Embodied carbon analysis on multi-story building using flat slab and conventional slab system

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Abstract. Concrete is a construction material that is responsible for a large portion of carbon emissions from the construction industry due to the use of heavy-duty machines during materials processes, transportation, and concreting. Improvement of engineering design has been conducted by previous researchers to develop an eco-friendlier built environment. The use flat slab system could reduce the work quantity due to the abstain of beams as structural members. Therefore, the flat slab should be designed to independently withstand flexure during the loading action. This current study intends to compare the resulting carbon embodied in the multi-story building which uses the flat slab system to one with the conventional system. Researchers use the building of the Faculty of Physical Education Science as a case study. This research will be investigated using Building Information Modelling-based program that incorporates the ICE Database for the carbon factor. The analysis is discretized in the cradle-to-gate phase. The use of flat slabs can reduce the need for concrete and reinforcing steel materials by up to 5.767%. With the use of reduced materials, the value of embodied carbon also decreased by a percentage of 6.607%.

1 INTRODUCTION

The construction sector is one of the sectors that contributes the largest carbon emissions in the world, amounting to 31% of the world's carbon emissions in 2022 [1]. On the other hand, *the Environmental Protection Agency* (EPA) states that, of all gases contained in the atmospheric layer, CO2 is the main contributor to global warming, which is 79% in 2020 (US EPA, 2022). Furthermore, *the United Nations Environment Programme* (UNEP) states that, if Greenhouse Gas (GHG) reductions are not made immediately, then there is a possibility that global warming will exceed the threshold and will endanger lives. This indicates that CO_2 emissions must be addressed as early as possible.

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In the construction sector, carbon emissions incurred during the manufacturing, transportation, and installation of construction materials are recognized as embodied carbon. Concrete is the largest contributor to embodied carbon generated by the construction sector [3]. The amount of embodied carbon value generated by concrete comes from the use of heavy equipment during material production, transportation, and concrete moulding processes. Until now, many steps have been taken by *stakeholders* to reduce the amount of carbon emissions in the construction industry, including project management aspects in the form of green construction guidelines and low-emission material innovations [4,5]. Despite these measures, the construction industry is still one of the largest contributors to carbon emissions. This is because infrastructure development, especially reinforced concrete construction, continues to be intensively carried out so that concrete materials are still used in large quantities. Several studies have been conducted, in order to analyse the value of carbon emissions in reinforced concrete buildings [6–8]. From previous research, it was concluded that the greater the proportion of material use, the greater the value of embodied carbon generated. Therefore, one of the steps that can be taken to reduce carbon emissions in the construction sector is to minimize the use of materials which in this case are concrete in the construction process.

Currently, there is an innovation in the building structure system, namely flat slabs. The flat slab itself is a slab that is only supported by a column without a supporting beam [9] The basic difference between flat slabs and conventional slab is in the thickness of the slab used. The use of flat slabs in building structures has several advantages, including the effective height of the floor getting higher because no beams are used, flexible in the installation of utility lines and piping, simpler repeating, and simple scaffolding, and formwork [10]

Research on the effectiveness of structural flat slab application has been conducted by Pradana et al. [11] In their research, Pradana et al. [11] compared the seismic base shear value, fundamental period, structural stiffness value, service limit and ultimate performance, and the maximum deviation value of flat slabs and conventional slab in the building of the Faculty of Sports Sciences, Universitas Negeri Malang (FIK UM). In the results of the analysis, it was found that the difference in structural rigidity between conventional slab and flat slabs reached 10 times, but the value of the floor deviation of flat slab structures was still below the safe limit of service limit and ultimate performance. So it was concluded that the flat slab system would be effective when applied to the FIK UM building.

In this study, the author will analyse the value of embodied carbon (CO_2-e) generated by the construction of the FIK UM building which has previously been analysed structurally including the conventional slab structure system and flat slabs. The analysis was carried out to determine the comparison of the value of embodied carbon caused and the extent to which material reductions can be made with structural modifications which are ultimately used as considerations for determining low-emission building designs.

2 METHOD

2.1 Research Design

This research was conducted using the Tekla Structural Designer (TSD) 2022 Educational Version to analyse the embodied carbon value generated by the building of the Faculty of Sports Sciences, State University of Malang (FIK UM) which was designed with a conventional slab system and flat slabs. The FIK UM building consists of 7 floors and 1 semi-basement floor. In this study, no structural analysis was carried out because the review had been carried out by Pradana et al. [11]. The dimensions of conventional slabs used in buildings are presented in Table 1.

Table 1. Dimensions of portal slab elements of conventional slab systems

Floor	Type	Thickness (mm)
1-3	S12	120
	S15	150
4	S14	140
	S15	150
5-6	S12	120
	S15	150
7-Roof	S15	150

Building with a flat slab system, the slab was designed using dimensions of 8000 × 8000 mm with a thickness of 240 mm. Drop panel or thickening on the column head with dimensions of 3000 × 3000 mm and 100 mm thick.

Modelling on TSD was carried out sequentially starting from columns, beams, and slab in buildings with conventional slab systems and columns as well as slab and drop panels in flat slab designs. Building models with conventional slabs and flat slabs are presented in Figure 1 and Figure 2.
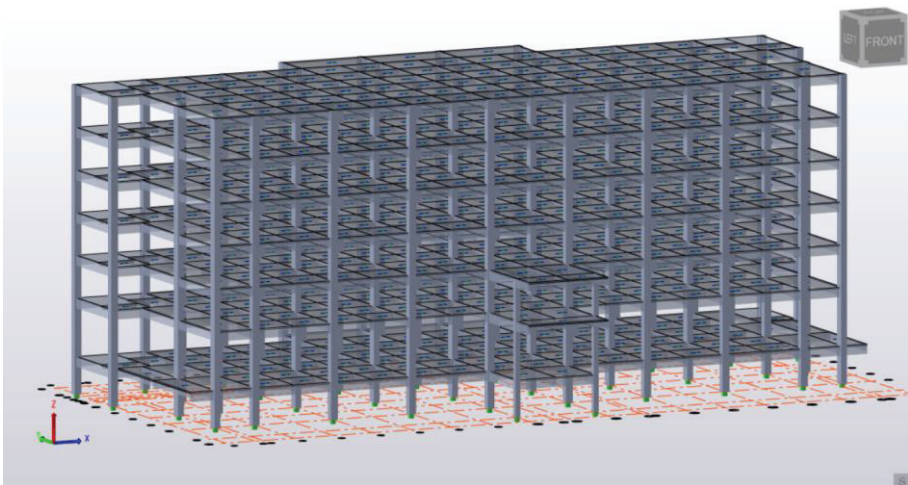
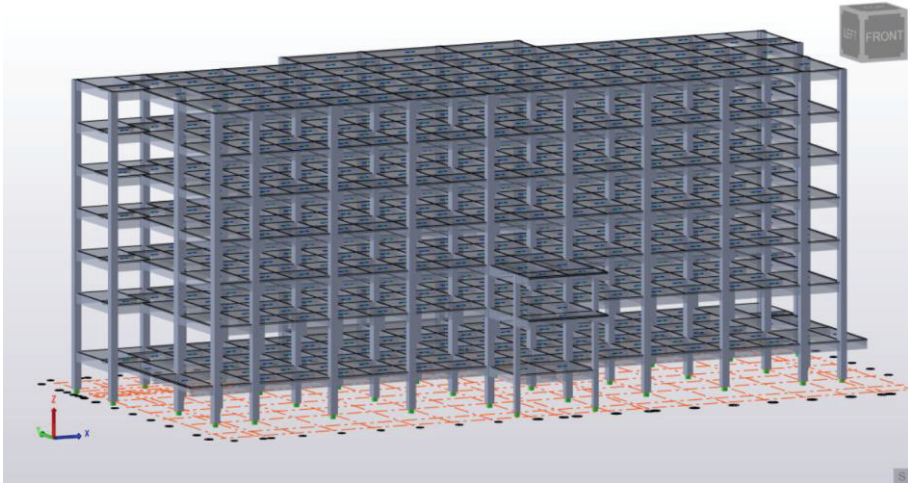**Fig. 1.** Building structure using conventional slab.

Fig. 2. Building structure using flat slab.

Once the model is complete, it is validated to check if any components are clashing between elements in the model. After the model was confirmed to be free of clash, structural validation was also carried out with the value of the loading assumption following the numbers used in the research of Pradana et al.[11]. Structural validation is carried out so that TSD can dense seize reinforcing steel on all structural elements as needed based on the loading assumptions applied so that a full embodied carbon value for reinforced concrete will be found. Embodied carbon analysis will be carried out in the cradle-to-gate phase or production stage.

2.2 Value of Carbon Factors

The carbon factor value used in the calculation is obtained from The Inventory Carbon and Energy (ICE) database or known as the ICE Database. The ICE Database is a lifecycle database representing a range of building and construction materials developed by Dr. Craig Jones while working at the Sustainable Energy Research Team (SERT), University of Bath, United Kingdom. ICE contains data specific to the UK, Europe, and Global average [12]. The carbon factor values used in the analysis are presented in Table 2.

Table 2. Dimensions of portal slab elements of conventional slab systems

Materials	Type	Specification/details	Default Value
Materials	Type	Specification/details	Default Value
Concrete	In situ (unreinforced)	Global average (excluding China)	0.175

3 Result and Discussion

3.1 Ratio of Slab Volume to Total Volume in Conventional Slab and Flat Slab Buildings

The calculation of the volume of concrete and reinforcing steel materials required by the 7-story portal of the FIK UM building is carried out automatically using Tekla Structural Designer. At the time of modeling, buildings were modeled with concrete elements without

reinforcement. Furthermore, in order to bring up the design of reinforcement on the portal, a static analysis was carried out with the assumption that loading was equated with the research of Pradana et al. [11]. The total material requirement can be seen through the Review feature on TSD. This feature allows TSD to display the amount of material requirements in predetermined units. The material will be automatically divided into reinforcing steel and concrete, which are the constituent components of the reinforced concrete portal. Based on the analysis conducted, it was found that the material required for the portal with a flat slab system was less than the conventional slab with a difference of 567366.6800 kg as presented in Figure 3.
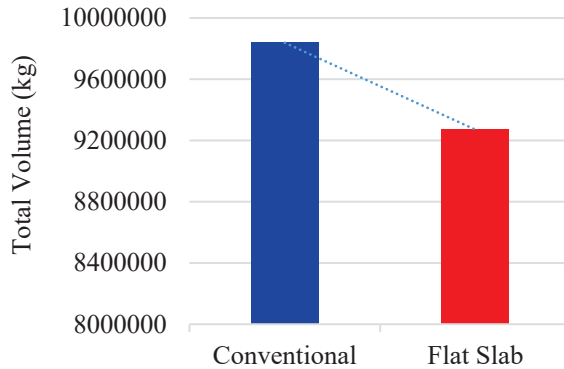
Fig. 3. Graph of the material structure-volume system relationship

In buildings with conventional slab systems, slab occupy the second position with a percentage of needs reaching 35.676%. Meanwhile, the number of material needs for beams and columns is 45.279% and 19.044% of the total needs for reinforcing steel and portal concrete, respectively. While in buildings with flat slab structural systems, slabs and drop panels take the largest percentage, amounting to 81.531% of the total need for reinforcing steel and portal concrete. While the column requires 18.469% material. The percentage of contribution of material requirements for each structural element in both buildings with conventional slab systems and flat slabs is presented in Figure 4.
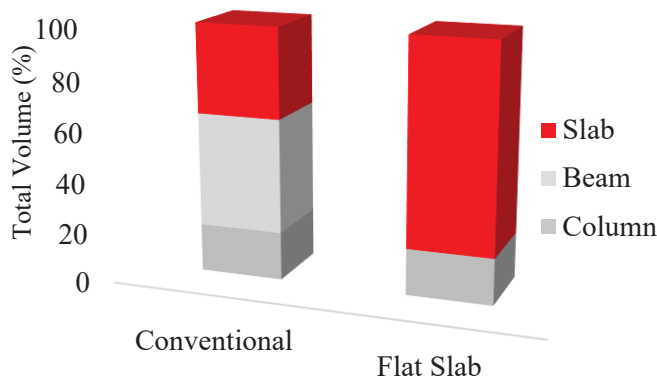

Fig. 4. The percentage of contribution of structural elements to the volume of portal material

The significant difference in the volume of slab material in buildings with conventional slab systems and flat slabs is due to the fact that in buildings with conventional slab, the thickness of the slab used is thinner. In addition, in buildings with conventional slab, it is necessary to have beams with predetermined dimensions so that although the material requirements for slab are not as large as slab in flat slab buildings, buildings with conventional slab systems require more material. In buildings with flat slabs, the volume of slab is very large, reaching more than ¾ of the volume of material of the entire portal because the thickness of the slab used is 2 times the thickness of conventional slab. However, the total volume of material required is actually less due to the absence of the use of beam. The load received by the slab is directly channeled to the column through drop panels or thickening at the column head so that the building remains structurally safe.

3.2 Ratio of Slab Embodied Carbon to Total mbodied Carbon in Conventional Slab and Flat Slab Buildings

The embodied carbon analysis conducted in this study was limited to the Cradle-to-gate stage or production stage. This is based on the analytical skills possessed by TSD as the main tool in analysis. The cradle-to-gate stage or the production stage itself consists of the raw material supply phase, raw material transportation, and manufacturing processes. Based on data obtained from the [13] cradle to gate stage is the largest contributor to emissions during the life cycle of buildings. The basic principle of embodied carbon calculation is to multiply the volume of the material by the value of the corresponding material carbon factors. Thus, the volume value of material and embodied carbon is always directly proportional. Carbon factors that are multipliers in the calculation of embodied carbon are the value of carbon dioxide emissions or Carbon dioxide equivalent emissions (kgCO2e) per unit of product expressed in $kgCO_2e/kg$ or $kgCO_2e/m^3$ ([14]. The carbon factors used in this study was the default values recommended by The Inventory of Carbon and Energy (ICE) for several materials considered.

The process of analyzing the embodied carbon value on the portal of the FIK UM building is carried out using the Embodied Carbon Factors feature which is a superior feature of TSD. A recapitulation of the total embodied carbon value for 1 portal will be shown in the upper left corner of the TSD window as presented in Figure 5 and Figure 6.
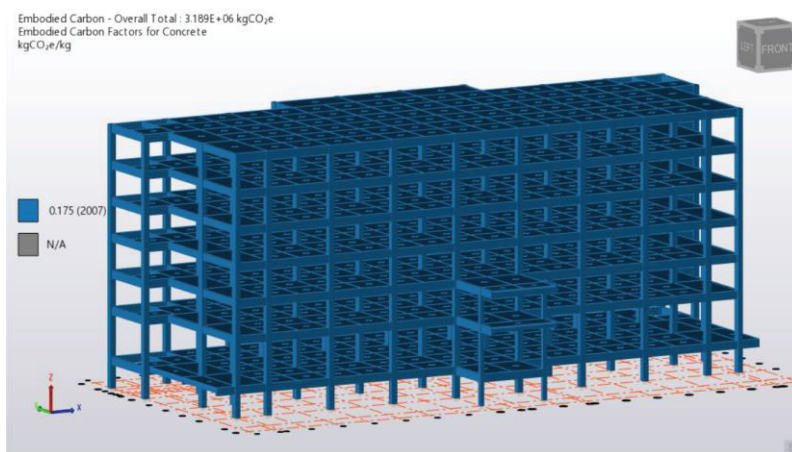

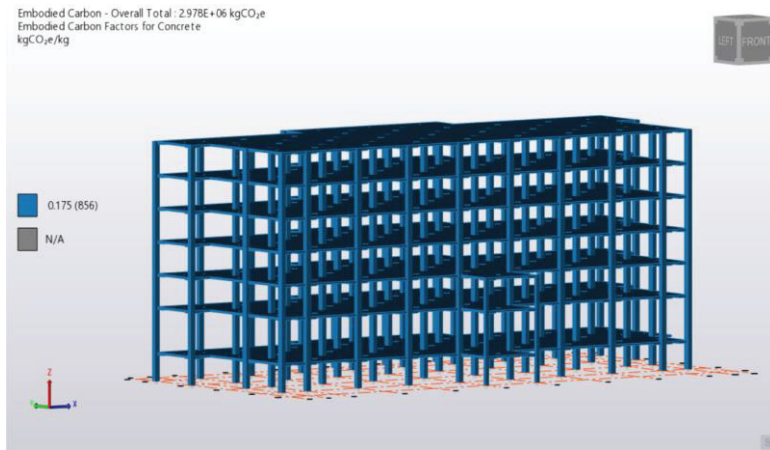**Fig. 5.** The value of embodied carbon in conventional slab buildings

Fig. 6. The value of embodied carbon in flat slab buildings

To facilitate the identification of elements that produce the largest embodied carbon value, TSD provides a review feature to display the embodied carbon amount of each structural element that is distinguished in colour scale as presented in Figure 7 – Figure 10.
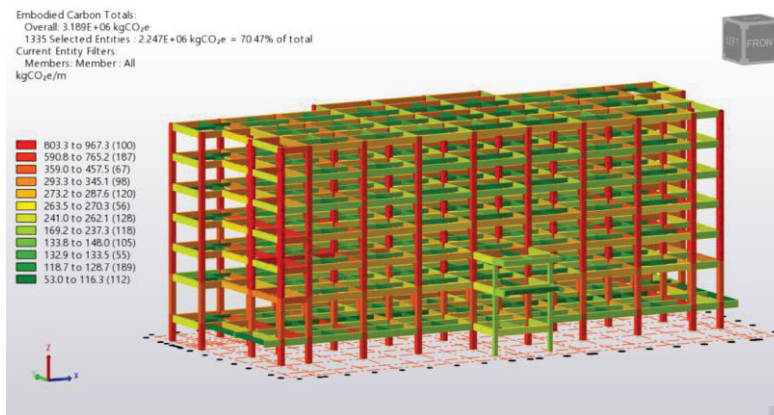

Fig. 7. The value of embodied carbon of beam and column in conventional slab structure system
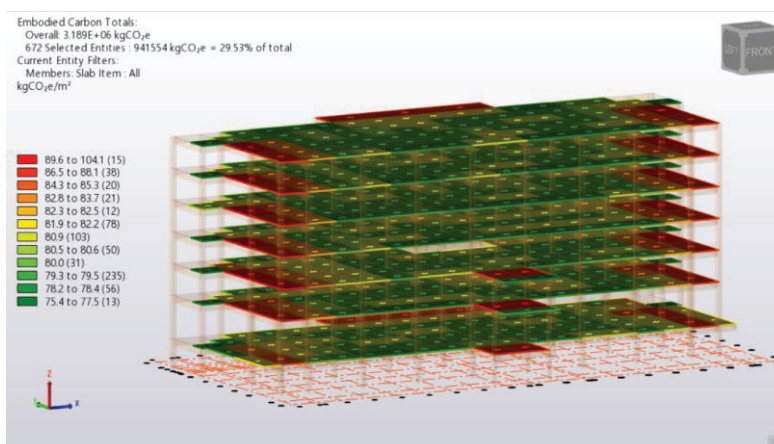

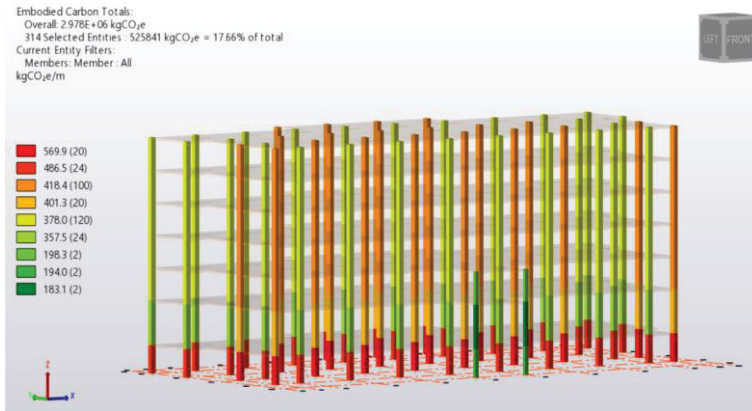**Fig. 8.** The value of embodied carbon of slab in conventional slab structure system

Fig. 9. The value of embodied carbon of column in flat slab structure system
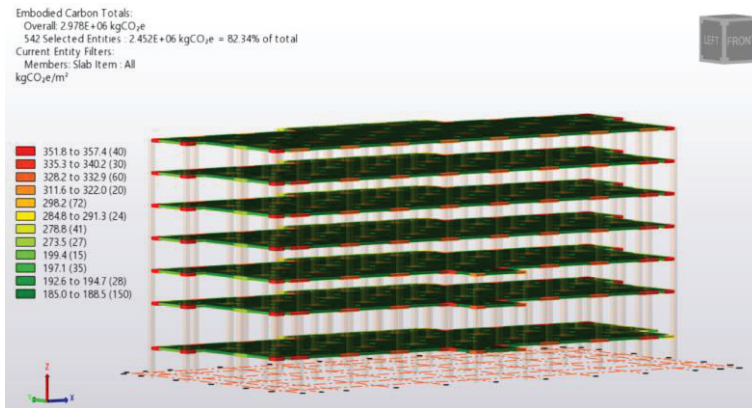

Fig. 10. The value of embodied carbon of slab in flat slab structure system

Based on the analysis conducted, it was found that the value of embodied carbon produced by buildings designed with a flat slab structure system was smaller than buildings designed using conventional slab systems with a difference of 210681.0067 kg CO_2e as presented in Figure 11. This is in accordance with the statement in Subchapter 3.1 which states that the volume of material and embodied carbon generated is always directly proportional. Therefore, when the volume of portal material with a flat slab system is smaller than a portal with a conventional slab structure system, the embodied carbon value will produce a similar value.

In buildings with conventional slab systems, slab contribute 29.529% to the total embodied carbon from portals. While the largest contributor is beams with a percentage of 43.636% and followed by columns with 26.835%. While in buildings with flat slab structural systems, slab and drop panels contributed the most, namely 82.342%. While columns contribute 17.658% to the total embodied carbon portal. The significant difference in the contribution of slab to embodied carbon in conventional slab buildings and flat slabs is due to the difference in total material in the two elements due to the removal of beams in flat slab buildings so that the slab is thickened and added with drop panels. The percentage contribution of structural elements to the value of embodied carbon portals is represented by Figure 12.
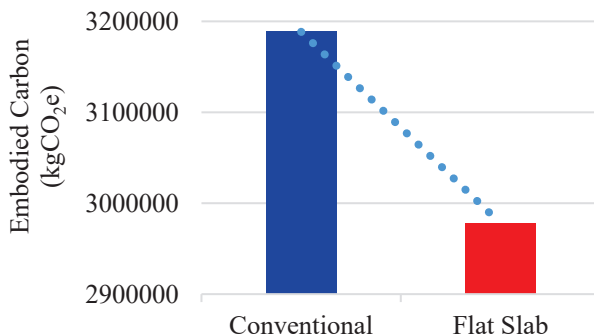
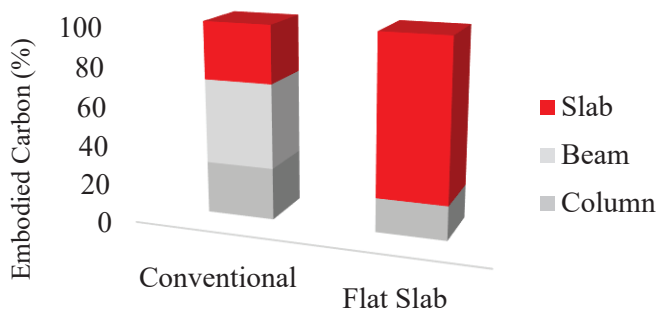**Fig. 11.** Graph of the structure-value system relationship of embodied carbon

Fig. 12. Percentage contribution of structural elements to embodied carbon value

3.3 Cost-to-Benefit of Using Flat Slabs over Conventional Slab

Based on the explanation of subchapters 3.2 and 3.3, it is concluded that the use of flat slab systems in building portals can reduce the use of concrete and reinforcing steel materials which in turn can reduce the embodied carbon caused. Based on the calculations that have been done, the use of flat slabs can reduce total material requirements by up to 5.767%. With the use of less material, of course, the embodied carbon value generated by the construction of the FIK UM portal is less, which is reduced by 6.607% against portals with conventional slabs. In addition to the use of flat slabs can make implementation simpler, precisely in the ironing process and scaffolding installation [15], fewer materials are needed so as to reduce carbon emissions, the use of flat slab systems can also reduce development costs by 19% and the duration of implementation by 17% [16].

Furthermore, based on a structural review conducted by Pradhana et al. (2019), the use of flat slabs remains effective for use in FIK UM building structures. With a reduction in concrete material of 396633.2400 kg and reinforcing steel of 170733.4400 kg, the performance of the structure has indeed decreased but still remains below the safe limit of service limit and ultimate performance so that it remains effective for use. The use of less material and the performance of the structure remains safe to apply will certainly provide benefits both in terms of finance and in terms of emissions caused.

4 CONCLUSION

The use of flat slabs on portals can reduce the need for concrete and reinforcing steel materials by up to 5.767%. With the use of reduced materials, the value of embodied carbon also decreased by a percentage of 6.607%. With the use of small materials and reduced emissions, as well as the performance of structures that are safe to apply, the use of flat slabs in the FIK UM building is effective.

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