p-issn: 2581-1347 | e-issn: 2580-2607 | Pg. 61-72

Building Information Modeling (BIM) Implementation for Low Carbon – Eco Friendly Housing

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ABSTRACT

Housing development in Indonesia is increasing annually, leading to high demand for housing provision. Recently, the Indonesian government has been facing a housing backlog of 13,5 million. To solve this problem, the government then focused on housing regulation by implementing the One Million Housing program in 2015. On the one hand, this regulation effectively solves the housing backlog, but in terms of environmental awareness, this massive development leads to increased carbon emissions. The impact is due to the building material and construction process that is far from eco-friendly. For this reason, a solution is needed to reduce the environmental impact. One of the solutions that can be done is to develop a low-carbon housing design using environmentally friendly alternative materials. Building Information Modeling (BIM) is one method to give a broad view regarding the carbon emission of housing by integrative design modeling. This study then aims to analyze a housing prototype of type 36 with low carbon emission. In this study, the material alternative for housing is a lightweight concrete panel using plastic waste. The result shows that the design alternative proposed in this study decreases carbon emission by 26% compared to conventional housing. The panel with 1 cm thickness has a value of emission carbon as the amount of 2.56 tCO2e, which is lower than the traditional wall panel.

Keywords: Building Information Modelling (BIM), Housing Design, Low-Carbon Emission, Light Weight Concrete Panel

1. Introduction

Nowadays, housing development in Indonesia is increasing to reduce the housing backlogs by announcing massive housing development initiated by the government. This initiative is effective in housing provision, but in terms of environmental awareness, it increases carbon emissions due to construction activities. The study exposed that developing countries in the construction sector account for almost 60% of the total global CO2 emissions [1]. 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. Therefore, the environmental impact of carbon emissions is the world's focus. The Paris Agreement in the United Nations Framework Convention on Climate Change (UNFCCC) on greenhouse gas emission mitigation, adaptation, and finance has been negotiated by 195 representatives at the 21st United Nations Climate Change Conference in Paris, France. Indonesia is one of the countries that signed this agreement on April 22, 2016 [2]. In addition, the Indonesian government sets 2020-2024 RPJMN IV to accelerate the achievement of national development targets. It has established six mainstreaming as an innovative approach that will become a catalyst for equitable and adaptive national development. One is about sustainable development and vulnerability to disasters and climate change. The regulation explains that sustainable development must be able to maintain the environment and make efforts to improve climate change mitigation through the implementation of low-carbon development [3].

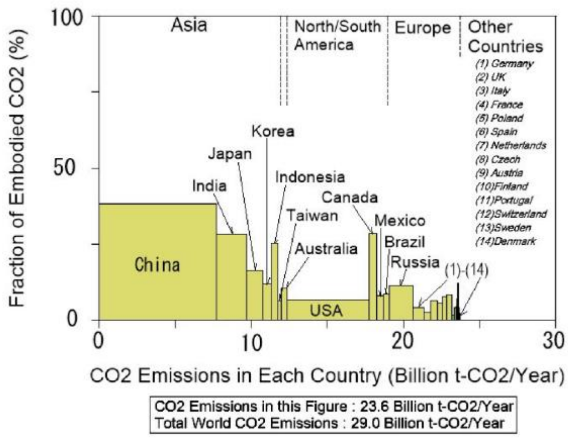

Figure 1. The level of carbon emissions due to the construction industry [1]

The construction industry, especially the housing industry, has the potential to produce significant carbon emissions. According to BPS census data, housing demand has increased annually to 1 million units per year, while the ability of the developers to provide housing units is only 400,000 units per year [4]. If this does not change, the housing backlog will be even higher. Coupled with a population growth of 1.49% per year, the community's need for housing will continue to increase [5]

In Indonesia, the developed subsidized housing is type 36 based on the standard given by the government [6]. The size of the subsidized housing is between 21 m² to 36 m², with a land area between 60 m² to 200 m² [7]. In the period 2015 to 2019, PUPR has distributed decent housing assistance reaching 1,052,371 units to 1,168,136 [3]. In addition, settlement data shows that 48.78% of households pay for housing costs for 11-15 years with an average monthly installment of 1 million [8]. This indicates that ordinary Indonesian people pay for housing in the middle/lower middle market segmentation.

Design plays an essential role in the success of construction activities. The right design strategy can estimate the value of carbon emissions, especially on building materials. This will contribute to reducing carbon emissions in the housing sector. Preventive steps are needed in solving the problem of carbon emissions due to construction activities, especially for Indonesia, which has a target in 2030 to reduce carbon emissions by 30%.

Management of carbon emissions in the building can be carried out from the initial phase or in the design and planning phase. The design phase is essential in construction management, and the quality of planning and design is a significant factor in the success of a project [9]. The better the quality of the design, the better the quality of the project. Furthermore, building design is essential because it defines various information on the building, such as specifications, plans, parameters, costs, activities, processes, and so on, to achieve the expected goals [10]. If the design is not planned correctly, it can have an impact, such as the results cannot be used optimally, building operations are disrupted, require costs and time for repairs, and so on [10].

A good design process is a design that can provide an integrative description of various kinds of information. The design phase can give an estimation of energy in a building. Building energy mitigation can start from the design or planning phase [11] [12]. If the architect can assess the energy of the building from the initial phase of construction, the environmental impacts that occur by large-scale development can be minimized. In principle, carbon emissions are the result and effect of building energy, both embodied energy building materials and building operational energy.

Table 1: Low Energy and Carbon Emission Design

Strategy

Regulation Tools	Strategy	Keywords
Greenship GBCI	• Accuracy of site development • Energy Efficiency and Energy Saving • Water saving • Material sourcing and recycling • Indoor Health and Comfort • Environmental conditions and building management	• Site and orientation • Operational energy savings (passive and active) • Water saving • Embodied energy materials • Indoor layout • Building management
IEA Annex 57	• Selection of structural materials • Use of recycled materials • Facade material selection • Building form • Use of local materials • Construction method • Energy use in construction	• Structural Materials • Recycled Materials • Sheath Material • Shape • Local materials • Construction Construction energy
Near Zero Energy Building [16]	• Bioclimatic Design • • Minimum operational energy • • energy efficiency and conservation • • New energy cycle	• Design system • Operational energy savings (passive and active) • Operational energy savings (passive and active) • Renewable energy generation (active)

A design strategy is needed to achieve a building's low energy and low carbon emission. Low-carbon building design strategies are obtained from several previous studies as follows in table 1.

Based on table 1, it is noted from the keywords that building materials are one of the most mentioned aspects in the design strategies above, for example, using materials with low carbon emission values or recycled materials. This material aspect is appropriate to be used for this research by exploration of house design with a focus on building materials.

After obtaining a low-carbon building design strategy, an appropriate design method is needed to assess. One of the design methods that can be developed is the Building Information Modeling (BIM) method. BIM is an approach to building design, construction, and management that allows for digital analysis, simulation, and manufacturing. These tools help the stakeholders understand the construction management process; BIM implementation can speed up project planning time by ±50%, BIM reduces human resource requirements by 26.66%, and saves personnel costs by 52.25% compared to using conventional applications [13]. This supports the project design, schedule, and other information well-coordinatedly. One of the building information within the BIM scope is information on building energy and carbon emissions [14-19].

Integrating BIM and calculation of carbon emissions aims to make the design process effective and efficient, meaning that in a design process, the architect or designer can simultaneously calculate and analyze the building's energy while the architect is designing. BIM has the features to perform processes that are integrated into every building life cycle. In the design phase, the feature used to protect the building's carbon emission value is the BIM plugin feature. The integrated process starts from making types of building components and selecting building materials, which will affect the analysis of building carbon emissions calculations. Thus, the function of implementing BIM, which is integrated with carbon emission analysis, is aimed at [20]:

• Avoid re-entry and manual data
• Enable real-time grading

• Can carry out an assessment of the entire life cycle of the building

• Adopt an intuitive and easy-to-use interface

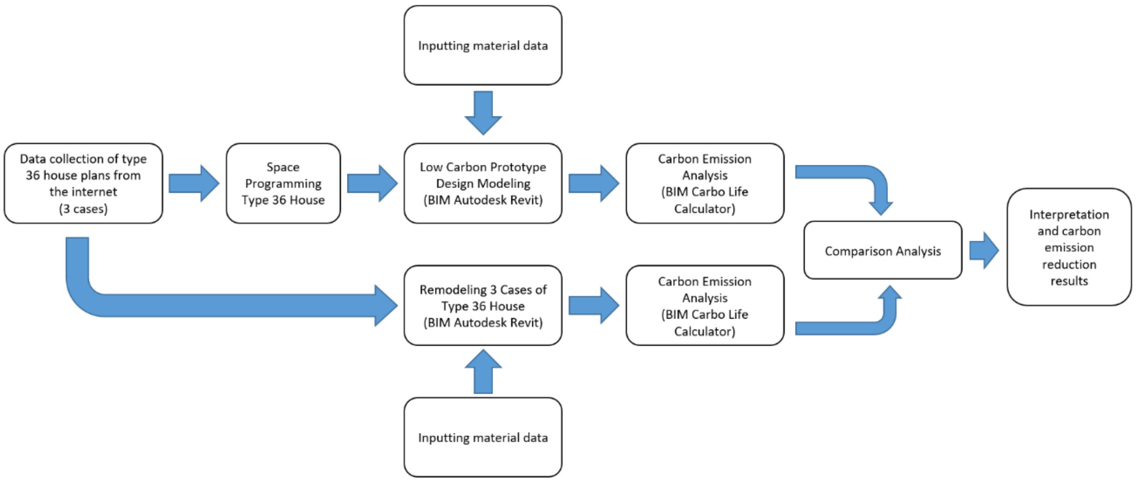

Figure 2. Research Methodology

Based on background, this study aims to provide an overview of the prototype low-carbon housing design type 36 by implementing an innovation of new materials from recycled materials [21–24]. Design exploration in this study will also focus on the application of these materials, which are later expected to produce low-carbon designs and contribute to reducing carbon emissions due to housing development.

2. Methods

The methods used in conducting this research can be seen in figure 2 and described as follow:

1. Collecting case study data of the existing housing design type 36 (3 cases design model.
2. Formulation of spatial programming from the existing design
3. Remodeling the design by using BIM software of Autodesk Revit platform. The BIM model used to conduct this research is the BIM model with a level of detail at LOD 200 (level of development). LOD 200 is a medium-level design model where The room plan, wall components, doors, windows, floors, and roof data are available and well defined. This data is provided to determine building materials' carbon emission value.
4. Develop a prototype design model based on a case study combined with new building material.
5. Calculating material carbon emissions for each design model, both existing and prototype designs, using the BIM Carbo Life Calculator plugin
6. Comparing the results of the calculation of carbon emissions of the prototype design with the existing design to see the difference and decrease the value of carbon emissions.
7. Interpret the findings and analysis the design model carbon emissions.

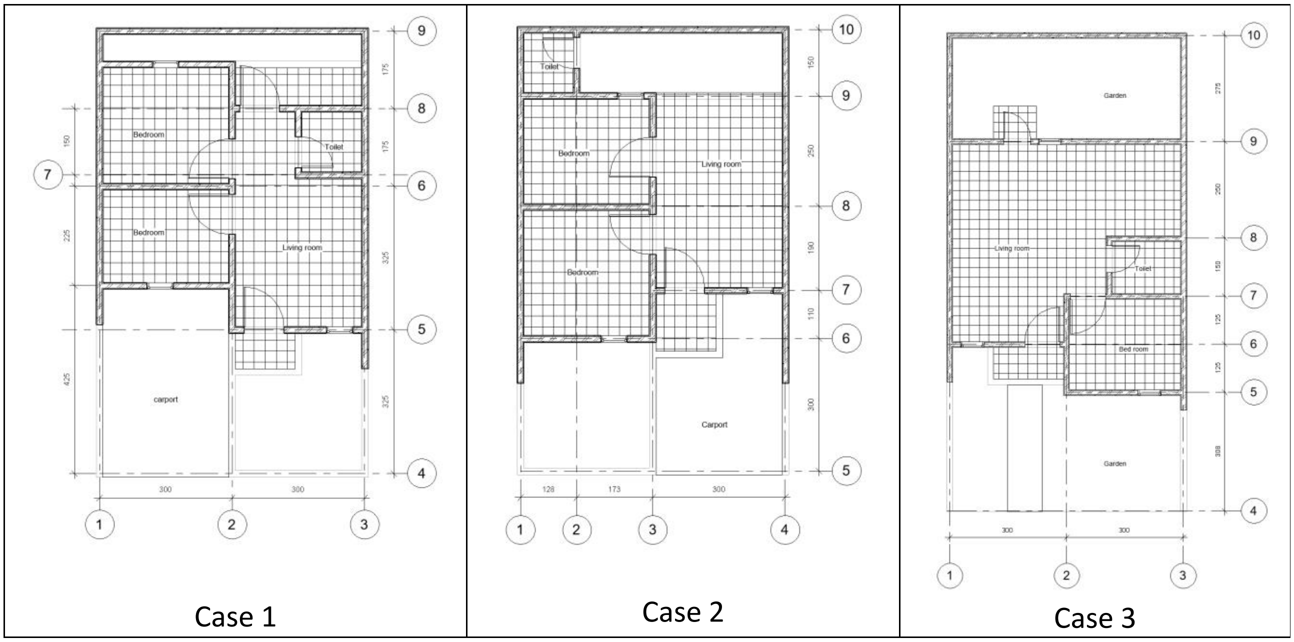

Figure 3. Type 36 floor plan drawing table from the existing model

3. Results and Discussions

The following figures are some examples of designs developed by housing developers for type 36 houses:

Figure 4. Example housing Type 36 [19]

From the results of data collection on the floor plan and the type 36 house design model, it was found that the programming space for a type 36 house consists of several rooms, namely:

1) 2 bedroom units with a size of 3x3 m or customize
2) 1 family room unit which is directly connected to the kitchen and dining room
3) 1 bathroom unit
4) 1 unit terrace
5) Front garden and back garden

The type 36 design modules mostly have a module size of 3x3 m with the overall module size of the building measuring 6x6 m. In addition, the type 36 house has material specifications, namely:

1) Light brick wall with cement plaster and paint finish
2) The window door uses wood material
3) Ceramic floor coating
4) Tile roof covering with light steel roof truss
5) Reinforced concrete structure with river stone foundation

Then the BIM model is created for the three cases of the existing type 36 design. The model made is a model with a LOD 200. This LOD level is expected to project the general carbon emission value of buildings and is also sufficient to represent most of the building components designed. At the LOD 200 level, designers or architects can also input data on the material components. For example, in figure 5, the data input for wall components is using 10

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cm light brick with plaster finishing, which makes the overall wall thickness equal to 15cm:

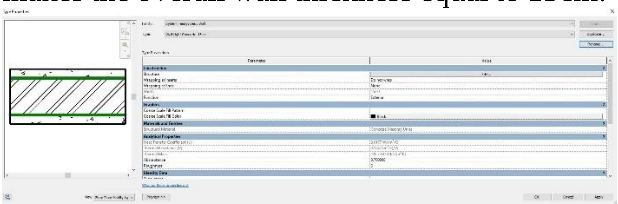

Figure 5. Wall material data input

The three cases' housing models have different spatial configuration patterns from one another. However, the rooms and the configuration of the spatial modules seem to have little in common. For example, consists of 2 bedrooms, with a basic room module of 3 meters; a living room or family room; a bathroom that is relatively the same size; a terrace; a front and back garden. However, there is one case that only has one bedroom, but the room module that should be used for an additional bedroom is used as an expansion area for the family room. The results of remodeling are shown in figure 4.

In addition to the different spatial patterns, the shape of the 3D building model in the three cases above is also different, especially from the use of the roof model. There is a design model that uses a continuous roof. A design model also uses a separate top between the right and left sides. The following figure 6 shows the results of the remodeling of the type 36 house design model using BIM.

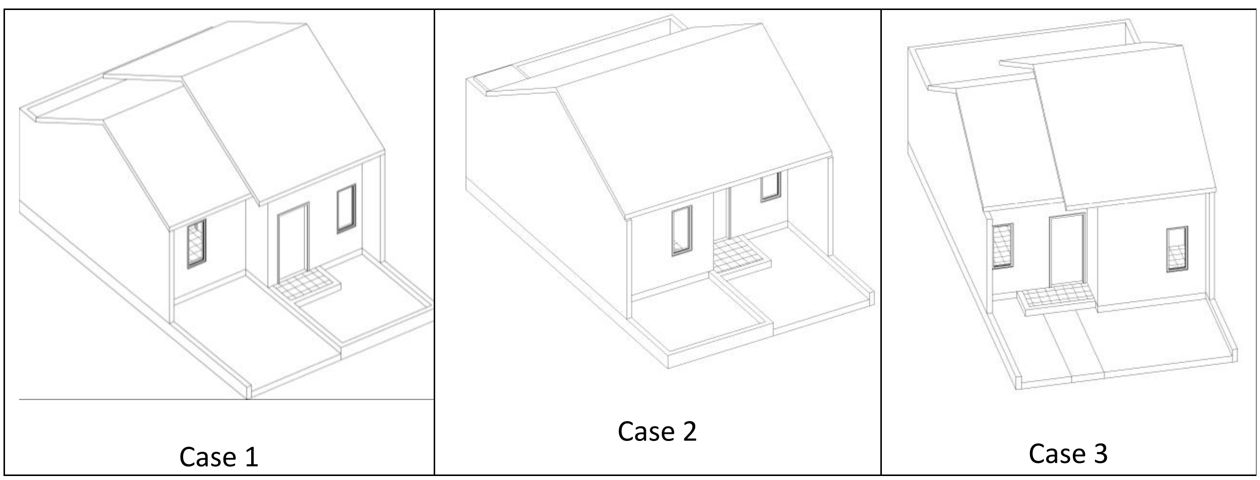

Figure 6. Existing 3D model house type 36

After remodeling the existing design of the type 36 house, the next step is to design a prototype model developed from the existing design room program. In addition, the wall material used is a wall panel material with a size of 60x60 cm which is a recycle material, namely using PCP (Plastic Concrete Panel) wall material which is a mixture of concrete and recycled plastic made from PET (Polyethylene) with a wall thickness of 1 cm [22] as showed in figure 7.

Figure 7. PCP Panel [22]

In addition to being used for wall panels, the materials mentioned above are also used for floor component materials. For building structural materials, such as beam-columns and wall panel frames, using 10x10 cm hollow steel and 4x8 cm hollow steel. Meanwhile, 4x4 hollow steel for frame material is used with a

p-issn: 2581-1347 | e-issn: 2580-2607 | Pg. 61-72

metal sheet roof covering for the roof components. Concrete materials with a pedestal or local foundation system are used for building foundation materials. The results of the exploration of the design of the type 36 prototype house model are as follows:

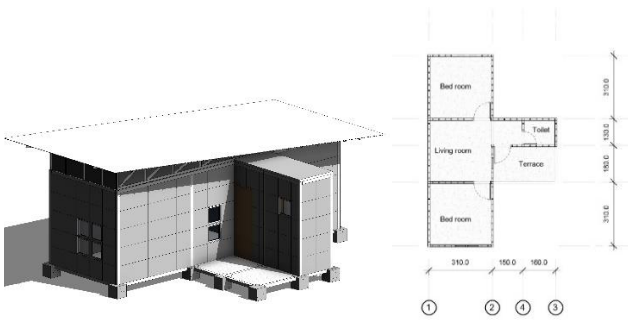

Figure 8. Layout and 3D model Desain Prototype

The spatial pattern is designed differently from the existing type 36, with an elongated spatial pattern. Unlike the current housing design, that often uses a square-shaped spatial pattern. This aim is to give proper orientation towards green open space. In addition, the house has the potential to have a fairly wide green open space compared to the existing type 36 house design. Orientation and open space are also part of and contribute to the previously described low carbon design strategy.

The next step is to simulate the calculation of material carbon emissions using the BIM Carbo Life Calculator Plugin, an Open-Source add-on plugin for the Autodesk Revit platform developed by David Veld [20]. The working principle is this tool can automatically calculate the carbon emission value of designs that have been made using the Autodesk Revit platform. The plugin uses UK standards in calculating carbon emissions, especially in terms of building material emission factor data. However, this plugin is open to changing the data manually by the user. Material data, especially emission factors, can be changed manually by the user if they have their emission factor data or from the results of their respective studies. The final result of this tool is the overall value of building material carbon emissions.

1. The portion of carbon emission value in all phases of the building's life cycle, starting from the material extraction phase to the end of life phase.
2. Social costs are needed to improve environmental impact. In this case, the social cost per tCO2 can also be changed manually. The template data in this plugin for social cost is 50 for a selectable currency unit ($/£/€).
3. Recommendations and information related to carbon emission results. The carbon emissions results from the designs made are equivalent to the emission values of car vehicles with UK standards. In addition, the effects of carbon emissions from building design are also equated with the number of trees that must be planted to improve and eliminate carbon emissions due to construction. These recommendations and information will indirectly motivate architects to enhance the environment and reduce the environmental impact of construction activities.
4. Comparison between one model and another so that the alternative model design with the lowest carbon emission value will immediately be known.

In this study, the material data used is direct material data owned by the Carbo Life Calculator Plugin or using template data from the plugin. The purpose of using this method will be to compare the existing design and prototype model that has been made. Following is the user interface of the results of the carbon as shown in figure 9.

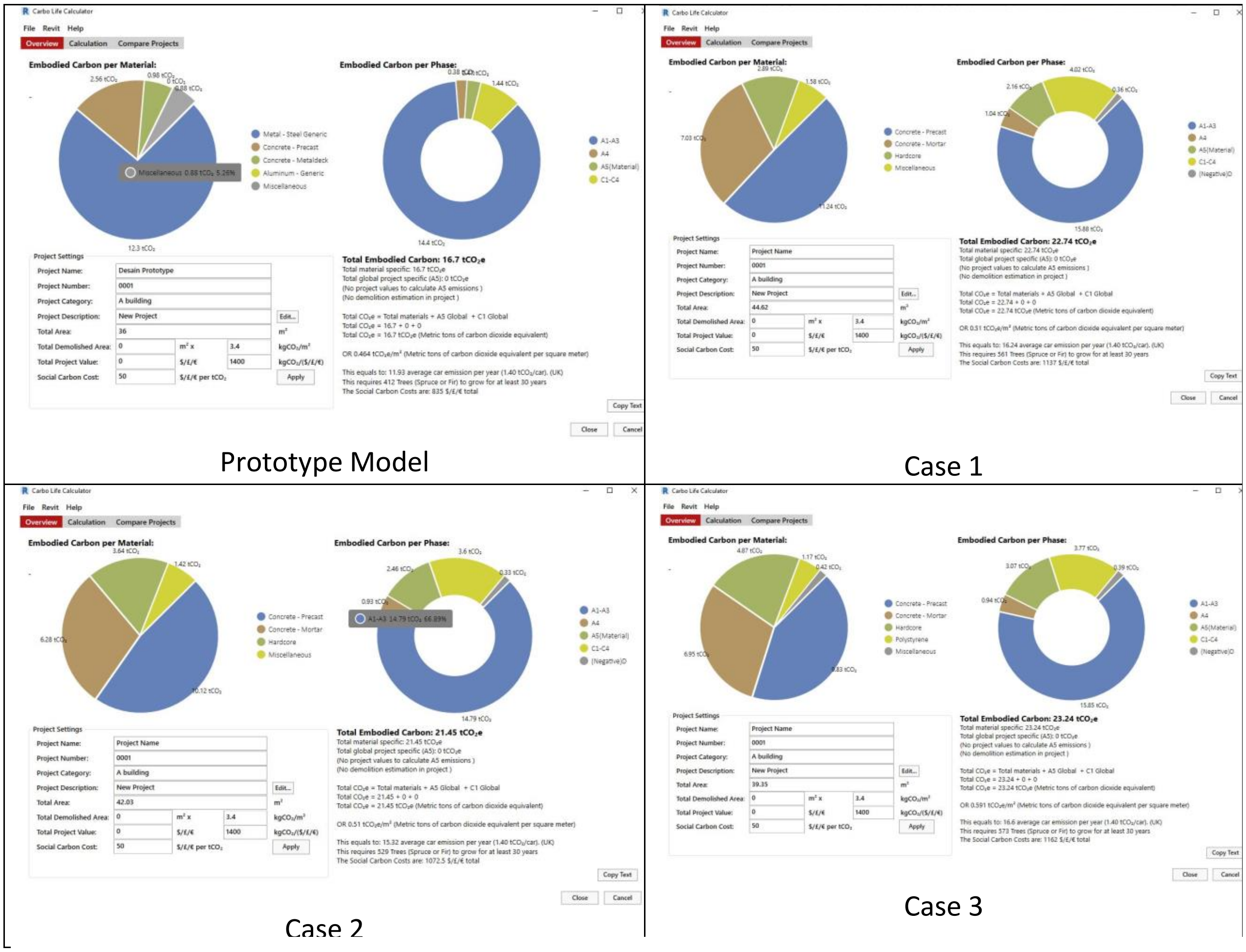

Figure 9. Results of all models using Carbo Life Calculator

The results of the comparison of the portion of the total carbon emission value in each phase of the building's life cycle are as follows:

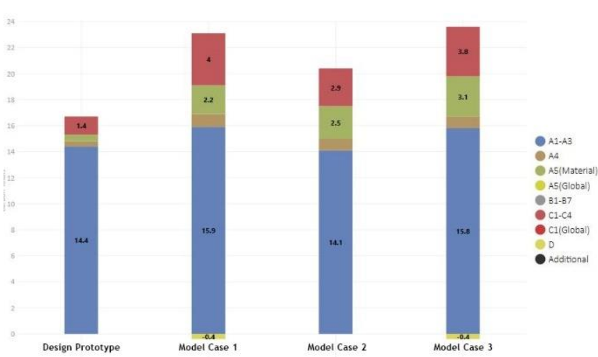

Figure 10. Comparison graph of carbon emission values across building life phases for all models

According to comparative analysis, it can be seen that the lowest carbon emission value is in the prototype model design, with a value of 16.7 tCO2e. The most significant portion of carbon emissions in the prototype design model is in structural material components that use iron material, which is 12.3 tCO2e, or about 73% of the total carbon emissions. Meanwhile, the emission portion of wall material is relatively small, only 15%, with an emission value of 2.56 tCO2e. However, based on the figure, the portion of the importance of carbon emissions in the entire building life cycle phase of the whole model shows that the A1-A3 phase or the material extraction phase is the most significant portion. In contrast, the construction and operational phases (A4 and A%) have an essential portion of the value. Relatively small carbon emissions.

Then the figure 11 is a comparison chart of the total overall carbon emission values for each design model.

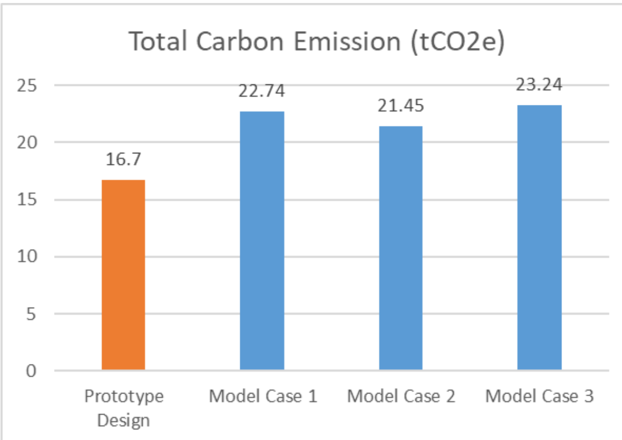

Figure 11. Comparison graph of the overall carbon emission values of building components for all models

It can be seen that the prototype design has the smallest carbon emission value of the entire model. If the carbon emission values of the three existing types of 36 case models are averaged, the carbon emission value is 22.47 tCO_2e. Using a prototype model design for an alternative design can reduce carbon emissions by 26%. In addition, the carbon emission of the wall material used also has the smallest value compared to the other three existing models. If using these alternative wall materials, architects can reduce carbon emissions in wall materials by 85%. The figure 12 compares the value of carbon emissions contained in the wall material of each model where the model is:

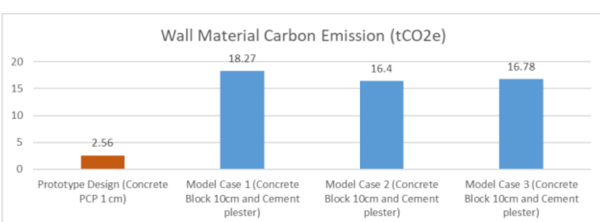

Figure 12. Comparison graph of wall material carbon emission values for all models

Another thing that can be seen from the analysis of carbon emissions using the Carbo Life Calculator is recommendations and information on the environmental impacts of carbon emission values similar to car vehicles. In addition, the environmental impact aspect related to how many trees should be planted to improve the environmental impact due to carbon emissions can also be seen here. In figure 13, it can be seen that the prototype design is the design with the most negligible emission value, which is equivalent to 11.93 cars per year, while the other existing designs are in the range of 15-16 vehicles per year. Regarding the environmental impact on the number of trees that must be planted and grown to remove the carbon footprint, the prototype design is the smallest at 412 trees. These values become interesting for architects and service users to know how much carbon will impact buildings in the future.

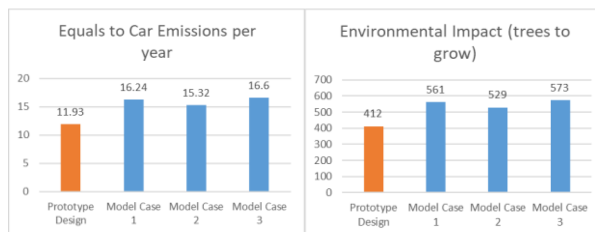

Figure 12. Environmental impact comparison chart

The latest information displayed from the simulation is the social costs arising from improving the environment. The final result shows that the social carbon cost that occurs to improve the most negligible environmental impact is on the prototype design with a value of 835 ($/£/€), which is shown in the graph below:

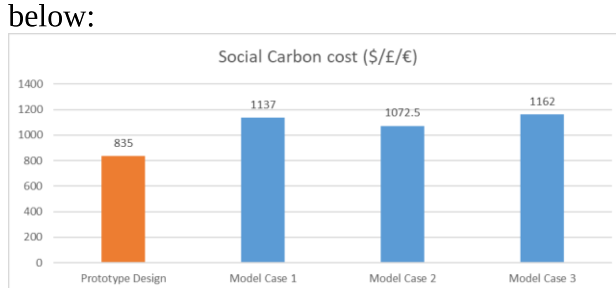

Figure 13. Comparison graph of Social Carbon Cost values for the whole model

4. Conclusion

The analysis of carbon emissions using the BIM method shows that the prototype design has a lower value than the carbon emission value of a type 36 house with a conventional design. This can be achieved from the strategy of using materials. The strategy of using materials that can be achieved is by several strategies:

1. Using innovative materials, for example using, recycled materials
2. Using modular materials with sizes according to modular standards so that it will not produce significant construction waste
3. Using building components with a thin thickness because the volume of material components will affect the value of carbon emissions

The largest portion of the carbon emission value in the prototype design is in structural components that use hollow steel as beams and columns. Therefore, further research is needed to explore structural materials to reduce their carbon emissions and become an alternative to environmentally friendly structural materials.

In addition, from the results of the discussion, what can be further highlighted is the use of the BIM method to predict the value of carbon emissions quickly and integrated with the design of the model made. The use of BIM at the LOD 200 level of detail can also provide several design alternatives and complete the calculation of carbon emissions of the building materials used. Thus, this will make it easier for architects or designers to estimate the environmental impact of their designs quickly at the beginning of the building design phase, especially in this case, a simple type 36 house design. And contribute to reducing carbon emissions due to housing construction activities.

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p-issn: 2581-1347 | e-issn: 2580-2607 | Pg. 61-72

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