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COMPARATIVE STUDY OF CARBON EMISSION AND PRICE ON THE ALTERNATIVES OF BUILDING WALL CONSTRUCTION

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ABSTRACT

The Indonesian government wants to meet the demand for housing by increasing housing development. However, the increase in housing development also contributes to a large percentage of carbon emissions. Therefore, it is necessary to evaluate autoclaved aerated concrete (AAC), a commonly used wall material, and precast sandwich panels (PSP), which have low emissions. The research was conducted to determine how the two materials compare prices to meet housing needs and emission reduction goals. The study is carried out by its price to meet the demand target and Life Cycle Assessment (LCA) to meet the emission reduction target. The subject of the study is one of a complex of 40 types of house buildings. Their wall construction cost and transportation cost determine the price. LCA approached the method with a cradle-to-handover framework, which is used to identify the carbon embodiment of a building. The results show that PSP walls cost 53.30% more to build than AAC walls but produce 37.20% less carbon emissions. The highest emissions occur during the production/manufacturing phase. Future studies could adopt a cradle-to-grave LCA framework to provide a more comprehensive assessment.

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1. Introduction

The Ministry of Public Works and Public Housing (PUPR), through the Directorate General of Housing, targets 70% of households to live in decent houses by 2024 (Rafie, 2024). The increase in housing production is also the government's fulfilment target in covering the gap between the number of houses built and the number needed by the community, which is called the housing backlog and according to data from the Ministry of Public Works and Public Housing (PUPR), 2023, an imbalance or backlog reached 12.7 million, which increased in the previous year by 1.7 million (Brilian, 2024). Along with the increase in housing needs, environmental aspects are closely related to the increase in housing production in terms of sustainability. Environmental concerns compound the challenge of meeting housing demands, as the construction sector is a major contributor to global carbon emissions, accounting for nearly 40% of total emissions, with significant portions arising from the embodied carbon building materials (Hunt & Osorio-Sandoval, 2023). The Indonesian government also has a carbon reduction aim as Indonesia's Enhanced Nationally Determined Contribution (ENDC) commits the country to a 31.89% reduction in emissions from business-as-usual levels by 2030 without international support and a 43.20% reduction with global backing. The government aims to achieve net zero emissions by 2060 (Indonesia, 2022). The Indonesian government seeks to meet the housing demand and decrease long-term carbon emissions.

Type 40 houses are popular in Indonesia, especially in big cities such as Semarang Regency. Its characteristic of being between type 36 and 60, with enough space for small families, makes it a choice for the middle class. The demand for type-40 homes is driven by the growth of young families looking for affordable housing that still meets their space needs. Consumer income and market prices influence the demand for such housing, which dictates the options available to potential homeowners (Mohebbi et al., 2023). It also shows that type 40 houses often have attractive minimalist designs and more affordable prices, making them suitable for young couples and small families of three to four people (Wiraciptagroup, 2023). Type 40 houses are seen as one way of solving the problem of housing needs because they are affordable and have enough space. However, they need to be increased in number to meet demand.

Furthermore, according to a report by the Global Alliance for Buildings and Construction (GABC, 2020), the construction sector accounts for about 39% of global carbon emissions, with 11% coming from the embodied carbon of building materials. This figure shows that operational emissions, which include energy used for lighting, heating, and cooling buildings, account for 28% of total emissions. Another 11% comes from embodied carbon emissions generated during the life cycle of building materials, including production, transportation, and installation. Adopting more sustainable construction practices to reduce both types of emissions is essential. Research shows that applying green construction materials and efficient design and use methods can significantly reduce carbon emissions in the construction sector (Narumi et al., 2021). When viewed from the context of building elements, the wall is a component that plays a significant role in the use of these materials because the wall is the component that has the most enormous volume in buildings, including houses. Mazur & Olenchuk (2023) stated that wall material, especially external walls, can account for the highest of the total embodied carbon in masonry buildings with 34,70%. In addition, walls also have a high proportion of the cost and the longest processing time in the building construction process. The larger the wall volume, the higher the embodied carbon produced. Thus, optimizing wall materials and design is a strategic step in reducing carbon emissions in the building sector.

One innovative approach to mitigating embodied carbon in the construction sector is precast construction systems. Precast technology, which involves prefabricating building components off-site, has shown significant potential in reducing carbon emissions. Precast walls, as one of the most common building elements, have been the focus of attention of researchers and construction practitioners. Several studies have confirmed several advantages of precast walls in the context of sustainability. Research indicates that using precast construction systems can significantly reduce carbon emissions associated with building activities. Precast walls, manufactured off-site, can decrease construction time by 30%-40%, reducing energy consumption and emissions related to construction processes (Son et al., 2021). According to another study, the life-cycle environmental impacts contributing towards GWP were 48% lower for precast than cast-in-place (Vasishta et al., 2023).

This reduction in construction time has direct implications for reducing carbon emissions associated with construction activities, such as energy and equipment use. In addition, precast systems also offer efficiency in terms of logistics and transportation. This is due to optimization in transportation planning and using more efficient vehicles to transport the assembled precast components. Overall, precast walls have great potential to contribute to the decarbonization of the construction sector. The advantages of precast walls in terms of construction time efficiency, logistics optimization, and potential use of sustainable materials make them an attractive alternative for reducing embodied carbon in buildings. According to research by. Compared to conventional methods, precast concrete façade walls can reduce carbon emissions through waste reduction and transportation efficiency (Antoni et al., 2022). In addition, using specialized vehicles for transporting precast elements and designing smaller modular elements can further improve logistical efficiency and reduce the construction process's environmental impact.

Several prefabricated wall models are developing today, including sandwich panel prefabricated walls. In Indonesia, Semarang district is one of the factories that produce prefabricated walls, including sandwich panels. Linking back to the embodied carbon aspect of buildings, other research shows that precast construction methods produce lower carbon emissions than conventional methods, mainly due to reduced material waste and logistical efficiency (W et al., 2022). Type 40 houses can be developed into a modular building type in terms of their wall components. Based on this, there is an opportunity for further discussion regarding the identification of the role of the use of prefabricated materials of the sandwich panel wall type in reducing the embodied carbon of the building and knowing the cost comparison with the use of AAC brick walls in the study of type 40 houses located in Semarang Regency. In understanding the process, the analysis method in Life Cycle Assessment (LCA) theory is used as a parameter to evaluate environmental impacts, especially carbon emissions from a product, material, or process during its life cycle. In the context of buildings, LCA is the main parameter for assessing embodied carbon, which is the carbon emissions generated during the entire life cycle of building materials. Using LCA, the information obtained can assist in making more sustainable and efficient decisions in material selection and car production processes. (Hao et al., 2020; Razali et al., 2017). The integration of Life Cycle Assessment (LCA) methodologies in evaluating the environmental impact of construction materials is critical for making informed decisions that prioritize sustainability (Hunt & Osorio-Sandoval, 2023). The cradle-to-handover LCA framework was chosen because the factors used in the assessment are relatively the same and do not include the behavior of building occupants, which makes the building more effective in the operational stage (Gámez-García et al., 2018). As seen in another study, the stage with the most significant environmental impact in all the categories was the production/manufacturing stage, which was more than 92.3% aggravating climate change (Gámez-García et al., 2018).

Building Information Modeling (BIM) uses three-dimensional digital models to describe the physical and functional characteristics (Ministry of Public Works and Housing, 2018). With BIM, all critical information about the design, construction, and maintenance of a building can be integrated into one platform, enabling better collaboration between all parties involved in the project. In this context, the Life Cycle Assessment (LCA) analysis method can be enabled to evaluate the environmental impact of products, focusing on carbon emissions generated from the "cradle to gate" stage. Integrating BIM with LCA enables a more accurate calculation of greenhouse gas emissions, as the material data generated from the BIM model can be used to calculate the carbon footprint based on the design model. Another study emphasized the importance of optimizing low-carbon material types using BIM data to significantly reduce transportation and construction carbon emissions (Hammond, 2011). In addition, a study by Lima et al. (2024) emphasized that integrating these two methods (BIM & LCA integration) is effective in assisting in selecting materials with a lower carbon footprint, thus supporting sustainability goals in the construction industry. Hence, the combination of BIM and LCA is limited to improving design efficiency and can contribute to studies identifying overall carbon emission reductions. Finally, the research determined how the two materials compare prices to meet housing needs and emission reduction goals. The study is carried out by its price to meet the demand target and Life Cycle Assessment (LCA) to meet the emission reduction target.

2. Literature Review

A literature study was conducted in ten journals using the keywords "cast in situ," "prefabrication," "carbon assessment," "cost," and "BIM." Some journals discussed how the method aims to help increase understanding of how to conduct the study. Then, the 10 journals that matched the topics are from Suryapratama et al. (2024), Ji et al. (2020), Sandanayake et al. (2019), Oei & Sukantara (2023), Uda (2021), Gao et al. (2024), Hao et al. (2020), Razali et al. (2017), Agustiningtyas et al. (2023).

From the following ten journals, several stages, and methods are used to assist in finding cost data and carbon assessment on precast wall materials and AAC brick types, which are then compared to write this study. The important thing in understanding the first initial stage of the study is how to calculate costs and what data is needed in calculating material costs, such as calculating the volume of precast walls and AAC bricks and the total cost of precast walls and lightweight bricks (Suryapratama et al., 2024). Meanwhile, according to Oei & Sukantara (2023). Calculating the Draft Budget Cost requires the unit price of work (HSP) and the work coefficient index based on the Minister of Public Works and Public Housing Regulation No. 1 of 2022. Volume in the form of Quantity Take-Off (QTO) is obtained from BIM.

Secondly, in assessing carbon emissions, LCA (Life Cycle Analysis) can be used to understand the framework and the data needed to conduct LCA. Life Cycle Assessment (LCA) is a technique used to assess the environmental impacts associated with a product by compiling and making an inventory of inputs and outputs related to the product. The potential environmental effects associated with these inputs and outputs are evaluated by interpreting the inventory analysis and impact assessment phase results. LCA is one way to determine the material use cycle of a product, which is identified from the beginning (raw material) to the end to assess the impact it causes (Agustiningtyas et al., 2023; Gao et al., 2024; Hao et al., 2020; Ji et al., 2020; Oei & Sukantara, 2023; Razali et al., 2017; Sajid et al., 2024).

Furthermore, LCA has a framework that is used for environmental impact assessment with the stages of the flow of material (product) use from manufacture or material (cradle to gate), material delivered to the site (cradle to site), construction material on site into buildings (cradle to handover), operation and maintenance of buildings (cradle to end of use), buildings in demolition (cradle to grave), material reused (cradle to cradle) (Agustiningtyas et al., 2023; Gao et al., 2024; Oei & Sukantara, 2023; Razali et al., 2017), 2023; Gao et al., 2024; Hao et al., 2020; Ji et al., 2020; Oei & Sukantara, 2023; Razali et al., 2017; Passer et al., 2017).

3. Research Method

This study, conducted in 2024, compares the carbon emissions produced by constructing type 40 house walls in a housing area in Ungaran Timur District, Semarang Regency, Central Java. The compared materials are Autoclaved Aerated Concrete (AAC) bricks and Prefabricated Sandwich Panels (PSP). PSP has EPS (Expanded Polystyrene) as the inner core and Calcium silicate board as the outer layer. The assessment was carried out using a Life Cycle Assessment (LCA) from cradle to handover, encompassing the production phase (A1-A3), transportation from the factory to the site (A4), and the construction process (A5) (Gámez-García et al., 2018; Hemmati et al., 2024; Li & Masera, 2024)Thus, this research can inform developers and policymakers when planning and developing housing projects.

At this stage, it is discussed how the object will be used as a study, starting from the stage of making a BIM model, the stage of calculating the price of 2 precast material schemes and AAC bricks from the total material price plus transportation prices, and then the stage in carbon calculations that use the cradle to handover so that it requires scenarios from material production, transportation to the construction site, and construction scenarios.

3.1 BIM Modelling Stage

This stage started with creating two models of type 40 buildings in Revit. The building is 6 meters (m) times 8 m tall, with two private rooms, one bathroom, and one living room. The building uses AAC bricks wall material with dimensions of 60 centimeters (cm) long, 20 cm wide, and 7.5 cm thick, and Precast Sandwich Panel wall parameters with modules 300 cm long, 60 wide, and 7.5 cm thick, as presented in Figure 1.

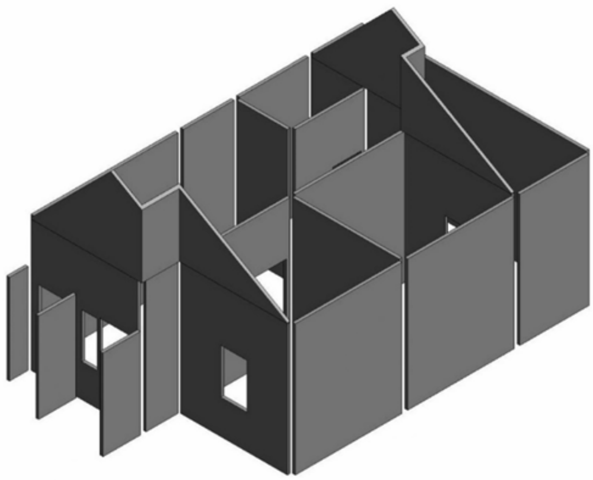


Figure 1. Wall Model of Type 40 Housing

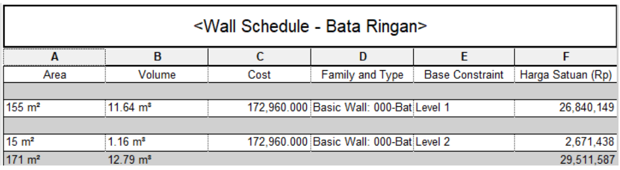
Table 1. Data and Data Source

Required Data	Data Acquired	Data Source
Embedded Carbon	**28 $KgCo_2/Kg$**	Carbon Calculator

Required Data	Data Acquired	Data Source
AAC Brick $KgCo_2/Kg$ Embedded Carbon PSP $KgCo_2/Kg$	**3.29 KgCo2/Kg**	Library Razali et al. (2017)
Factory and Distributor Distances	Distance from Factory (Mojokerto) to Distributor (Demak) = **309 Km**, Distance from Distributor (Demak) to Site (Ungaran) = **42 Km**	Survey
AAC brick cost	**Rp 172,956.00**	AHSP, Semarang Regency
PSP cost	**Rp 572,381.00**	Personal Analysis Based on AHSP
AAC brick density	**700 kg/m2**	Material product catalogue
PSP density	**510 kg/m2**	Sajid et al. (2024)
AAC brick construction duration	**70 m²/ hari**	Benchmarking with data from (Suryapratama et al., 2024)
PSP construction duration	**11 m²/ hari**	Benchmarking with data from (Suryapratama et al., 2024)
Embiod Carbon Diesel	tank-to-wheel emissions of **2.56 $kgCO_2$** per litre well-to-tank emissions of **0.61 $kgCO_2$** per litre well-to-wheel emissions of **3.17 $kgCO_2$** per litre	(Carbon+Alt+Delete, 2024)

3.2 Total Construction and Transportation Price Calculation Stage

We will start by analyzing the unit prices (AHSP) of work on Precast Sandwich Panel walls and AAC brick walls. Then, enter the AHSP parameters of precast sandwich panel walls and AAC brick walls in the Revit wall schedule to determine the cost needed to build the wall components of one type 40 house. Figure 2 shows an example of the calculations of volume and price by scheduling Revit.



<Wall Schedule - Bata Ringan>

A	B	C	D	E	F
Area	Volume	Cost	Family and Type	Base Constraint	Harga Satuan (Rp)
155 m²	11.64 m³	172,960.000	Basic Wall: 000-Bat	Level 1	26,840,149
15 m²	1.16 m³	172,960.000	Basic Wall: 000-Bat	Level 2	2,671,438
171 m²	12.79 m³				29,511,587

Figure 2. The Total Cost Calculation of AAC Bricks Using Revit Wall Schedule

The Revit scheduling found that the volume of wall building is 171 m^2. The unit price found is the cost of building 1 m^2 of AAC brick wall, which is Rp 172.950, and PSP is Rp 572,381. The total wall construction price of the AAC brick wall is Rp 29,575,476 and Rp 97,877,151. The total cost must be added to the transportation cost because it's not included. The cost of labor, tools, and machines is already included in calculations of unit price or AHSP. The cost of transportation is the same in AAC brick and PSP because the transportation cost is assumed to be calculated from the distributor to the site as per ride cost. The AAC material scenario costs Rp.29,925,476, and the PSP is Rp 98,227,169.

3.3 Carbon Calculation Stage

The LCA framework used is cradle-to-handover, with carbon calculations divided into the stages of the production process of making wall materials, transportation of materials to the site, and the construction process.

A. Material Production Stage

Calculation of production process carbon according to Gao et al. (2024) Using the formula (1):

$$P_{MT} = \sum_{k=0}^{n} Q_i \, x E_{iCO_2} \quad (1)$$

P_{MT} is the total carbon emission in the production phase ($KgCO_2$), Qi material volume (kg, m^2, m^3), and E_iCO_2 multiplier factor for carbon embedded material (kgCO2/kg, $kgCO_2/m^2$, $kgCO_2/m^3$). We can also perform carbon calculations in the production phase using the Revit plugin carbon-life calculator.

B. Transportation Stage

Precast sandwich panel material flows start from the factory in Mojokerto City, move to the distributor in Kendal City, and then to the site in Ungaran, Semarang Regency, with a distance of 351 km. The vehicle used is a 10-ton truck, with the number of transports once by truck (fill / empty) when returning with a distance of 42 km, so the total vehicle mileage is 393 km. PTT is the total carbon emissions at the transportation stage (KgCO2), TDi is the total vehicle mileage, EiVCO2 is the transportation embedded carbon multiplier (kgCO2/kg, kgCO2/m2, kgCO2/m3), or, using the Revit plugin, the carbon-life calculator, as example seen in Figure 3.

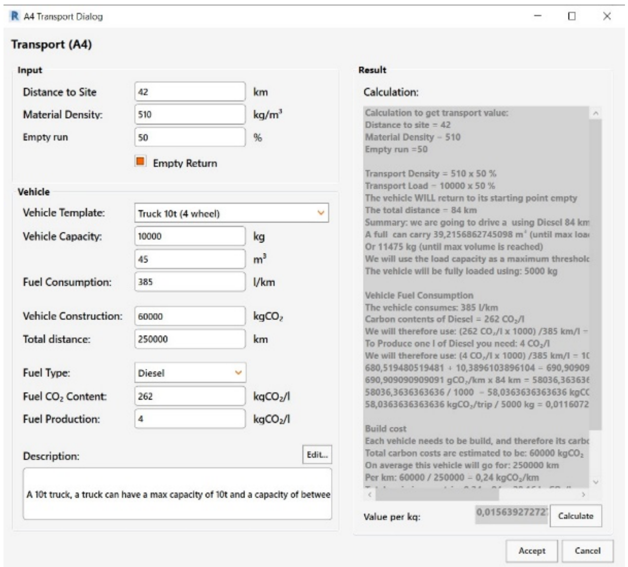


Figure 3. Carbon Coefficient Calculation of Transportation Stage Example

The flow of AAC brick materials is transported from the factory (factories and distributors in one city) to Kendal city, then to the site, 42 km located in Ungaran, Semarang Regency. The vehicle used is a 10-ton truck, with the number of deliveries once. With the car (fill/empty) when returning with 42 km. So, the total distance is 84. The construction scheme will use a crane by rental, and the crane distance to the site is 5 km back and forth from the collection warehouse to the site. Calculation of carbon emissions according to the transportation stage according to Gao et al. (2024) using the formula (2):

$$P_{TT} = \sum_{i=I}^{n} TD_i \times E_{iv\,CO_2}$$

C. Construction Stage

The building will be built in Kalongan, Ungaran, with many buildings in one complex of 45 houses, and the size is 40m^2. The construction scenario is built one by one because the building will be built if there is already a buyer, so there is no need for a warehouse. In constructing precast materials using heavy equipment cranes with a load specification of 1.3 tons for 7 hours per day as per data in Table 1 and transportation from the crane rental place is 5 km from the site so that the diesel fuel consumption used in the construction phase amounts to 19.9 liters.

Table 2. The Total Material Cost of Two Material Schemes

Material Scenarios	Wall Areas (m^2)	AHSP/ Unit prices (Rp)	Total Material Cost (Rp)
AAC Brick	171 m^2	172.956	29.575.476
Precast Sandwich Panel (PSP)	171 m^2	572.381	97.877.151

Table 3. The Total Cost of Two Material Scenarios

Material Scenarios	Transportation Cost (Rp)	Total Material Cost (Rp)	Total Cost (Rp)
AAC Brick	350.000	29.575.476	29.925.476
Precast Sandwich Panel (PSP)	350.000	97.877.151	98.227.169

A total of 19.9 liters is obtained from the hourly vehicle fuel consumption (2.56 liters/hour) multiplied by the length of time the tool is used per day (7 hours) to work on one house (1 house is worked on for 3 days) and summed up with the fuel consumption for a 10 km trip that consumes 1 liter. The following are the data, their use in the study, and their data sources for LCA calculations with the cradle-to-handover framework. The study can be arranged into a figure scheme to explain the steps to do this study. The scheme will be divided into two material schemes: precast sandwich panel (PSP), as seen in Figure 4—and AAC brick, as seen in Figure 5.

4. Results and Discussions

4.1 Calculation cost result

After the calculation, the total cost budget needed to build one house in two scenarios is found. The previous methods explained were used to make models of wall types (AAC brick and PSP) in Revit to obtain the wall areas. Then, a calculation is added to get the unit price of a particular kind of work by calculating the cost requirements for labor, materials, and equipment called AHSP. Last, the total material price scenarios are calculated by multiplication of wall areas by unit price (AHSP).

The calculation of the material transportation cost of two scenarios included obtaining the cost result. The

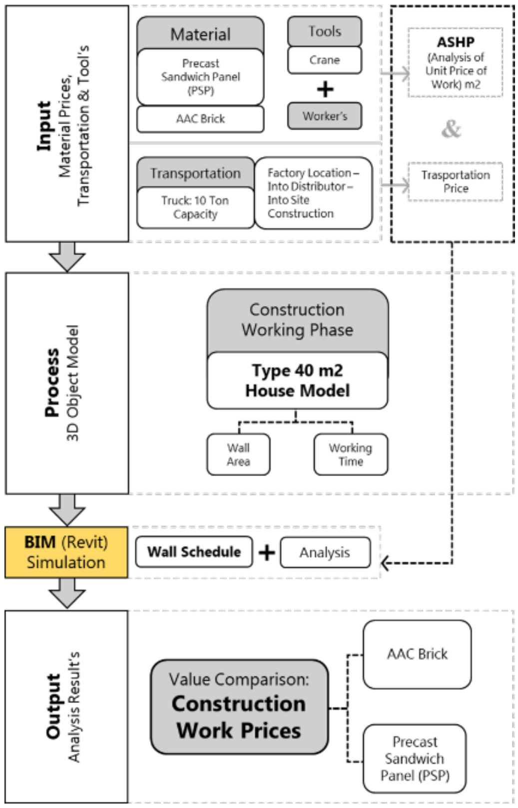


Figure 4 . Schematic of Price Comparison Analysis of Precast Sandwich Panel (PSP) and AAC Brick Materials

Source: Author (2024)

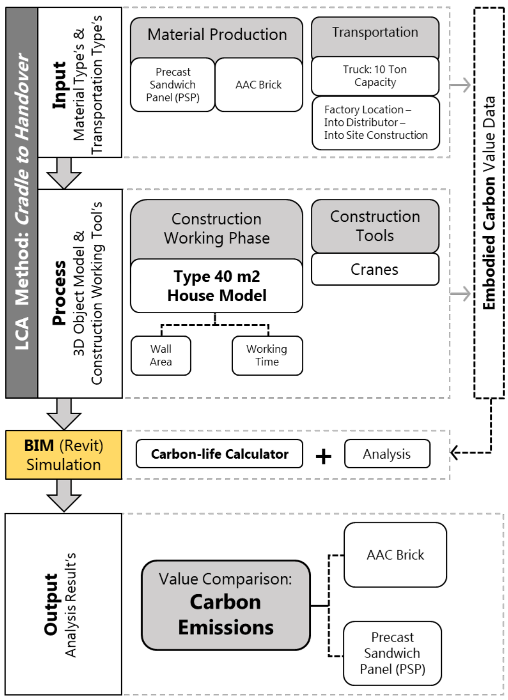


Figure 5 . Schematic of Embodied Carbon Analysis using LCA method - Cradle to Handover

transportation of materials price scenarios is the same. Because of the transportation from the AAC brick and Precast, the sandwich panel production factory and the site are at the same distance and can be transported by the exact type of vehicle, a 10-ton truck. According to Table 2 and Table 3, the total cost shows that the Precast Sandwich Panel (PSP) is more expensive than AAC brick as a wall material for constructing type 40 houses. The total price of the material Precast Sandwich Panel (PSP) used for construction is 3.2 times that of the material AAC brick.

4.2 Calculation Embodied Carbon result

Calculating embodied carbon requires a life cycle assessment (LCA) method. Life cycle assessment (LCA) refers to a specific framework that evaluates the environmental impacts associated with a product. In this case, it is wall material construction throughout its life cycle. The LCA has many frameworks adjusted from stage to stage with the calculation of a material product. In this study case, LCA conducts from the stage extraction of raw materials to the stage where the product is handed over for use called cradle the handover framework. This Life cycle assessment by cradle-to-handover approach encompasses several stages of a product's life, such as producing material, transportation, and construction. The total calculation of embodied carbon results can be obtained by summarizing all three stages: production, transportation, and construction.

The first step in calculating the carbon embodied by the framework cradle to handover is calculating the producing material stage. The first data needed is material weight, which can be obtained by multiplying material density by the areas of wall material data used. Then, the production material stage can be calculated by multiplying the embedded carbon by material weight.

The second step in calculating the carbon embodied by the framework cradle to handover is calculating the carbon produced by transportation materials to the site, which is the transportation stage. The carbon-embodied transportation stage is obtained by calculating the total vehicle mileage multiplied by the transportation-embedded carbon multiplier.

The third step in calculating carbon embodied by the framework cradle to handover is calculating carbon produced by the construction, which is called the construction stage. The carbon embodied construction stage is obtained by calculating the vehicle or tools used to construct a carbon-producing wall. In this case, the AAC scenario assumes that carbon is not produced because it is a conventional method of human labor, but precast sandwich panels use a crane. A Crane used for construction emits carbon, calculated by multiplying hourly vehicle fuel consumption by the duration the crane is used in a day and adding to the carbon emitted by the transportation crane from the rental location to the site.

Finally, the total calculation of embodied carbon emissions is obtained by summarising carbon emissions from the material production process (production stages), the carbon emitted from vehicles used for transporting material from the production factory to the site

Table 4. Calculation Embodied Carbon

Material Scenarios	Carbon emission ($KgCO_2$)			Total emissions ($KgCO_2$)
	Production stage	Transportation stage	Construction stage	
AAC Brick	219,25	0,12	0	219,37
Precast Sandwich Panel (PSP)	35,47	1,86	63,08	100,413

(transportation stage), and the carbon emissions produced by the construction process (construction stage).

Summarizing all stages shows AAC brick produced higher embodied carbon than precast sandwich panel PSP. According to Table 4, the carbon emission from AAC brick is 2.18 times more than that from the precast panel sandwich. The higher emissions on AAC brick are shown in the production stages as 6.18 times higher carbon emissions than the precast sandwich panel (PSP). However, usage of the AAC scheme assumed that carbon would not be produced in the construction stage, unlike the precast sandwich panel (PSP), which produced 63,083 KgCO2 because it used a crane to construct the wall. The transportation stage does not highly affect the results of embodied carbon calculations because the carbon emitted is too low compared to the carbon produced in the other stages.

4.3 Material Scheme Comparison

Comparing the two calculations shown in Table 5. The scenario using precast sandwich panels costs more than using AAC bricks. However, in the calculation of carbon emissions, lightweight bricks have a higher rate than the use of PSP.

Table 5 . Price and Carbon Emission Comparison of Two Material Scenarios

Material Scenarios	Total Cost (Rp)	Carbon emission ($KgCO_2$)
AAC Brick	29.925.476	219,37
Precast Sandwich Panel (PSP)	98.227.169	100,413

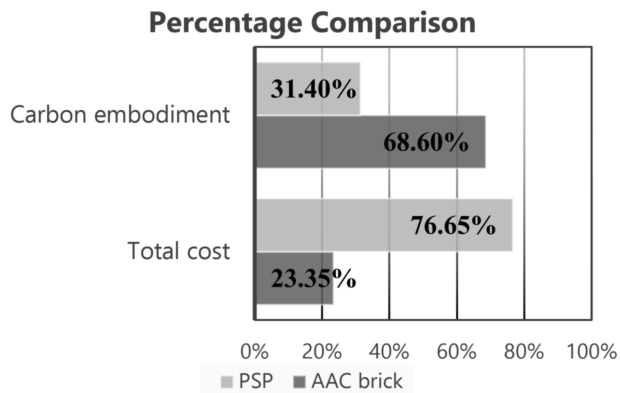


Figure 6. Percentage Comparison Between Two Material Scenarios

The percentage comparison between the two material scenarios shows that the scenario using a precast sandwich panel (PSP) has a higher percentage of 76.65% summarizing two total cost schemes than the AAC brick scenario, with 31.40% summarizing two total cost schemes. The precast sandwich panel (PSP) wall scenario is 53.30%

higher than the scenario using lightweight bricks; however, in calculating carbon emissions, as seen in

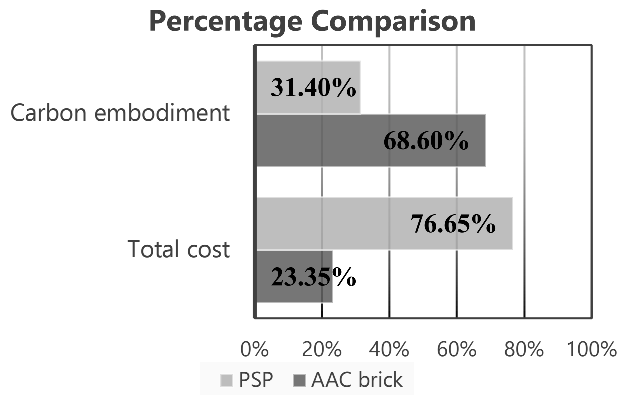


Figure *6*. Precast sandwich panels (PSP) have a lower percentage of 31,40% summarizing two total carbon embodiment schemes than AAC bricks of 68.60% summarizing two total carbon embodiment schemes. The AAC brick has a 37.20% higher carbon embodiment rate than PSP.

This result must be validated by benchmarking other papers with similar methods, objects, and results. We found several papers from previous research:

1. Chang et al. (2011, 2012) and Gámez-García et al. (2018) The study concerns the Life Cycle Assessment of 20 external wall systems usually used in Spain. The results of the study show that climate change has an impact of environmental impact on the 20 types of material walls ($KgCO_2$) by 92.3% total in the production stage (A1-A3), 7.5% total in the transportation stage (A4), and 0.18% in the construction stage (A5). This research is benchmarked by comparing the previous research to this study, using the same LCA Framework, which is used by percentage from the production stage (A1-A3), transportation stage (A4), and construction stage (A5).

   The previous study's carbon percentage is similar to the AAC brick wall scenario in this study but a different percentage to the PSP wall scenario. The comparable percentage value between the previous research and the AAC wall scenario shows that the production stage has the highest percentage value, followed by the transportation stage, and the last construction stage has the lowest value. The production stage (A1-A3) has a higher carbon percentage value because it consists of approximately 74.45% of the total carbon embodiment (A1-A5) of the building comes from (Li & Masera, 2024).

   The transportation stage (A4) cannot be assumed to be similar to the production and construction stages because the distance, vehicle, and geographical location used in those studies were too different and produced too varied a result. For example, the previous research was conducted in Spain, with an average distance from the factory to the site of 100 kilometers (km), and it used a 16-ton lorry/truck. In contrast, this study was conducted in Indonesia, with a total distance from the factory to the site of 393 km, and it used a 10-ton lorry/truck. The two types of vehicles have different loads, distances, and values of fuel consumption, resulting in different carbon emissions emitted.

   The construction stage between these two studies has the same scenarios, not counting on carbon caused by labor but the carbon emulated by tools and machines used for construction, such as cranes. The percentage of carbon between the previous study and this study in the construction stage shows the same tendency, which is the lowest value compared to other stages, where the previous research has 0,18% and this study 0% in the AAC scenario. This negligible value emission resulted because the construction stage mainly uses a labor force and conventional tools to build the building and is assumed to have zero value in this previous and this study. On the other hand, using machines and tools has little impact on carbon emissions because the time the machine is used is not much, and the workload uses little energy.

2. Vasishta et al. (2023) Conducted a comparative study of LCA and cost between cast-in-situ and Precast. The study's results show that the environmental impact indicators of Global Warming Potential (GWP) (Kg CO2-Eq) of all phases of the precast sandwich panel are 48% lower than those of cast-in-place. The previous study conducted by Vasishta et al. (2023) is similar to the previous one because it has identical results when the precast sandwich panel (PSP) has a lower total impact than cast-in-place. The result shows a similar output value, which, in the previous study, was around two times larger in the cast-in-place impact on GWP than the precast sandwich panel (PSP).

   The similarity is shown because, in the previous study, the marginal differential value was found only in the installation/construction phase; however, the other phases, such as raw material extraction and manufacturing, operation, and demolition, have slightly similar values between the precast sandwich panel and cast-in-place. The related condition appeared because the different construction approaches caused different tools and machines to be used for the PSP and cast-in-place. Nevertheless, in this study, the primary differentiated value that defines the result is shown in the production/manufacturing materials phase because this study uses the embedded value to calculate the emissions from this phase. The calculation method for the production/manufacturing material phase between the two studies differs from the previous survey. It is more comprehensive because it calculates carbon emissions from the transportation and manufacture of the raw materials that form construction materials. This study calculates the carbon emission of the production/manufacturing material phase by its carbon-embedded standard time and the weight of the material used. Therefore, the results of the previous study are more credible than those of this study.

   Remember that similar results were conducted using different approaches; previous studies have utilized different methodologies to assess carbon emissions, even if they have identical percentage results but use other indicators. First, the Previous study approach indicates emissions in terms of Global

Warming Potential (GWP), measured in kilograms of CO_2 equivalent (kg CO_2-eq). GWP quantifies how much heat a greenhouse gas traps in the atmosphere compared to carbon dioxide over a specific period, typically 100 years (Vasishta et al., 2023). This approach allows for calculating other gases' (for example, methane) impacts based on their potential to contribute to global warming relative to CO2 but in suitability, as they may provide extra insight or be of particular policy relevance (Lynch et al., 2020). However, this study uses carbon emission ($KgCO_2$) as the direct impact of the building life cycle (in this case, the embodiment of the carbon of the building) on the environment. However, the two indicators used in the two studies have similarities in showing the impact of emissions on Global Change. Second, the framework used differentiates this study from the previous one. The previous study used Cradle grave, which has a more complete assessment of the life cycle of a building than this study, which used cradle the handover approach.

5. Conclusion

The housing sector is a concern as the government aims to increase the number of decent housing units in line with growing demand. However, this increased housing construction certainly contributes to significant emissions as the construction industry is one of the central carbon emitters worldwide. The increase in carbon produced by the rise in building construction needs to be solved because it is contrary to the Indonesian government's long-term goal of implementing emission reduction and gradually implementing zero emissions in 2060. Therefore, there is a need for building strategies that can reduce the production of carbon emissions while still achieving the goal of solving the housing problem.

Precast materials, such as precast sandwich panel walls, can reduce carbon emissions as they are considered efficient in time, logistics, and leftover materials. In the context of type 40 houses, using precast materials is a strategy considered to have potential compared to the conventional approach of using lightweight bricks. LCA analysis is essential for assessing the environmental impact of using building materials seen throughout their life, from production to recycling. Integrating BIM and LCA allows for more accurate planning of material use in terms of price calculation. It is more sustainable as an effort to reduce overall carbon emissions.

The study was conducted on two wall materials, precast sandwich panels (PSP) and AAC brick, using the price calculation method through a model created in BIM to obtain the total building construction price. The total building construction price is added to the cost required for material transportation to get the total price. Meanwhile, the calculation of carbon emissions uses a framework from material production to building construction (cradle to handover) using the carbon calculator plugin from the Autodesk Revit application with a specific artistry scheme starting from material production, transportation, and tools and conditions used in the construction process.

The result of the study is that the total cost required for construction and transportation of the Precast Sandwich Panel wall is Rp 98,227,169, while the lightweight brick wall is Rp 29.,925,476. The calculation of total carbon emissions in the Precast Sandwich Panel wall material is 100.413 KgCO2, while the lightweight brick wall is 219.37 KgCO2. The percentage of precast sandwich panels has a higher cost figure of 53.30% than the scenario that uses lightweight bricks. However, AAC brick is 37.20% higher than Precast Sandwich Panels (PSP) in the embodied carbon calculation.

The following study can use a more complete life cycle assessment framework, such as cradle-to-grave, to calculate carbon emissions and gain a full view of carbon emissions in a complete cycle of construction projects of 40-type houses.

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