Floor Design Strategies for Low Carbon Apartment towards Sustainable Transit Oriented Development

Dewi Larasati 1, Yulita Hanifah 2, Noveryna Dwika Reztrie 3, Fathina Izmi Nugrahanti 4
1,2,3,4 Department of Architecture, SAPPD, Institut Teknologi Bandung, INDONESIA
1 dewizr@ar.itb.ac.id

Abstract. Reconsider design strategies for apartment constructions to achieve the ideal vision of TOD can be implemented through material use. It expected people living in urban areas are increasing and the construction will be increasing. A case study analysis is presented in order to show how floor design contributes to a building’s embodied impact. Results are presented in the form of an impact allocation scheme and an impact reduction scheme. Strategies of floor material usage can be implemented by the designer to reduce carbon footprint impacts. Material finishing such as ceramics and the size of modular material consistently giving significant impact, however, the designer also needs to consider the unit layout. Waste of the material affected to give rise the carbon emission. A designer should consider the factor of carbon emission impact since the early design stages on these decisions that achieve a large embodied impact reduction.

1. Introduction

Transit-Oriented Concepts or TOD is an urban transportation strategy in the high-density area to integrate public transportation and land-use in order to create walkable, diverse neighborhoods in both center city and suburban settings [1]. This concept is expected to reduce common transportation problems in urban areas such as common transportation problems (e.g., the low usage of land resources, high environmental pollution from motor vehicle engines, over-use energy, heavy traffic congestion), and possibly achieving an ideal vision of sustainability [2]. This concept is first implemented in the U.S and the result is considered successful to reduce the problems. Therefore, many local governments in the urban city area, which confront the common transportation problem including Indonesia [3], try to implement this concept to the urban area. However, TOD is believable still primarily focus on sustainable transportation and still lack to consider the ecological and environment area, such as embodied carbon [4].

TOD is frequently associated with high-density mixed-use development; it means that TOD is associated with apartment constructions. Basically, TOD will be successful if the housing is in the proximity of the TOD [1,4], which means close enough to walk. However, housing has been the third most energy-consuming sector nowadays, which is one of the biggest carbon emission sources [5]. The construction method of a building offers a significant impact on energy use, greenhouse gas (GHG) emissions, and especially global warming potential (GWP) [6]. Furthermore, urbanization is increasing rapidly in Indonesia. It expected people living in urban areas are increasing to 305 million in 2035, which means the construction of the apartment will be increased [7]. Consequently, it is important to
reconsider design strategies for apartment constructions to achieve the ideal vision of TOD which is a sustainable urban area.

Material design and selection of building constructions are assumed to be one of the keys to reduce carbon emission [8,9]. Closer inspection in that area is important to achieve sustainable TOD. This paper will focus on floor material. This is because the floor material has a more diverse type than wall and ceiling materials. In addition, the floor material is directly related to the layout of the unit, so it can be seen which strategies are efficient to use in apartment units. The focus of the paper is to find some strategies to reduce the low carbon impact in construction apartment.

2. Methodology

2.1. Life Cycle Analysis: Input-Output Table

This study uses the LCA method as a method for calculating embodied energy and carbon emissions. There are three types of methods that can be used including input-output, process, and hybrid. The method that is considered comprehensive in calculating EE and EC is the IO table. IO method takes a top-down approach and treats the whole economy as the boundary of analysis [10]. This method approach also has economic interdependence which makes it one of its strengths compared to the process-based method because the process-based method has a limit to track all direct and indirect inputs and related environmental burdens [11].

As mentioned before, the IO table uses economic data to trace the direct and indirect input of each material. In this study, all the data were obtained from the national database of Indonesia. The economic data will be calculated with the data of Fuel Consumption, Calorific Value, and Carbon Emission Factor to obtain the intensity of embodied energy (GJ/Million IDR) and embodied carbon (kg.CO/Million IDR) [10,12]. After that, the intensity data is multiplied by the price of each material (Million IDR) used which is calculated through the quantity material data obtained from the contractor/consultant in each case. The results of these calculations will then produce data on the embodied energy (GJ) and carbon emissions (kg.CO) of each material as shown in Equation 1 below.

$$\sum_{i=1}^{n} EE_i = EEI \cdot Qty_i \cdot Price_i \cdot \gamma_i \cdot n$$

(Eq. 1)

while:

- EE : Embodied energy (GJ)
- EEI : Embodied Energy Intensity (GJ/Million IDR)
- Price : Material unit-cost (Million IDR)
- Qty : Quantity of material
- \(\gamma\) : Coefficient of material
- i : Material type
- n : Total amount

The data in the study are compared based on the area of their to be comparable. So that a comparative analysis between the work was determined using 1 m² of building area as a comparable functional unit for materials and construction stages.

2.2. Waste material analysis

In addition to calculating the embodied energy and embodied carbon in each material, this study also examines the waste materials of each flooring material of each unit to identify how effective the material modules in the flooring layout design of each unit that obtained from the Detail Engineering Drawing (DED). At this stage a calculation of the percentage of wasted material is calculated as shown in the Equation 2 below. The calculation of the quantity of floor coverings is done with the consideration that the material can be cut to 1/2 of the module and not broken or damaged.

$$\sum_{i=1}^{n} Waste material_i = \frac{\sum_{i} Material \ module \ area_i - \sum_{i} \ Unit \ area_i}{\sum_{i} \ Unit \ area_i} \cdot 100\%$$

(Eq. 2)
while:

\[ \sum_{i=1}^{n} \text{Material module area}_i = \text{Qty} \times \text{material}_i \times \text{Material module area}_i \quad (3) \]

(Eq. 3)

Table 1. Apartment description of case studies

| Apartment | Class     | Total floor | Total unit | Unit Type |
|-----------|-----------|-------------|------------|-----------|
| A         | Middle    | 18          | 425        | v v       |
| B         | Middle-Low| 23          | 1124       | v v       |
| C         | Middle    | 24          | 1318       | v v       |
| D         | Middle-Low| 21          | 704        | v v       |

Table 2. General information of studio unit of each cases

| Case Studio | Area (m2) |
|-------------|-----------|
| A           | 26.7 m2   |
| B           | 21.3 m2   |
| C           | 24 m2     |
| D           | 24 m2     |

Table 3. General information of 2-bedroom unit of each cases

| Case 2BR | Area (m2) |
|----------|-----------|
| A        | 56.5 m2   |
| B        | 34.4 m2   |
| C        | 40.5 m2   |
| D        | 33.2 m2   |
3. Result and Discussion
The results showed that the floor materials used were summarized into seven main types of material namely marble 600 x 600 mm, wood parquet 90 x 300 mm, homogeneous tile 600 mm x 600 mm, homogeneous tile 600 mm x 600 mm bathroom type, homogeneous tile 400 mm x 400 mm, ceramic tile 300 mm x 300 mm, ceramic 200 mm x 200 mm. Each main material will be constructed with layer material. Layer material consist in two material which are mortar and waterproofing. Mortar are applied in all area of the units, while waterproofing only applied in wet area such as bathroom and balcony. The description of material is explained in the Table 4.

| Main material        | Module (mm) | Layer material       | Studio (m²) | 2 BR (m²) |
|----------------------|-------------|----------------------|-------------|-----------|
| Marble               | 600*600     | Mortar               | 17,16       | 19,26     |
| Wood Parquet         | 90*300      | Mortar               | 13,50       | 20,60     |
| Homogenous Tiles     | 400*400     | Mortar + Waterproofing | 14,51   | 27,13  | 27,49 |
| Homogenous Tiles Bathroom | 600*600   | Mortar + Waterproofing | 3,26   | 4,12  | 3,14 |
| Ceramic Bathroom     | 300*300     | Mortar + Waterproofing | 3,99   | 4,24  |         |
| Total Gross Area (m²)|             |                      | 23,38       | 17,76     |

In terms of volume, the use of homogenous tile with mortar is the most used in middle class apartments (See Figure 1). The class of apartment determines the type of material used. Apartments with higher classes tend to use materials with larger module sizes and heavier model unit sizes such as marble.

![Material Use in The Apartment Unit](image)

**Figure 1.** Comparation of Material Usage in All Cases

3.1. Embodied Energy and Embodied Carbon
The dominant embodied energy values on the floor material, as seen in Figure 1., are found in marbles. Marble embodied energy is the biggest compared with any main material such as Homogenous Tiles, Ceramic and Parquet. In the studio cases, EE of marble is higher (0.319 GJ/ m²) than the 2 BR (0.173 GJ/ m²) case because all area (excluding bathroom) are use marble, however in the case of 2BR marble...
is only used as much as half of the area of the unit. The material use then affects the value of EE/ m\(^2\) that is higher than the 2BR.

**Figure 2. Comparison of Embodied Energy Material (GJ/m\(^2\))**

Homogenous Tiles also give big contribution to the EE value. Among the cases that do not use marbles, the use of homogenous tiles has the highest EE value compared to other materials. The homogenous tiles EE values have almost the same value even though the size in each case is different, in case B studio is 0.109 GJ/ m\(^2\), studio case C 0.105 GJ/ m\(^2\), studio case D 0.098 GJ/ m\(^2\), 2BR case B 0.121 GJ/ m\(^2\), 2BR case C 0.122 GJ/ m\(^2\), and 2BR case D 0.113 GJ/ m\(^2\).

Other than that, in the 2 BR case A, wood parquet is used, and the area is almost equal with the marble. However, the EE is quite low which is 0.034 GJ/ m\(^2\). It has a significant margin with the marble that has EE value with 0.173 GJ/ m\(^2\), which means EE marble is five times higher than the wood parquet. Thus, parquet can be an option because it has a low EE/ m\(^2\).

**Figure 3. Comparison of Embodied Carbon Material (kg.CO/m\(^2\))**
Compared between table 1 and table 2, most materials have a linear EE value with a CE value, except parquet. Parquet has a large CE value considering that parquet wood usually uses teak wood (long-lived wood) or wood laminated panels that require a fairly long process to get the expected quality. The process requires additional material and energy in the production or finishing process. The use of short-lived wood and with natural processes can reduce CE from parquet utilization.

From Figure 2, it can be seen that marble also has high CE value, which is 1.003 kg.CO$_2$/m$^2$ in studio case A. This is linearly match with the EE value comparison, although the margin is higher in CE. However, the wood parquet CE is higher than marble in 2BR case A, which means wood parquet is the highest CE in any materials. Based on the identified result, an attempt to reduce more embodied energy and carbon emission is needed. Marble need to be efficiently used as it is the main contributors of the EE and CE. Homogenous tiles or ceramic tile strongly suggested as main material than marble or wood parquet, as both have big contribution to the embodied carbon. Moreover, homogeneous tile and ceramic tile also shows the same pattern of the value of EE and CE.

### 3.2. Waste Material

Based on the data (see Table 5 and 6), layout unit that have most waste material is case A both in the unit studio and two-bedroom. It is because the material module that use in this case is 600*600 mm that affect on the produce off the cut off floor material. As shown on the table, material that have bigger module tend to have more waste than the smaller module. For example, waste material in the case B and D unit studio that have 300*300 mm size have more waste than material that have 200*200 mm size.
### Table 5. Comparison of waste material in unit studio

| Main material         | Module (mm) | Case A | Case B | Case C | Case D | Studio (m²) | % Waste |
|-----------------------|-------------|--------|--------|--------|--------|-------------|---------|
| Marble                | 600*600     | 17.16  | 18.18  | 1.02   | 6%     | 0           | 0       |
| Wood Parquet          | 90*300      | 0      | 0      | 0      | 0%     | 0           | 0       |
| Homogenous Tiles      | 600*600     | 0      | 0      | 0      | 0%     | 0           | 0       |
| Homogenous Tiles      | 600*600     | 6.22   | 6.84   | 0.62   | 10%    | 0           | 0       |
| Homogenous Tiles      | 400*400     | 0      | 0      | 0      | 0%     | 0           | 0       |
| Ceramic Bathroom      | 300*300     | 0      | 0      | 0      | 0%     | 0           | 0       |
| Ceramic Bathroom      | 200*200     | 0      | 0      | 0      | 0%     | 0           | 0       |
| Total                 |             | 23.38  | 25.02  | 1.64   | 7%     | 17.77       | 18.58   |

### Table 6. Comparison of waste material in unit 2 bedroom

| Main material         | Module (mm) | Case A | Case B | Case C | Case D | 2BR (m²) | % Waste |
|-----------------------|-------------|--------|--------|--------|--------|---------|---------|
| Marble                | 600*600     | 19.26  | 19.8   | 0.54   | 3%     | 0        | 0       |
| Wood Parquet          | 90*300      | 17.4   | 17.915 | 0.51   | 3%     | 0        | 0       |
| Homogenous Tiles      | 600*600     | 0      | 0      | 0      | 0%     | 0        | 0       |
| Homogenous Tiles      | 400*400     | 9.79   | 10.8   | 1.01   | 10%    | 0        | 0       |
| Homogenous Tiles      | 300*300     | 0      | 0      | 0      | 0%     | 0        | 0       |
| Ceramic Bathroom      | 200*200     | 0      | 0      | 0      | 0%     | 0        | 0       |
| Total                 |             | 46.65  | 48.51  | 2.065  | 4%     | 31.25     | 32.85   |

- Table 5: Comparison of waste material in unit studio
- Table 6: Comparison of waste material in unit 2 bedroom
Figure 4. Flooring layout of each cases

Case Studio A

Case Studio B

Case Studio C

Case Studio D

Case 2BR A

Case 2BR B

Case 2BR D

Note:
Green: Homogenous Tiles/ Ceramic
Blue: Homogenous Tiles/ Ceramic (Wet Area)
Orange: Parquete

Figure 4 show the layout of the material module. The calculation is based on the whole size and half size of the module. Based on the analysis in terms of spatial layout, unit case A is the unit that has the least possible waste, compared to other units (see Figure 4). This is because from the DED document, only a few tiles were cut-off from the area of the unit. Compared to other unit layouts, the D case unit layout has the greatest possible waste, especially in the toilet and balcony areas. It can be seen on the Figure 4 that some of the module is on the outside of the unit area, which means the cut-off material of the module.

It has been known in the previous explanation that large modules have the possibility of more residual material. In unit case D, the material module can be categorized as small, namely 300*300 mm, but the waste of material produced is quite large, reaching 70% of the total area of the unit two-bedroom. It is because the unit layout is difficult to adjust with the module size, which affects to the number of modules that are cut-off from the unit layout. If the module is replaced with a larger size, it is more likely that the material waste will be greater. Thus, it is important to assess the size of the material and the layout of the space to reduce waste on the floor material. Moreover, if the value is multiplied by the total value of the units constructed, the result will be very large.

4. Conclusion
Based on the explanation, it can be identified that every material has different embodied energy and carbon emission value. Type of material affects the value of embodied energy and carbon emissions. In this study, marble is one of the materials that have high EE and CE values. Marble need to be efficiently used as it is the main contributors of the EE and CE. Homogenous tiles or ceramic tile strongly suggested as main material than marble or wood parquet, as both have big contribution to the embodied carbon.
However, the strategy of designing unit layouts and selecting material modules is also very important in relation to environmental impacts as the more waste produce, the more material is needed. Material quantity is the key of the embodied energy and embodied carbon value of building. Embodied energy and carbon can be reduced as the waste of the material reduce. In the terms main purpose and vision of TOD, its likely very important to think how to reconsider embodied energy and embodied carbon of apartment, as the vision of the TOD is possibly achieving an ideal vision of sustainability in all aspect. As a designer, it important to 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. Implement material strategies used in buildings projects is important to carried out during the design stage. Based on the results of the analysis, it is very likely that this implementation can provide cost savings, waste reduction, and energy and carbon reduction which can certainly contribute to the vision of the TOD sustainability concept.

5. Reference

[1] J. Jacobson and A. Forsyth, “Seven American TODs: Good practices for urban design in Transit-Oriented Development projects,” *Journal of Transport and Land Use*, 2008.

[2] W.M. Wey, “A Commentary on Sustainably Built Environments and Urban Growth Management. Sustainability,” *Journal of Sustainability*, 2018.

[3] B.C. Basyir and H. Isnaeni “Maximizing RUSUNA Development in TOD Jakarta-Case Study TOD Lebak Bulus Jakarta,” *E3S Web of Conferences 3rd i-TREC 2018*, 2018

[4] W. Huang and W. Wey, “Green Urbanism Embedded in TOD for Urban Built Environment Planning and Design,” *Journal of Sustainability*, 2019

[5] K. Kensek and D. Noble, “Peran Pemerintah dalam Pembangunan SMART CITYEnergy and Buildings.,” 2015.

[6] T.J. Wen, H.C. Siong and Z.Z. Noor, “Assessment of embodied energy and global warming potential of building construction using life cycle analysis approach: Case studies of residential buildings in Iskandar Malaysia,”*Energy and Buildings*, 2017.

[7] BAPPENAS, BPS, UNFPA, “Proyeksi Penduduk Indonesia 2010 – 2035,” *Jakarta: Badan Pusat Statistik*, 2013

[8] N.D. Reztrie and D. Larasati, “Factors Influence Embodied Energy and Embodied Carbon Value at Design Phase of Low Middle Class Apartment in Indonesia,” *IOP Conference Series: Earth and Environmental Science 294 (1)*, 2018

[9] Y. Hanifah, N.D. Reztrie, T. Ramadhan and D. Larasati, “Evaluation of Material Selection on the Initial Embodied Energy Value of Low-Middle Apartment in Indonesia,” *IOP Conference Series: Earth and Environmental Science 294 (1)*, 2018

[10] U. Surahman, “Life Cycle Assessment of Energy and CO2 Emissions for Residential Buildings in Major Cities of Indonesia,” *Hiroshima University: Dissertation*, 2014

[11] S. Joshi, “Product Environmental Life-Cycle Assessment Using Input-Output Techniques,” *Journal of Industrial Ecology 3 (2), 2000*

[12] K. Nansai, Y.Moriguchi, and S. Tohno, “Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables (3EID),” *Ibaraki: National Institute for Environmental Studies Japan, 2002*