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Factors Influence Embodied Energy and Embodied Carbon Value at Design Phase of Low Middle Class Apartment in Indonesia

Factors Influence Embodied Energy and Embodied Carbon Value at Design Phase of Low Middle Class Apartment in Indonesia

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Abstract In 2015, it has been estimated that the housing backlog in Indonesia reaches 11.4 million units while the government has projected the decrease in 2019 as low as 6.8 million units. On the other hand, a massive development being implemented in Indonesia requires a high amount of material to be continuously provided in which those materials consume high amount of energy in their production. The Embodied Energy (EE) parameter can be used to measure the carbon emission being ejected during the material production process. The EE parameter can further be used in the development policy to anticipate the process since its planning until the later construction phase. This paper explains the factors influencing EE parameter value in the design phases for typical unit in lower-to-middle class apartments in Indonesia. Several properties on the material are measured including volume, types, and module. This research finds that embodied impacts on cement based material, ceramics and modular material choices are consistently the most significant, regardless of building design configuration. Certain mitigation needs to be conducted in the design phases to prevent any environmental damage caused by unrestricted usage of building materials such as by preventing or reducing waste material mainly in terms of the limited available space for waste disposal.

Keywords : Embodied Energy, Embodied Carbon, Apartment, Indonesia

1. Introduction

Current residential development in urban areas has led to vertical housing development. As seen in the graph below, there has been a significant increase in the number of apartment units from 2007 to 2015 in Jabodetabek, Indonesia. Similar things happen in all major cities in Indonesia. This is partly due to the high level of urbanization in Indonesia which reached 49.9% in 2010 and 53.3% in 2015 [1]. This level of urbanization increases annually and encourages the development of infrastructure to support and accommodate the high population growth in urban areas.

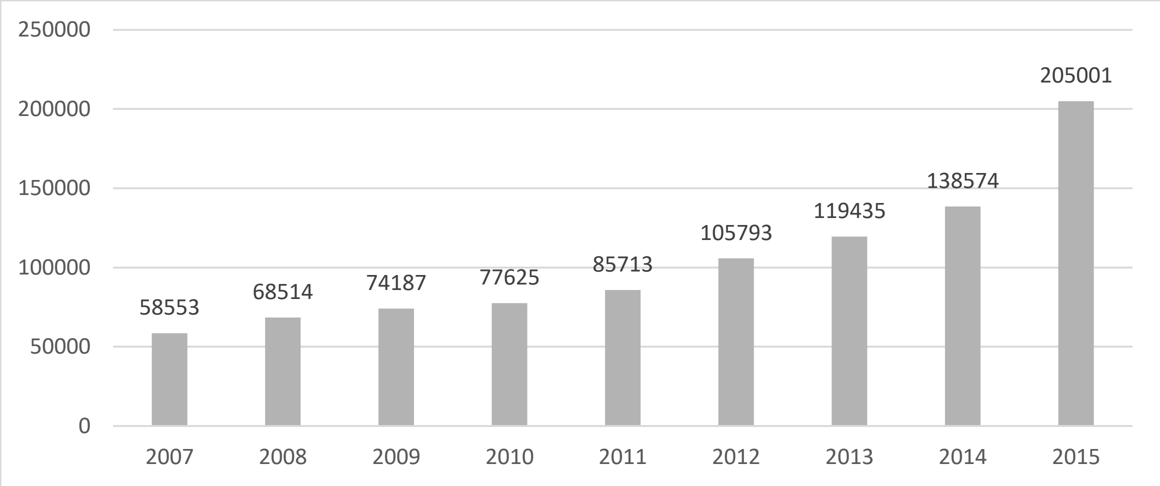

Figure 1 Trend of Apartment Growth in Jabodetabek, Indonesia (thousand units)
Source: [2]

Since late 2015, the Ministry of Public Works and Housing has begun a housing development program known as 'one million housing development program' to meet the growing number of housing needs in Indonesia. However, mass housing development that occurs in all regions of Indonesia will have an impact on the building materials supply needs that are increasing continuously. This can be seen in the graph below, which shows the expenditure value of building materials used in construction activities increases annually.

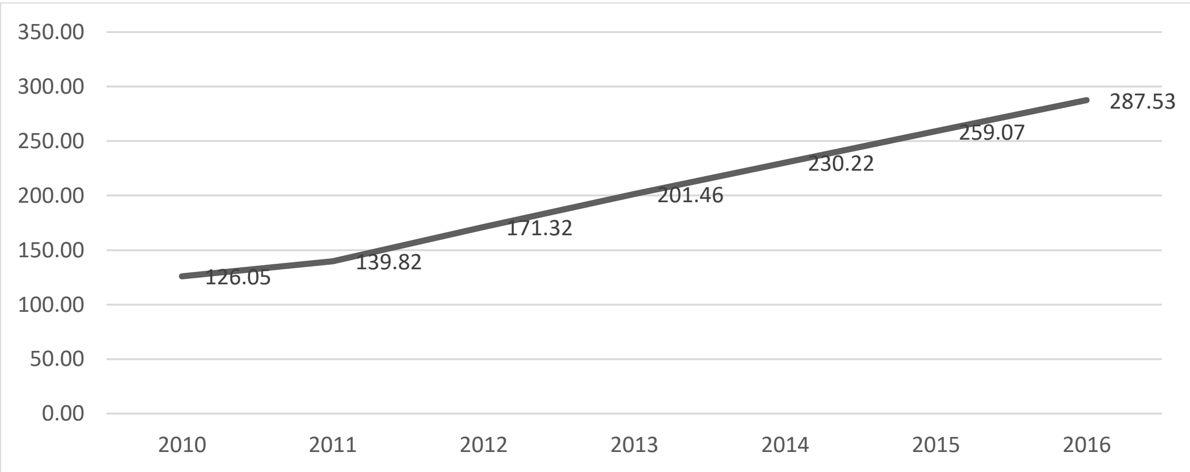

Figure 2 Value of Expenditures for Building Material Used (Trillion Rupiah)
Source: [3]

The building material needed is ready-to-use material, which is produced in many stages and requires large energy consumption in the production, transportation and installation processes. As seen in the diagram below, a brief description of the material stages from the extraction stage to the installation at the construction site, each stage in all phases requires energy. Large energy use if not controlled can lead to greater environmental impact. In addition, besides requiring energy, building materials undergo a process that causes carbon emissions at each of these stages.

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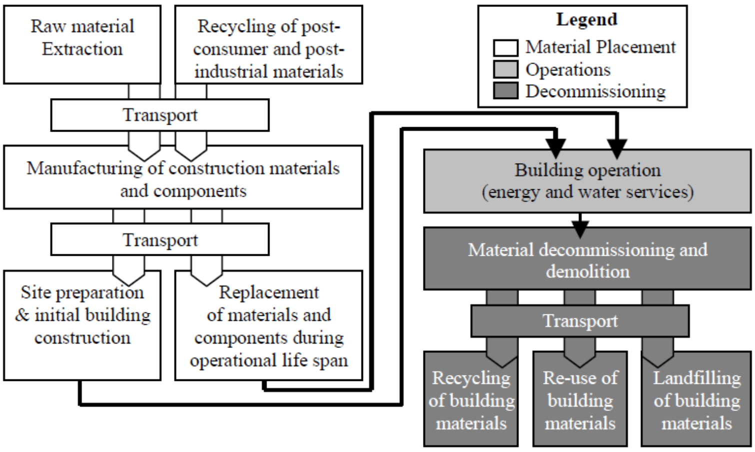


Figure 3 Life Cycle Phase Diagram
Source: [4]

In recent years, a few researchers have estimated the embodied energy values related to residential building in different locations. Ramesh et al. [5] has quantified embodied energy values of RCC based residential houses in Allahabad, India. Shukla et al. [6] evaluated embodied energy of an adobe house for India. Citherlet and Defaux [7] analyzed and compared a family house by changing its insulation thickness and type. The study confirmed that good insulation provides a significant reduction in energy (about 50%). Utama and Gheewala [8] also analyzed clay and cement based single landed (Storied) houses in Indonesia and observed that energy consumption of clay. Within the scope of vertical housing, attention to embodied energy and carbon emissions in the apartment unit is important since the design of apartment units is often found in the form of a typical design for the entire floor of the building. Therefore, every design decision in a typical apartment unit will have a large impact, especially related to energy use and carbon emissions. This study will calculate the influence of a typical unit design decision towards the values of embodied energy and carbon emission. This study will also formulate the factors that influence the value of embodied energy and carbon emission in the design phase of a typical unit of lower middle class apartments in Indonesia. The calculation of embodied energy and carbon emission is done through the identification of material use, material type, layout unit design and modular material selection.

2. Method

Carbon emission calculation is based on the energy values contained in building materials, this value is called Embodied Energy (EE). The amount of EE value can give an earlier picture of the level of carbon emissions that will be produced. This is very useful in decisions making that consider environmental aspects in the planning stage. EE calculations carried out in this study using the input-output analysis (IOA) method. This method is an EE analysis method based on the input-output table of goods and services in the economic sector. The Input Output (I-O) table is a statistical description in the form of a matrix that presents information about the transactions of goods and services and the interrelationships between units of economic activity in a region for a certain period of time. I-O table used in this calculation is the updated I-O table in Indonesia, namely the 2010 I-O table issued by the Indonesian Central Bureau of Statistics. The IOA stages were carried out in accordance with the diagrams issued by Surahman et al. [9] as follows:

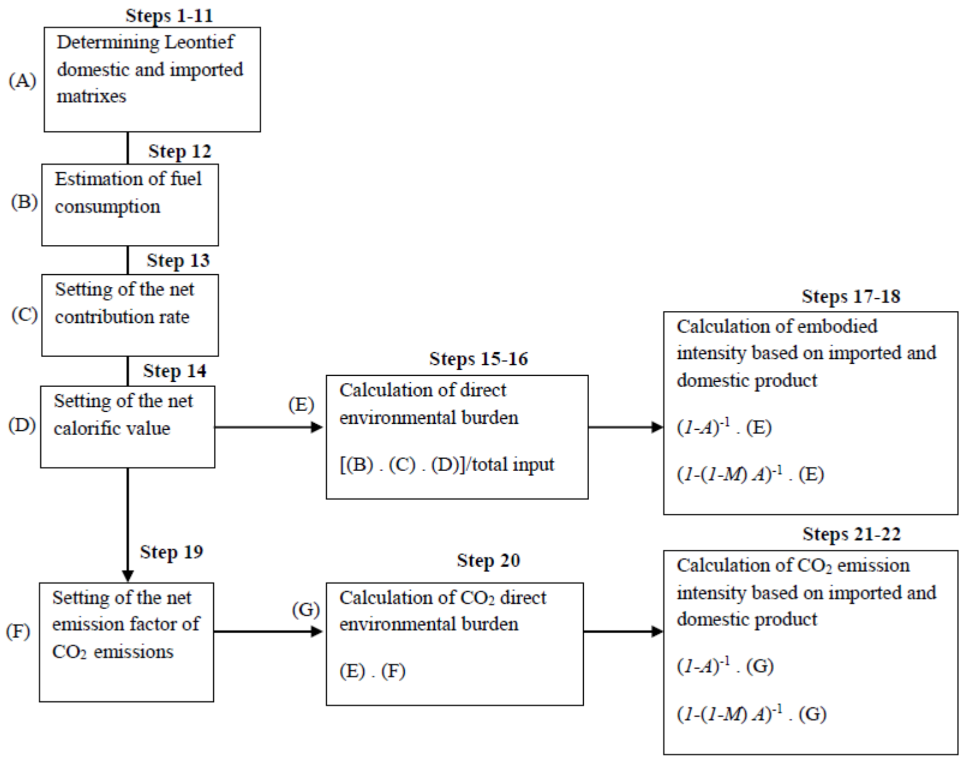


Figure 4 Detailed flow chart of calculation procedure for estimating embodied energy and carbon emission
Source: [9].

Data needed in this calculation include updated Indonesia input-output table (in 2010), fuel consumption of material construction data, net contribution value of each fuel, carbon emission coefficient and existing building data in the form of unit work drawings equipped with details material volume.

2.1. Case Study

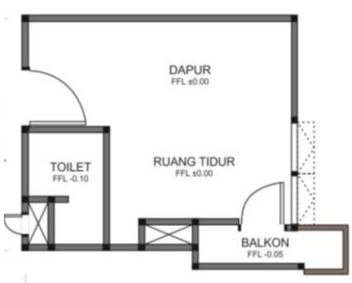
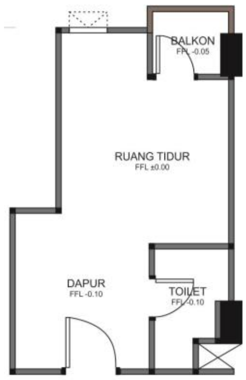
The embodied energy and carbon emission calculation in this study was carried out in three case studies. Three of these case studies were chosen to be compared so the significant factors that influence energy use and carbon emissions for typical unit construction could be obtained. The case study taken was the construction of apartments in Bandung, Indonesia, such as Landmark Apartment, The Jarrdin Apartment and Parahyangan Residence Apartment. These three apartments are middle to lower class apartments with initial data shown in the table below. In table 1, it can be seen that one of the studio units in each apartments has a common unit area.

Table 1 Data related to Area and Type of Unit in the Three Case Studies

Apartment	**Typical Units**			
	Studio	**1 Bedroom**	**2 Bedroom**	**3 Bedroom**
Parahyangan Residence	Type A (22.5 m^2) **Type B (24 m^2)** Type C (25 m^2)	Type A (31.42 m^2) Type B (34.37 m^2) Type C (29.69 m^2)	Type A (41.8 m^2) Type B (42.65 m^2) Type C (43.82 m^2) Type D (44 m^2) Type E (41.48 m^2) Type F (46.43 m^2)	Type 3 BR A (52.21 m^2)
The Jarrdin	Type 1 (18.5 m^2) **Type 2 (24 m^2)**		Type 1 (33m^2) Type 2 (40m^2)	
Landmark	**Type Cedar (24 m^2)**	Type Maple (44.9 m^2)	Type Chestnut (62.9 m^2)	Type Mahogany (89.6 m^2) Type Ebony (132 m^2)

The selected case study is a studio unit with an area of 24 m^2 in each apartment. These selected case studies have represented the layout and material specifications trends of studio units for low-middle class apartment in Indonesia. According to [10], the average area of studio units in middle to lower apartments is 23.1 m^2. In addition, these three case studies have a similar layout, which is an open space category, with a similar space configuration, which has a service area within the unit and has a balcony. The table below shows the unit plan and material specifications for each apartment.

Table 2 Floor Plan and Specification of Three Case Studies

The Jarrdin Apartment	Landmark Apartment	Parahyangan Residence Apartment
		
Specification: Area: 4.8 m x 4.5 m Wall Material : Light Weight Brick Finishing Paint Bathroom wall : Ceramic Ceiling Material : Gypsum board Floor Material : Homogenous Tile Ceramic HPL	Specification: Area: 4 m x 5.85 m Wall Material : Light Weight Brick Finishing Paint Bathroom wall : Ceramic Ceiling Material : Gypsum board Floor Material : Homogenous Tile Ceramic HPL	Specification: Area: 6.7 m x3.5 m Wall Material : Light Weight Brick Finishing Paint Bathroom wall : Ceramic Ceiling Material : Gypsum board Floor Material : Homogenous Tile Ceramic HPL

These three units have different material quantity variations due to differences in unit plan and material type selection. As seen in Figures 5, 6 and 7, which shows the quantity of material on the walls, floors and ceilings, the dominant material used in each unit has similarities, as in wall material is dominated by the use of paint materials, floor material is dominated by mortar, while each ceiling material used has the same quantity.

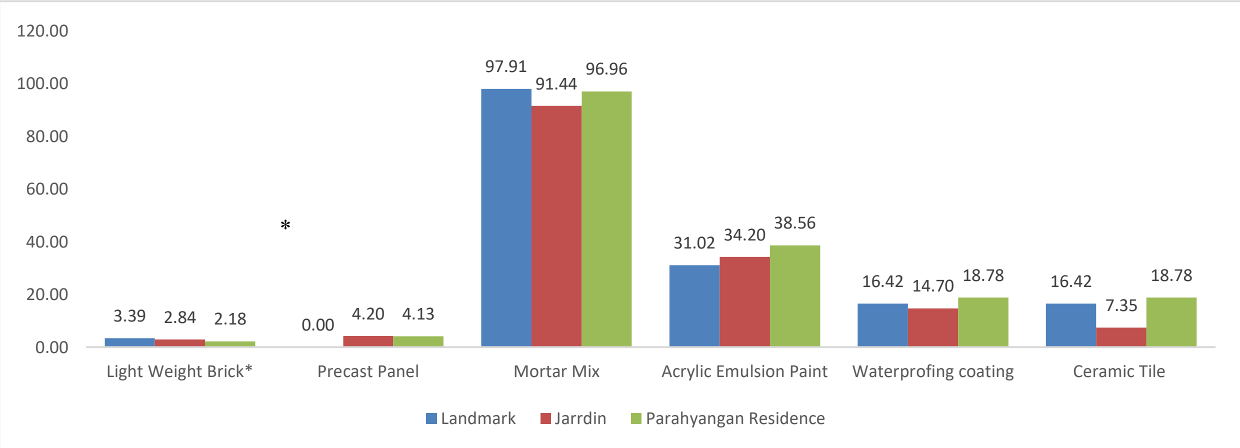


Figure 5 Distribution of Wall Material Volume in Each Case Study (in m^2)
*=unit in m^3

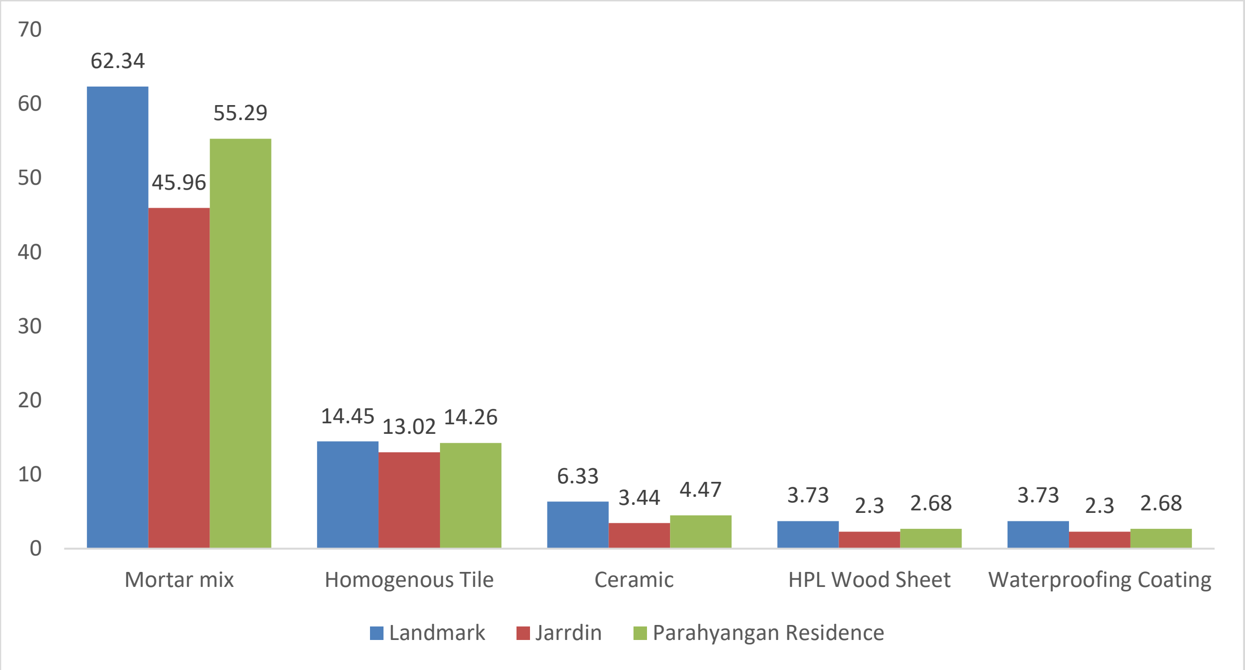


Figure 6 Distribution of Volume of Floor Materials in Each Case Study (in m^2)

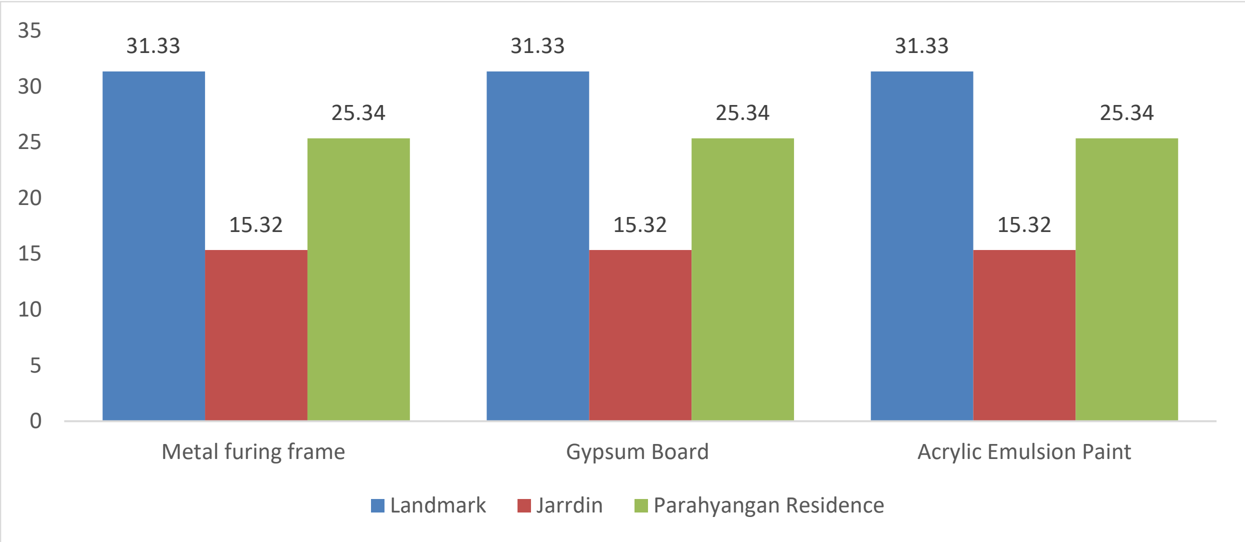


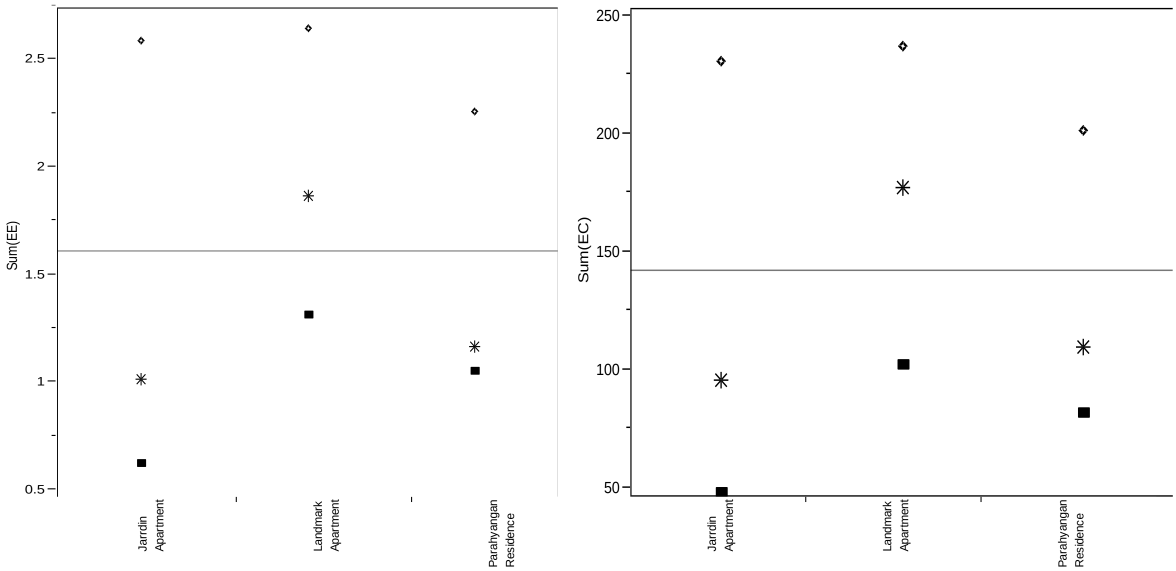
Figure 7 Distribution of Volume of Ceiling Materials in Each Case Study (in m^2)

Calculations using the IOA method are carried out to see the influence of studio unit design decisions, in the form of material selection, material volume, unit area dimensions and the use of modular materials, toward the value of embodied energy and carbon emission.

3. Result and Discussion

3.1. *Value of Embodied Energy and Embodied Carbon*

The initial calculation based on the material quantity of the unit produces EE and carbon emission values for each type of material (walls, floors and ceilings). As seen in the picture below, unit material that has a significant influence on energy use and carbon emissions is wall material followed by floor material and ceiling material.



■= Ceiling Material □= Wall Material ∗= Floor Material
Figure 8 Embodied Energy (GJ) (left) and Embodied Carbon (kg-C) (right) in Each Apartment

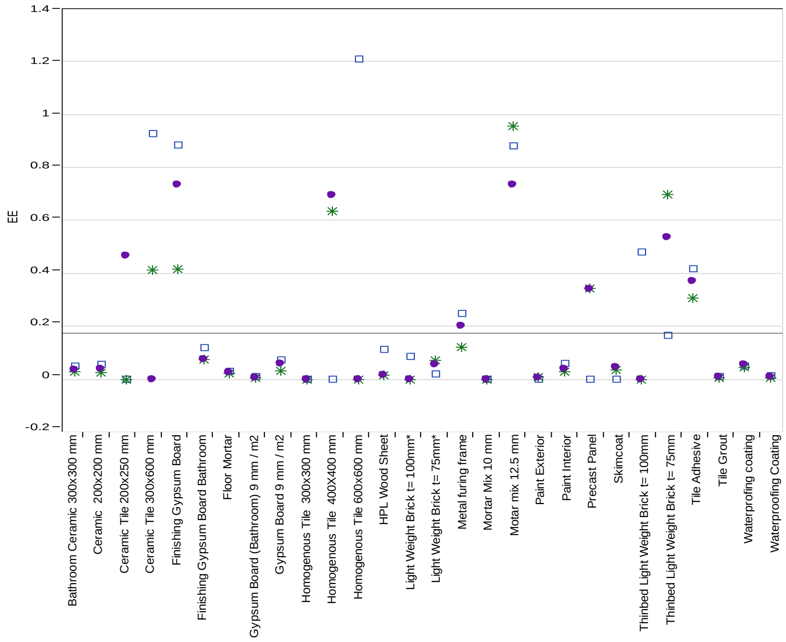
Meanwhile, based on the case taken, Landmark apartments have the highest embodied energy and embodied carbon values for all materials used. Whereas the dimensions of Landmark apartment units are the smallest among the other two case studies. It is proven that the unit area has no effect on the embodied energy and carbon emission values in this case.

3.2. *Design Effect Factors*

Based on the previous calculations, the wall material has the highest EE and carbon emission values compared to floor and ceramic materials. This is related to the large variety of wall materials and the number of quantities. Thee material specification that will be used is determined at the design stage. The influence of design decisions toward the EE and carbon emission values are explained as follows:

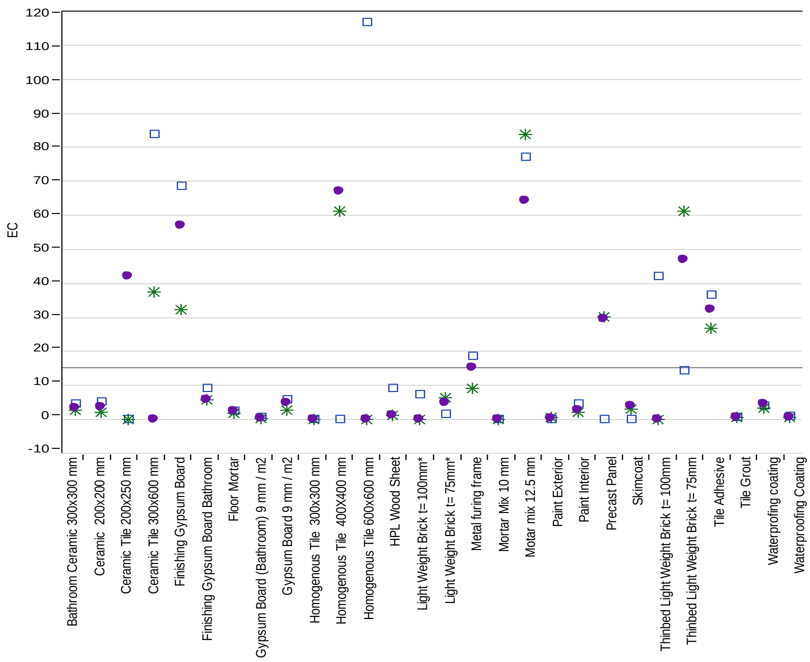
3.2.1. Selection of Material Type and Material Volume

Walls material used are summarized into eleven types of materials, including light weight brick materials with a thickness of 75 and 100 mm, precast panels, mortars mix with thicknesses of 10 and 12.5 m^2, light weight brick thinbed 75 and 100 mm^2, skimcoat, paint exterior, paint interior, waterproof coating, ceramic tile 300 mm x600 mm and ceramic tile 200 mm x250 mm. The value of embodied energy and carbon emission of each material, seen in Figures 9 and 10 below, is directly proportional, where material derived from cement such as light brick, mortar, and thinbed have the highest EE and carbon emission value followed by ceramic material.



□= Landmark Apartment ●= Parahyangan Residence ✳= Jarrdin Apartment
Figure 9 Embodied Energy of Each Building Materials

Floor materials used are summarized into ten types of materials, including floor mortar, tile adhesive, grout tile, homogeneous tile 600 mm x 600 mm, homogeneous tile 400 mm x 400 mm, homogeneous tile 300 mm x 300 mm, ceramic 200 mm x 200 mm, HPL wood sheet, 300 mm x 300 mm bathroom ceramic and waterproof coating. The dominant embodied energy and carbon emission values on the floor material, as seen in diagrams 9 and 10, are found in ceramic and adhesive materials. This result is similar to wall material. It can be concluded that ceramic and cement based material has a high embodied energy and carbon emission value in the construction of studio units for middle to lower class apartments in Indonesia.



□= Landmark Apartment ●= Parahyangan Residence ✳= Jarrdin Apartment
Figure 10 Embodied Carbon of Each Building Materials

While for ceiling materials, the highest EE and carbon emission values are found in gypsum finishing materials. Of all the material that has been calculated, it can be seen that landmark apartments always have the highest EE and carbon emission values followed by The Parahyangan Residence apartment and The Jarrdin apartment. Overall the type of material that has the most significant EE and carbon emission value is cement-based material, ceramic material and gypsum board finishing material.
There have been many studies related to cement-based materials carried out to see the importance of energy efficiency and carbon emissions reduction throughout the life cycle. Barcelo et al [11] said that the volume of Portland cement required for concrete construction makes the cement industry a large emitter of CO2. The International Energy Agency recently proposed a global CO2 reduction plan. While for the use of ceramic materials, issues that can be found besides the high value of EE and carbon emission at the manufacturing stage, there are also issues related to waste where in the installation process often found errors in cutting ceramics so there would be many remaining ceramics whose quality decreases and cannot be reused. Problems that occur in one typical unit apartment can occur in another typical unit at the same building, in other words, problems in one unit can be repeated in the entire typical unit. Therefore, it is important to know the influence of unit space dimension and modular materials, especially ceramic materials for the floor, toward the value of embodied energy and carbon emission of typical units.

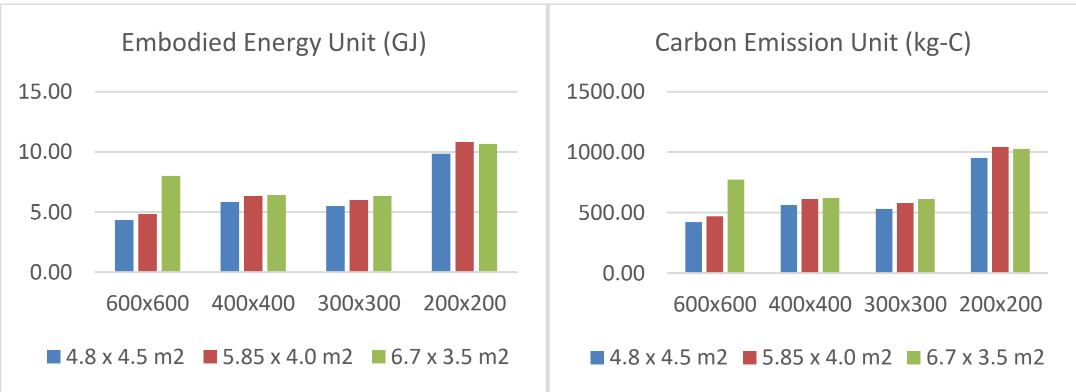
3.2.2. Space Layout and Modular Material

In studio type units, the dimensions of space greatly affect material modules, especially ceramic and ceiling materials because of the open layout (only consists of one main room and one bathroom). Previous analysis has found significant material in studio unit, for architectural work, where ceramic and cement-based materials have the highest embodied energy and carbon emission values. This analysis will compare three types of spatial dimensions from three case studies with ceramic modules commonly used in studio units (ceramic modules 600 mm x 600 mm, 400 x 400 mm, 300 mm x 300 mm, and 200 mm x 200 mm). The main consideration of this analysis is the use of minimum energy, carbon emissions and waste.

Table 3 Floor Module Analysis of Space Dimensions

	600 mm x 600 mm		400 mm x 400 mm		300 mm x 300 mm		200 mm x 200 mm	
Unit Dimension	Total Ceramics (pieces)	Total Waste (pieces)	Total Ceramics (pieces)	Total Waste (pieces)	Total Ceramics (pieces)	Total Waste (pieces)	Total Ceramics (pieces)	Total Waste (pieces)
4.8 m x 4.5 m	52	0	120	1.88	210	0	473	0.5
5.85 m x 4.0 m	58	0.96	130	2.4	229	0.83	519	5.63
6.7 m x 3.5 m	96	5.56	132	0	242	3.22	512	0

* assuming that the wall thickness is 15 cm, all ceramics cut neatly, and can be used again



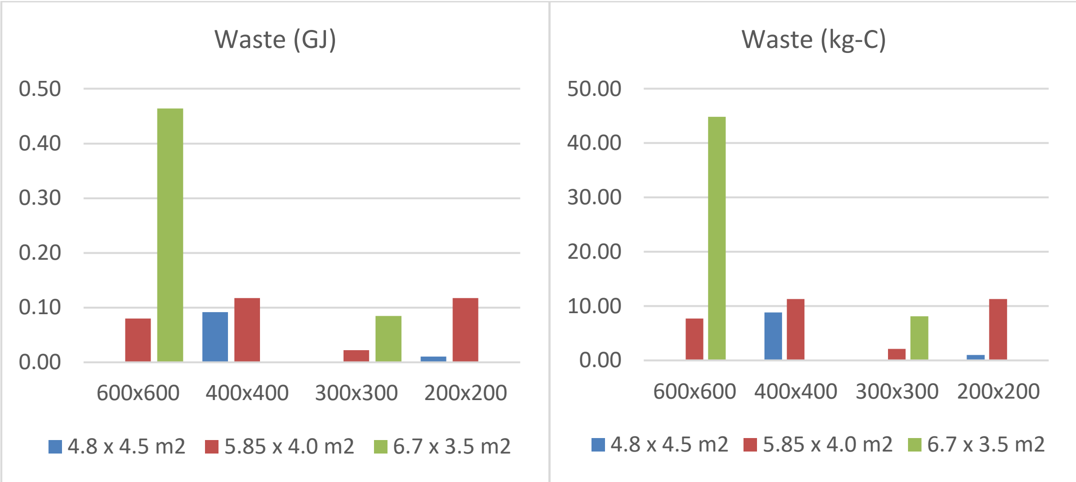


Figure 11 Influence of Modular Materials and Dimensions of Space on The Value of Embodied Energy, Carbon Emission and Waste

From the results, it was found that the dimensions of space 6.7 m x 3.5 m has the greatest waste potential, while the dimensions of space 4.8 m x 4.5 m has the smallest waste potential. While related to ceramic modules, that have the smallest embodied energy value and the smallest possible waste is a ceramic module 300 m x 300 m, since the value of embodied energy, embodied carbon and wastes is the smallest when applied to the three alternative spatial dimensions. In other words, material modules and space dimensions have a significant effect on energy savings and carbon emissions reduction for a typical unit apartment.

A number of researchers have highlighted the potential benefits in preventing or reducing demolition and construction waste (e.g. Graham and Smithers [12]; Faniran and Caban, [13]). Treloar et al [14] said that the energy embodied in the extra materials ordered to cover wastage was 4.6 per cent of the total embodied energy of the house, while most of the wasted embodied energy was in the floor, roof and wall elements, respectively. By appreciating the principles of handling and using materials on site, attitudes to prevent waste can be developed and the construction process can be managed more efficiently [15].

4. Conclusion

A case study analysis is presented in order to show how designers can understand which building component decisions consistently contribute to a building's embodied impact. Results are presented in the form of an impact allocation scheme, and an impact reduction scheme. A building's embodied impact can potentially be concentrated in the interiors. Embodied impacts on cement based material, ceramics and modular material choices are consistently the most significant, regardless of building design configuration. A designer should focus during the early design stages on these decisions that achieve a large embodied impact reduction and defer less important decisions to the design development stage.

The scope of this method is limited to interior units components for which dimensional thickness ranges can be predicted at the early design stages. Future work will consider additional sizing parameters besides thickness in order that structural components and service equipment may be included in the sizing decisions. Cost & energy of material transportation to the construction site has not been considered in this study, as it is really difficult to trace authentic source and medium of transportation of materials at site, however this may change the results. Finally, the additional case study applications will be required to comment more generally on the performance and robustness of the proposed decision support method.

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