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Environmental Impact and Cost Comparison of Different Partition Walls

Emmanuel M. Atienza*, Jason Maximino C. Ongpeng

Department of Civil Engineering, De La Salle University, Manila 0922, Philippines
emmanuel_atienza@dlsu.edu.ph

Conventional construction materials used in building industry is one major contributor to the increasing amount of greenhouse gases (GHG) and other pollutants in the atmosphere, which is responsible to the worsening effects of climate change and other threatening environmental issues worldwide. In addressing this alarming situation, construction key players must apply strategic development and consider the exploration of alternative materials, methodologies, and energy-saving measures for both new and old buildings. The application of Life Cycle Analysis (LCA) is one recommended initiative to identify, analyse, and compare the environmental impacts of traditional and new alternative materials used in the industry. In this study, with the integration of Building Information Modelling (BIM) tool to Life Cycle and Cost Analysis (LCCA), the environmental impact and total construction cost of different partitions walls namely concrete hollow blocks (CHB), gypsum drywall, foamed concrete, and foamed geopolymer wall have been efficiently analysed and compared. Based on the results of LCA, significant values had been observed on the six environmental impact categories namely fossil resource scarcity, land use, human non-carcinogenic toxicity, human carcinogenic toxicity, terrestrial ecotoxicity, and global warming. Concrete Hollow Blocks (CHB) wall exhibits greater impact on fossil resource scarcity, foamed concrete wall to land use and global warming, and dry wall to human non-carcinogenic toxicity, human carcinogenic toxicity, and terrestrial ecotoxicity categories. On the other hand, cost analysis shows that among all partition walls, the construction of CHB wall gave the lowest total cost value while the construction of foamed geopolymer wall costs the highest. Overall, results of this study indicate the potential use of other alternative materials to achieve sustainability in the building industry.

1. Introduction

The continuous growth of construction and building industry is directly connected to rapid urbanization and economic competitiveness of the world. Quantitatively, 50 % of GHG emissions, around 20-50 % of finite land resources consumption, and 50 % of waste generation are coming from the industry. The building sector is responsible for an estimated 19 % of GHG emission and 32 % of total final energy use worldwide (Vasilca et al., 2021). These consequential outcomes from the industry are major contributors to intensifying effects of climate change and other pressing environment-related issues. That justifies the negative impacts which calls the attention of researchers and policy makers all over the world (Khasreen et al., 2009).
Numbers of studies in developing sustainable construction practices are highly appreciated and acknowledged. According to Venkatarama Reddy (2009), energy conservation, minimization of high-energy materials use, and utilization of industrial waste are some of the guiding principles in satisfying the need for energy-efficient and environment-compatible alternative materials. One example is the development of geopolymer binder in reducing the use of cement-based products in construction. Compared to the conventional Ordinary Portland Cement (OPC), geopolymer uses low energy for its production and emits lesser amount of carbon dioxide. In addition, industrial waste such as fly ash, blast furnace slag, and silica fume can be incorporated in the binder mixture while exhibiting competitive mechanical and durability properties (Okoye, 2017).
Aiming to lessen the impact of the industry, application of environmental assessments on existing buildings is also a must to consider. Life Cycle Assessment (LCA) is one tool that can be use in identifying and evaluating potential environmental impacts of an existing building (Gervasio and Dimova, 2018). Aligned to ISO 14040

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standards, it is composed of four important parts namely goal and scope definition, inventory analysis, impact assessment, and interpretation. The assessment will cover processes such as extraction, production, and transportation of raw and secondary materials used on its complete life cycle. However, the complexity of building systems made the application of LCA challenging and time consuming (Safari and AzariJafari, 2021). The integration of Building Information Modelling (BIM) to LCA application in large-scale projects like buildings is one solution. The use of BIM in sustainable construction is known for its benefits such as design optimization, facility management, integration of project delivery, waste reduction, cost and risk mitigation, and schedule improvement (Haruna et al., 2021).

In this study, BIM was used in quantifying interior partition walls of an existing 4-storey school building located at Manila, Philippines. Aiming to identify and recommend environmentally compatible construction materials, the data from BIM Revit 2020 was used for the life cycle and cost analysis comparison of the existing concrete hollow blocks (CHB) vs other wall materials namely gypsum drywall, foamed concrete, and foamed geopolymer. The data presented in this research will be beneficial to identify materials that shows notable negative impacts to the environment and to understand the benefits and potential use of other alternative materials in reducing carbon dioxide emission from traditional construction materials.

1.1 Materials and specification

Different wall types for interior partition application are being considered in the study. This includes the existing concrete hollow blocks (CHB) wall of the school building and three other types of partition walls namely gypsum drywall, foamed concrete, and foamed geopolymer wall. To define its application, the functional unit being used was 1 m^2 of each 100 mm-thick wall type and a similar density, compressive strength, and heat transfer coefficient or U-value of 0.20-2.90 W/(m^2·K) as shown in Table 1. Based on the identified properties and on the American Concrete Institute (ACI) standards, the considered wall types may be categorized as Class II or "structural and insulating lightweight material" having a density of 800-1,400 kg/m^3, compressive strength of 3.4-17 MPa and thermal conductivity value of 0.22-0.43 W/(m^2·K) (Ming et al., 2019). The indicated values for CHB and gypsum drywall are common wall properties in the Philippines setting. On the other hand, the values for the density, compressive strength, and U-factor of foamed concrete wall came from the study of Arunkumar et al. (2018). And lastly, the wall properties for foamed geopolymer were taken from the study of Agustini et al. (2021).

Table 1: Summary of mechanical and thermal properties

Wall Type	Density (kg/m^3)	Compressive Strength (MPa)	U-factor (W/(m^2·K))
CHB Wall	1,441.66	3.45	0.86
Gypsum Drywall	862.00	3.15	2.85
Foamed Concrete Wall	1,037.00	6.50	0.24
Foamed Geopolymer wall	1,256.46	7.65	1.23

2. Methodology

2.1 System Boundaries

The considered processes were aligned to the cradle-to-gate life cycle of concrete hollow blocks, gypsum drywall, foamed concrete, and foamed geopolymer wall as illustrated in Figure 1. The system boundaries include inputs starting from the extraction of raw materials, energy consumption for the production and transportation of by-products, up to the final output which is the construction of the four different partition walls. The project site where the walls will be constructed is located at Manila, Philippines.

In the life cycle assessment, the potential environmental impacts of all materials and processes under the cradle-to-gate life cycle of the four walls will be quantified, investigated, and categorized to 18 different impact categories. Following the ISO 14044 impact assessment method, values from these categories will undergo characterization and normalization. On the other hand, Eq(1) will be used for the computation of the total life cycle cost (C_T) of CHB, gypsum drywall, foamed concrete, and foamed geopolymer wall (Fernando et al., 2021). C_{MP} is the cost for raw materials manufacture and C_{EU} is the energy cost for the cradle-to-gate life cycle of the four walls. The unit for all costs is in USD.

$$C_T = \sum((C_{MP} + C_{MT}) \cdot M_i) + C_{EU} \tag{1}$$

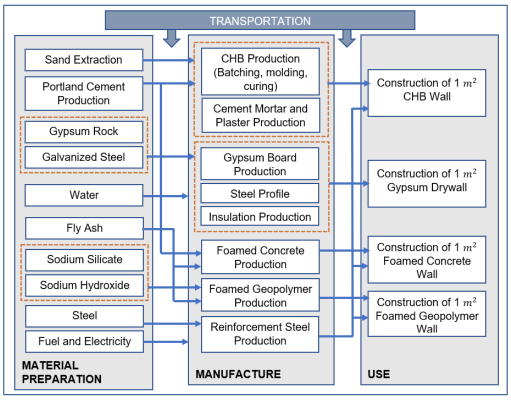

Figure 1: System boundaries for life cycle and cost analysis

2.2 Life Cycle Inventory

The breakdown of input and output materials for the life cycle and cost analysis of the walls are shown in Table 2. The emission factors for the production, energy consumption, and transportation of raw materials and its by-products for the construction of 1-m^2 CHB, gypsum drywall, foamed concrete, and foamed geopolymer wall was gathered using SimaPro database. The quantity of the materials used for the construction of concrete hollow blocks (CHB) and gypsum drywall were calculated using standard estimates method of masonry and drywall. The mix design of foamed concrete came from the study of Arunkumar et al. (2018). And lastly, the design of foamed geopolymer was taken from the study of Agustini et al. (2021). Every material has its corresponding transport distance from the place of extraction or purchase to the location of the project site where the walls will be constructed. The materials listed below were extracted and/or purchased from local stores and manufacturers in the Philippines.

Table 2: Life cycle inventory for every 1 square meter wall type

Description	Quantity	Unit	Unit Cost (USD)	Transport Distance (km)
CHB Wall				
4" CHB	13.00	pcs	0.27/pcs	15.70
Cement	80.00	kg	0.13/kg	8.40
Sand	0.06	m^3	21.55/m^3	9.70
Water	61.00	L	0.60/L	0.00
Steel Bars	2.00	pcs	3.06/pcs	3.20
Gypsum Drywall				
Gypsum Board	2.00	pcs	7.16/pcs	1.10
Metal Track	1.00	pcs	1.56/pcs	1.10
Metal Studs	8.00	pcs	1.74/pcs	1.10
Joint Compound	3.79	L	1.67/L	1.10
Joint Tape	0.30	m	1.18/30 m	1.10
Screw	14.00	pcs	3.51/500 pcs	1.10
Rockwool Insulation	1.00	pcs	7.60/pcs	1.10
Foamed Concrete Wall				
Cement	57.80	kg	4.74/40 kg	8.40
Fly Ash	57.80	kg	77.11/t	4.80
Water	52.00	L	0.60/L	0.00
Foaming Agent	23.10	kg	0.90/kg	14.20
Steel Bars	7.90	kg	0.39/kg	3.20
Foamed Geopolymer Concrete				
Fly Ash	63.49	kg	77.11/t	4.80
Sodium Silicate	14.82	kg	4.80/kg	9.20
Sodium Hydroxide	7.41	kg	3.33/kg	9.20
Foaming Agent	600.00	L	0.90/kg	9.20
Steel Bars	7.90	kg	0.39/kg	9.20

2.3 Building Information Modelling (BIM) application

In this study, BIM Autodesk Revit 2020 was utilized to identify and quantify the total area of all 100 mm-thick interior partition walls of the existing four-storey school building. The obtained values from the software are necessary to efficiently calculate and compare the environmental impact and total cost of the materials used for the construction of existing CHB wall vs the other partition walls namely gypsum drywall, foamed concrete, and foamed geopolymer wall.

3. Results and discussion

3.1 Life Cycle Assessment result

Using ReCiPe model's midpoint impact assessment of SimaPro Software, the resulting values of each wall type were normalized to systematically analyze the degree of contribution of each category to the overall environmental impact. The values obtained from the construction of 1-m^2 CHB, gypsum drywall, foamed concrete, and foamed geopolymer wall to all eighteen impact categories were identified including the amount of carbon emission produced under the global warming category. Based on the result, all wall types exhibit notable high values on terrestrial ecotoxicity category and least values on stratospheric ozone depletion category. Most of the impact categories shows that the environmental impact of gypsum drywall is greater than the other wall types.

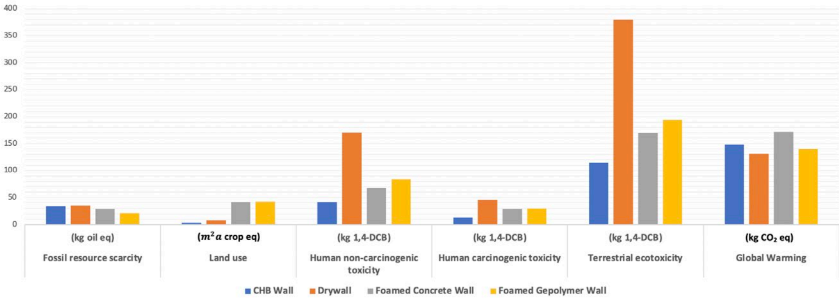

Figure 2: Significant environmental impacts

Significant values had been observed on six environmental impact categories namely fossil resource scarcity, land use, human non-carcinogenic toxicity, human carcinogenic toxicity, terrestrial ecotoxicity, and global warming as shown in Figure 2. Obtained values indicate that comparing to other types of walls, the construction of drywall exhibits greater impact on fossil resource scarcity, human non-carcinogenic toxicity, human carcinogenic toxicity, and terrestrial ecotoxicity categories, while the construction of foamed concrete wall to land use and global warming categories. Drywall wall production involves crushing, heating, and dehydrating raw gypsum that produces powder, which releases particulates, sulfur dioxide, nitrous oxide, and carbon monoxide in the atmosphere. The findings obtained are also due to lethal hydrogen sulfide gas and dangerous sulfates that may infiltrate to the groundwater table (Sibole, 2013).

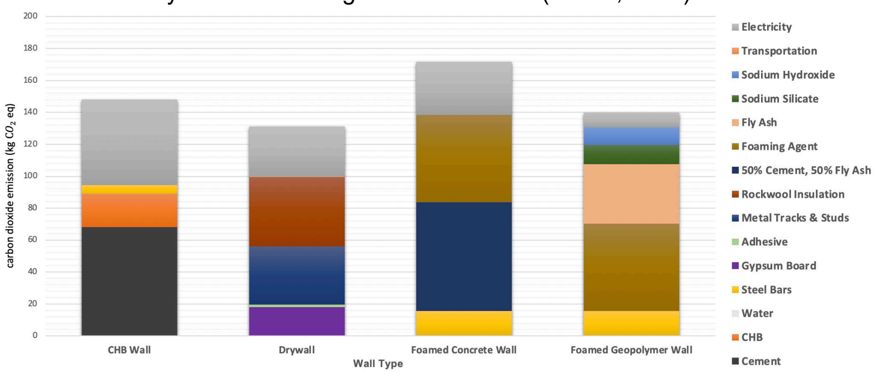

Figure 3: Impact contribution of materials and processes to the global warming category

The impact values of each material used for constructing four different partition walls on the global warming category have been investigated and illustrated in Figure 3. Results shows that the materials namely Portland cement of CHB wall, rockwool insulation of gypsum drywall, cement with fly ash of foamed concrete wall, and foaming agent of foamed geopolymer wall gave the largest values and is responsible to 46 %, 33 %, 40 %, and 39 % of the total impact contribution of each wall type. Overall, the construction of foamed concrete wall gave the highest value of carbon emission while the construction of gypsum drywall gave the lowest amount among them all. However, the emission coming from the construction of foamed geopolymer wall is 33 % and 22 % lower than the two concrete partition wall namely CHB and foamed concrete. This significant difference is due to the mining of calcareous and argillaceous materials that is necessary to produce cement. According to Juarez and Finnegan (2021), 40 % of carbon emission is coming from the processing of these raw materials in producing clinker – a base component of cement, 50 % by the chemical reaction in producing calcium and magnesium oxide, and 10 % from the transportation and energy consumption.

3.2 Cost analysis result

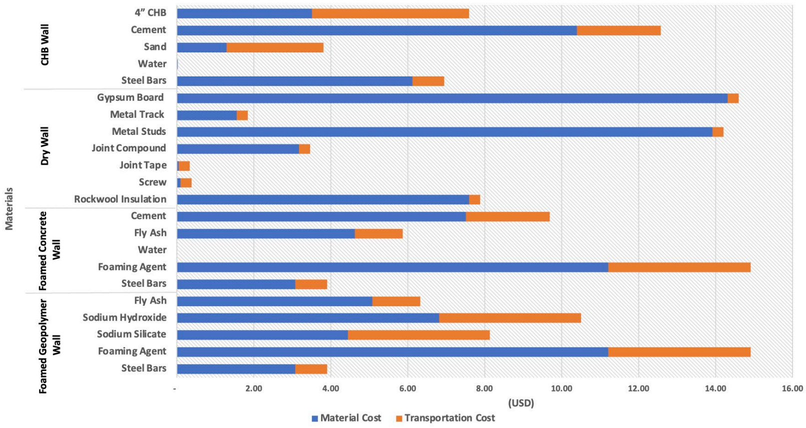

Figure 4: Total construction cost of the four partition walls

Result of the cost analysis shows that CHB wall gave the lowest total construction cost while the construction of foamed geopolymer wall costs the highest as shown in Figure 4. In percentages, the materials that show highest contributions are cement (34 % of the total construction cost) for CHB wall, gypsum board (33 % of the total construction cost) for gypsum drywall, foaming agent (33 % of the total construction cost) for foamed concrete wall, and alkali activators namely sodium silicate and sodium hydroxide (26 % of the total construction cost) for foamed geopolymer wall. The cost for the transportation of materials to project site shares 31 %, 5 %, 23 %, and 30 % of the total construction cost for CHB, drywall, foamed concrete, and foamed geopolymer wall. However, changes may be applied to these sum totals depending on the location of the extraction or production of the raw materials and by-products used (Rintala et al., 2021).

3.3 Case Study: BIM-LCCA application in school building

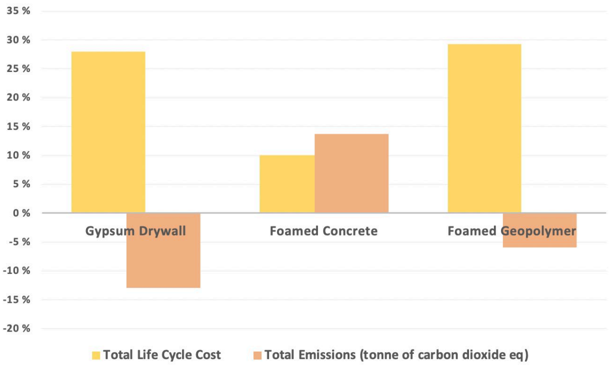

Figure 5: Comparative analysis of BIM-LCCA results

Building Information Modelling (BIM) was utilized as an essential tool to conduct life cycle and cost analysis to optimize and apply sustainability in an existing 4-storey school building in Manila, Philippines. The “materials quantity take-off” function of BIM Revit 2020 was used to easily extract, filter, and quantify all 100 mm-thick interior partition walls of the building. A total wall area of 1,962 m^2 have been calculated and was multiplied to resulting values of Life Cycle and Cost Analysis (LCCA) to get the total construction costs and emissions of the walls. As shown in Figure 5, the amount of CO_2 emission from the existing CHB wall was reduced by 13 % and 6 % when gypsum drywall and foamed geopolymer wall were used instead. Cost analysis shows that the construction of the existing CHB wall have the lowest cost value and is 28 %, 10 %, and 29 % cheaper than gypsum drywall, foamed concrete, and foamed geopolymer.

4. Conclusions

Using BIM Revit 2020, SimaPro software, and considering cradle-to-gate life cycle of CHB, gypsum drywall, foamed concrete, and foamed geopolymer wall, significant impact values have been observed on fossil resource scarcity, land use, human non-carcinogenic toxicity, human carcinogenic toxicity, terrestrial ecotoxicity, and global warming impact categories. In terms of GHG reduction, result of LCCA recommends the use of foamed geopolymer and gypsum drywall as they produce lesser amount of CO_2 emission compared to the existing CHB wall of the school building. Despite of its high-cost value, foamed geopolymer wall emits lesser amount of CO_2 at the atmosphere compared to the two cement-made concrete interior walls namely CHB and foamed concrete. Specifically, the materials that greatly contributed to the total carbon dioxide emissions of each wall type are cement at 46 %, rockwool insulation at 33 %, combination of cement and fly ash at 40 %, and foaming agent at 39 %. These results may be used as a reference and a guide in material selection for further exploration of new alternatives in the industry. For future studies, researchers may apply BIM-LCA to other materials or methodologies in construction considering complete building life cycle for a more extensive scope and application of building sustainability assessments.

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