefabricated concrete material has an EE reduction value of 74%. Thus, the use of substitution material indicates that it is able to reduce the EE value by a significant value.

4. Conclusion

The use of BIM which is used to assess the embodied energy in apartment buildings during the design phase is able to make several alternative uses of materials and makes it easier to discover the lowest value of the building's embodied energy so that it will support the concept of a sustainable building in the future. The value of embodied energy reduction can also be seen from the substitution material that is used for substituting conventional materials that are commonly used. Data from the analysis of the use of BIM can also be presented attractively in the form of tables and graphs so that it can increase the validity level of the building design that has been made. However, this study still has some shortcomings, namely the EE Coefficient data used still uses data from the ICE table which is not yet in context with local material. The material properties data used are also the material properties data from the BIM software which may not necessarily match the local conditions in Indonesia. For this reason, it is hoped that further research on the collection of EE inventory and material properties is suitable for the Indonesian local context so that the development of research on BIM implementation will be better in the future.

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