Development of the Life Cycle Analysis (LCA) Method in calculating Embodied Energy Materials on Residential Buildings

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Abstract. One of the benefits of BIM towards a sustainable design is it can make a design system that will calculate the building energy in aim to give alternatives on energy-efficient design. BIM can be utilized to integrate the calculation of Embodied Energy (EE) Building Materials with the Life Cycle Analysis (LCA) method. EE calculation could be easier for architects; hence, the architects can understand the impact of carbon emissions caused by construction activities during the design process. This paper aims to provide an overview of the use of BIM in calculating the EE value of the designed building material on the apartment project. Since the development and construction of flats and apartments, especially in Indonesia, are growing fast, this will give highly environmental impact if it is not properly controlled. The results showed that the BIM implementation in calculating the EE value could be done. Collaboration with other platforms can also be done to make the final calculation, and it will be displayed in attractive data visualizations. The percentage comparison of the embodied energy value in all of the building component materials can also be seen in the results of the analysis. In this case, the highest embodied energy percentage is the structural component, which is 53.16%. It is hoped that the development of this calculation method will contribute to the development of LCA so that EE can be easy to be calculated and have a good impact on the construction industry in the future, especially in Indonesia.

Keywords: BIM, Design Phase, Embodied Energy, LCA, Residential Building.

1. Introduction
The era of information technology disruption has penetrated the industrial sector nowadays and is known as Industry 4.0. If industry 3.0 is marked by the use and mass adjustment as well as the flexibility of automation and robot-based manufacturing, the next industry 4.0 is marked by the presence of cyber-physics and manufacturing collaboration [1] [2]. Industry 4.0 is used in three interrelated factors: 1) digitalization and economic interaction with simple techniques towards economic networks with complex techniques; 2) digitalizing products and services; and 3) new market models [3]. In facing the industrial phenomenon 4.0, the construction sector needs to take steps for changing. At this stage, what needs to be done in the construction business is to increase efficiency, reduce production costs and improve the production process; one of which can be done to achieve these things is by doing the digitization process.
A terminology that stands out in the construction industry 4.0, especially in the process of digitizing construction products, is Building Information Modeling (BIM). The use of BIM is starting to expand among construction industry players, both building planners/architects, and contractors. Building Information Modeling (BIM) is a concept or way 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 [4].

![Building Information Modeling (BIM)](image)

**Figure 1** integration of the whole process of the construction life cycle  
*Reference: Eastman, 2011 [5]*

BIM can integrate into the entire building life cycle, from the design process to construction to post-construction. One thing that can be integrated with BIM is the calculation of Embodied Energy in buildings in the building design phase. Embodied energy is one of the bases for calculating carbon emissions in the construction sector. This is important because embodied energy in construction activities can be one of the causes of global warming. Huang, 2018 [6] states that developing countries in the construction sector account for nearly 60% of total global CO2 emissions. The intensity of direct and indirect carbon emissions in the construction sector in developing countries is greater than the value of carbon emissions in developed countries. Indonesia is a developing country that also has a developing construction industry, especially in the vertical housing industry.

![Carbon emissions in the construction sector](image)

**Figure 2.** Carbon emissions in the construction sector. Developing countries produce more carbon emissions  
*Reference: Huang, 2018 [6]*

From the energy efficiency perspective, the construction industry is still one of the areas with large energy consumption. Also recorded in BPS Indonesia (Statistics Organization of Indonesia) [7], the 2014-2018 Energy Balance data stated industrial, and construction energy use was the highest in 2018. The construction sector is one of the main contributors to national development but has a great potential for environmental degradation. For this reason, efforts are needed to be able to control environmental impacts because basically, the operation of buildings as mandated in the Building Law Number 28 of 2002, must be carried out by considering environmental sustainability [8]. One way to control this is by
mitigating the embodied energy in the design phase by calculating the amount of embodied energy contained in the materials used in the building design, especially in this case, the residential building, namely vertical housing.

Embodied Energy in buildings is the amount of energy used when producing building materials [8]. The added energy goes through various stages, including the extraction of raw materials; raw material processing; manufacture of building materials and products; building construction; maintenance; improvement; demolition; and disposal [9]. Many previous studies have proven that embodied energy is able to explain a significant amount of energy contained in a building's life cycle.

The calculation of embodied energy is included in an analytical mechanism called the Life Cycle Analysis. The basis for calculating the embodied energy used is usually a single material unit model that requires similarity in the calculation unit according to the EE unit (MJ / Kg) [10]. The single material unit is then translated by calculating the material unit analysis which is derived from the unit price analysis commonly used in Indonesia to calculate building coefficients and volumes. The volume of this building material will determine the overall EE calculation results. In addition, the EE value is also influenced by the unit weight material and the inventory EE coefficient. The calculation of the EE coefficient for this material refers to the Carbon and Energy inventory data [11]. The calculation of the EE value is obtained from the calculation with the formula below:

\[ EE \text{ (MJ)} = \text{Volume Material (m}^3) \times \text{Unit Weight Material (Kg/m}^3) \times \text{EE Coef. (MJ/Kg)} \]

In calculating EE, researchers must be observant in seeing the unit value in order to get the right results. For that, we need a method that can quickly regulate and carry out an inventory of the values contained in these building materials, namely BIM. BIM stores material properties data that can be used in EE calculations. Material property data can also be arranged into a data table with changeable variables. The data is directly connected to the BIM model created. Research on BIM and EE analysis has begun to develop a lot, including the previous research [12], which tested three alternative models to see their EE value in the design phase. The parameter values entered into the BIM model are especially for building material components for processing data, among others: specific gravity, material transportation energy, transportation costs, material purchase costs, EE coefficient / EE per unit weight, and energy used to extract and process materials.

Another research [13] also did similar research that tested two alternative building models to see the comparisons of energy calculation data for each building material component by entering material energy data into the model's BIM material parameters. In BIM, energy data processing can be done in 2 ways: 1) with the BIM collaboration method and statistical software such as Excel; 2) using the semantic programming language BIM. As in another previous research [14] who developed the LCA calculation method by creating a BIM programming language that is implemented in the BIM software plugin. The aim is to be able to enter as many data properties related to the embodied energy material as possible and to be able to produce data analysis directly without entering and processing data manually. The two methods are still being developed in research so that the field of research on BIM and LCA, especially related to embodied energy, will continue to develop.

2. Method

This paper is to explain how to use the BIM method in calculating and analyzing Embodied Energy calculations. The method used is a mixed-method qualitative-quantitative with the following description:

1. Using the BIM Model from previous research that has been done
2. Make a material take-off schedule, sort data on material types, volume, and enter the EE Coefficient and unit weight values, which are variables in the building embodied energy calculation.
3. Perform data analysis from the material-take-off schedule table to calculate the total value of the building's embodied energy
4. Make a comparison analysis between the embodied material of each component in the form of percentage comparison data
5. Formulate the steps for calculating the LCA for EE using BIM

3. Discussion

The first step in developing LCA using BIM is to access the BIM model that has been created in the BIM software. The BIM model used is the BIM model from previous research [15], which is the result of an exploration of the design of a 5-story vertical housing with an area of 30 m² for each unit and a total building area of 850 m². The building is designed with a low carbon design concept. The low carbon apartment design strategy that has been applied to this design is as follows:

1. Using recycled materials
2. Using a passive design system
3. Using prefabricated materials that have been proven to be energy efficient
4. Implementing a renewable energy system installation, namely solar panels on the rooftop of the building

In addition, this BIM model has been tested by simulating solar radiation so that it has been proven that the BIM model has a good performance against thermal comfort due to the results of using materials and the use of passive design aspects in the design concept. In the previous research, the EE calculation test of each building component had not been carried out. This study will do the EE analysis using BIM to determine the value of each building component, both architectural and structural components.
Architectural components are limited to walls, floors, doors, windows, and rooftop components. Meanwhile, the structural components are limited to the column and beam structural components. The explanations for the building components and materials that will be assessed by EE are as follows:

Table 1. Building components and materials

| No | Component              | Type of Component | Material                  |
|----|------------------------|-------------------|---------------------------|
| 1  | Prefabricated Wall     | Architectural Component | Concrete PCP Panel       |
| 2  | Prefabricated Floor    | Architectural Component | Concrete PCP Floor       |
| 3  | Prefabricated Roof     | Architectural Component | Concrete PCP Roof       |
| 4  | Door frame and Panel   | Architectural Component | Wood                     |
| 5  | Window Component       | Architectural Component | Wood and glass          |
| 6  | Structure-Column       | Structure Component  | Steel                    |
| 7  | Structure-Beam         | Structure Component  | Steel                    |

The material that is used is PCP (Plastic Concrete Panel) material, which is the result of previous research (Harmaji, 2019), which made a prototype of concrete material mixed with recycled plastic with a mixture content of 5%. The plastic used is plastic with the type of PET (Polyethylene), which has been tested to withstand loads up to 48.69 MPa.

Figure 5. PCP panel prototype size of 60x60x1.5 cm tested in the laboratory
Reference: Harmaji, 2019 [16]

The next step is inventorying material. Material inventory of the BIM data was carried out using the material-take-off scheduling method. From there, then group and sort are carried out to facilitate the material inventory process. In addition, the material-take-off also functions to see the respective volume of material used in each building component. The material volume of these building components is used as a basis for calculating the embodied energy of the building material. In this material-take-off method, additional parameters needed to calculate the material embodied energy can be added, namely the EE Coefficient data for each material taken from the ICE (Inventory of Carbon and Energy) data and the unit weight, which can be seen from the respective data. The material in the BIM software material data.
Figure 6. a) Material-take off scheduling b) Exploded axonometric of building component

The EE total data can also be added to the material-take-off schedule data, which is the final calculation data for the embodied energy material calculation. The material-take-off data can then be exported into text data for statistical data to be processed using Excel software.

The results of the embodied energy analysis can be displayed in several alternative data visualizations, that are the calculation results of the total embodied energy of building components, the percentage of the total embodied energy of the material, the graphical data analysis of the percentage distribution of the embodied energy of the material, and the percentage of the comparison of the total embodied energy material between architectural and structural components. From the analysis, it is found that the total embodied energy contained in the steel structure material is the greatest if it is compared to other material components. The results of calculating the EE total of each component and the percentage of each EE material component are described in the table below:

Table 2. The results of the analysis of the calculation of Embodied Energy Material for each building component

| Material: Name | Material: Volume (m³) | Family and Type | EE Coef. (MJ/Kg) | Unit Weight (Kg/m³) | EE Total (MJ) |
|----------------|-----------------------|-----------------|------------------|---------------------|--------------|
| Concrete, PCP floor | 85.002 | Floor: PCP floor 10 cm | 2.595 | 3680 | 811,735.10 |
| Concrete, PCP roof | 20.503 | Basic Roof: PCP Roof | 2.595 | 3680 | 195,795.45 |
| Concrete, PCP wall | 90.459 | Basic Wall: Prefabricated PCP Wall 7 cm | 2.595 | 3680 | 863,847.27 |
| Door - Frame | 1.248 | M_Single-Flush: 90 | 50 | 650 | 40,560.00 |
| Door - Panel | 4.68 | M_Single-Flush: 90 | 50 | 650 | 152,100.00 |
| Glass | 0.1 | M_Fixed: 80 | 18.5 | 3680 | 6,808.00 |
| Steel, 45-345 | 10.289 | Structural Column and Beam | 29.36 | 7849.05 | 2,371,080.58 |
| wooden windowpane | 0.27 | M_Fixed: 80 | 18.5 | 3680 | 18,381.60 |

The EE total percentage of structural components is also the largest if it is compared to the percentage of other architectural components. The following is the result of the analysis of the percentage of EE total by building material for each component:
The data shows that it can be used as a reference in the process of designing an apartment building so that it can be known what the greatest embodied energy is and can help architects in planning other alternatives to the use of lower energy materials. At this stage, architects can carry out the design and analysis stages of EE calculations in parallel and can be well integrated. For example, in this case, it turns out that the total EE calculation for the steel structure component is the largest, so that alternative materials are needed in order to reduce the total EE value in the structural component material. Meanwhile, most architectural components have a relatively smaller total EE value when compared to the total EE value for structural components. However, in order to be able to assess the total EE of the architectural component whether it has a low EE value, it is necessary to recommend the next step, namely to make alternative choices of architectural component materials that can be directly selected on the existing BIM data in the BIM software. That way, it can be formulated what materials can be low EE materials, which will later be applied to apartments that have been previously designed.

**Figure 7.** The graphic that describes the percentage comparison of the Embodied Energy calculation for each building component material

data for each building component material

| Building Component | Structural | Architectural |
|-------------------|------------|---------------|
| EE Percentage     | 53.16%     | 46.84%        |

**Figure 8.** a) diagram of comparison of the percentage of Embodied Energy between structural and architectural components b) diagram of the percentage comparison of Embodied Energy between work items

| Item               | Wall | Floor | Door and Window | Structural | Roof |
|--------------------|------|-------|-----------------|------------|------|
| EE Percentage      | 53.16%| 4.88% | 19.37%          | 18.20%     | 4.39%|

| Construction works | 4.39% | 19.37% | 18.20% | 53.16% | 4.88% |
The final step of this research is making the framework in order to integrate BIM and EE analysis. The framework is made to be an additional recommendation when the development of BIM and Life Cycle Analysis integration is needed in the future and as input for other researchers if they want to develop similar research. The BIM and LCA framework formulas are described in the graph below:

![Figure 9. framework of BIM and Embodied Energy integration](image)

Because the data used are material properties data obtained directly from BIM software, this research has limitations, which is the material properties used are not material properties owned by the research location. In addition, the EE coefficient data used in this study are taken from the international standard ICE (Inventory of Carbon and Energy) so that the data can still be changed according to the context of the research location. For example, if an embodied energy calculation model is to be developed in apartment buildings in Indonesia, the material properties data and the EE Coefficient must be adjusted to the Indonesian context. Thus, it is recommended for further research to be able to formulate the EE coefficient value and material properties in the local Indonesian context in order to develop an analysis of the EE calculation appropriately.

4. Conclusion
In Indonesia, research on EE mostly develops at the construction stage. On the other hand, research in the design phase that is integrated into the EE calculation is not well developed. This is a great opportunity to develop research on EE at the pre-construction level, especially when it is related to BIM integration. BIM is able to document various kinds of data related to buildings, especially building material properties and the EE coefficient of each building component material using the material-take-off scheduling method. Existing data can be arranged in accordance with the data held by researchers or building planners, and architects. A collaboration of data between BIM and other platforms will be able to help the calculation process be more precise and can display interesting data visualizations. Processed data can be in the form of data on the overall embodied energy of the building or data on the percentage comparison of each component. With the results of the analysis in the form of data visualization, it can help architects to present the results of their calculations to all stakeholders so that they have a broad picture of the building's embodied energy so that later it can support the creation of sustainable construction. It is hoped that this research can be continued to other research so that the development of
embodied energy calculations can be better in the future. Research development that can be carried out is, for example, the development of research on the EE value of local materials that will be used by using the material properties and the local EE coefficient so that the calculation results will be valid for that area, for example in Indonesia considering the value of the material properties and the EE coefficient have international standards which are not necessarily appropriate with the local context.

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