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PAPER

A comparative Life Cycle Assessment of vulnerable dwellings along Davao River Basin using Athena Impact Estimator for Buildings

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ABSTRACT

Every year, more and more buildings are built, but many have problems because they are exposed to harsh weather and are used. Some of these problems are cracks, dead holes, and a high level of air infiltration, all affecting how much energy is used. This study aims to compare the embodied energy (EE) using life cycle analysis (LCA) of a row house model and a walk-up apartment model of housing in the riverine area of the Davao River. Assessment of the tool's life cycle is the research approach used for this investigation (LCA). A life cycle perspective can be helpful in several situations, including but not limited to better appreciating the potential benefits of the repurposing project and its impacts on the environment and providing information for future building stock management. Results have shown that row housing produces more building materials than walk-up buildings, with almost 50% less consumed. The row housing model also has a higher environmental impact on the assembly areas: foundation, roofing, and flooring materials. Meanwhile, walk-up dwellings contribute more wall components, columns, and beams. The findings of the life cycle assessments revealed that, in general, row housing units were impacted more during the production stage (A1 to A3), with 86% of the total. Throughout the same period, walk-up residences had a higher contribution during the construction phase (A4 and A5) with 11% and beyond the building life (D) with an average of 6%. Both models tie in with 2% for the use category (B2, B4, and B6) and 11% for the end-of-life category (C1 to C4). Row housing units impact the surrounding environment more than walk-up apartment units, assuming that the same measurement criteria are objectively applied to both models. According to the study's findings, implementing in-situ vertical development in sensitive areas is preferable because it involves less material consumption and has a smaller negative impact on the surrounding environment.

KEYWORDS

Life Cycle Analysis, Sustainability, Climate Change, Vulnerable Housing, River Basin

1 INTRODUCTION

Every year, more and more buildings are built, but many have problems because they are exposed to harsh weather and are used. Some of these problems are cracks, dead holes, and a high level of air infiltration, all of which affect how much energy is used [1]. The Australian Sustainable Built Environment Council [2] says that existing buildings use close to 19% of their energy and release 23% of their carbon dioxide (CO2). The influence of the building construction sector on the environment in terms of resource usage, energy consumption, and greenhouse gas emissions is enormous. It has been estimated that the building and construction industry is responsible for around 33 percent of the world's total greenhouse gas emissions [3]. Energy efficiency is one of the main ways to accomplish sustainable development in the 21st century due to rising energy and electricity demand in all industries. Tropical buildings receive everyday sun radiation. To provide thermal comfort and reduce air conditioning and power demand, buildings should minimize heat gain and enhance evaporative cooling [4]. To determine the causes of the gap between awareness and application levels of energy management in the local construction industry, it is crucial to investigate the obstacles that impede its adoption [5].

In many countries, the built environment is a critical factor in determining whether or not sustainability efforts are successful. The construction industry, also infamously referred to as "the forty-percent sector," is accountable for forty percent of the world's total energy and resource consumption [6]. Climate change and reducing carbon dioxide (CO2) emissions are two of the world's most critical problems. Currently, governments worldwide are trying to build things that use less energy to reduce the effects of climate change. Existing residential buildings emit much CO2, but only about 2% of the market is built yearly [7]. The Philippines is vulnerable to a wide range of natural disasters, which, along with political, social, and economic factors, make it one of the countries most likely to be hit by disasters. Damage and loss from disasters are spread out differently across the Philippines. Pieces of evidence from previous studies show that disaster risk is not the same everywhere, which cannot be explained by environmental conditions alone [8].

Between 30% and 100% of residential buildings' total life-cycle energy consumption is embedded energy. This study describes the significant contribution of embodied energy to global greenhouse gas emissions and a comprehensive and reproducible methodology for measuring embodied energy in new technologies. In addition, a case study is provided to demonstrate outputs [9]. Studies concentrating on more general facets of sustainable construction are also available [10], with others on life cycle studies. Sfakianaki [11], based on a study of the relevant literature, has focused on the importance of coordinated supply chain activities in the construction industry and the need for construction companies to train their employees in resource-efficient building methods and practices as well as invest in in in these areas. This attention has been brought to the significance of coordinated supply chain activities in the construction industry. The author stressed the necessity of new approaches to managing and implementing sustainability and the commitment of all stakeholders. The topic of developing sustainable supply chains in the United Kingdom was investigated by Dadhich et al. [12], who used the supply chain for plasterboards to find hotspots in the system. Life Cycle Assessment (LCA), Life Cycle Energy Assessment (LCEA), and Life Cycle Carbon Emissions Assessment (LCCO2A) were compared by Chau et al. [13] based on their objectives, methodologies, and findings. The comparison focused on the different life cycle studies used to evaluate the effects of building construction on the surrounding environment. Research has been done to improve the energy efficiency of households and businesses in countries with cold or moderate temperatures, where the majority of energy use is accounted for by heating. The focus is slowly moving toward tropical climates, where cooling needs most of the energy. However, more must be done on low-income tropical housing, where space heating and cooling need almost no energy (aside from cooking and hot water). Many studies on Life Cycle Assessment and embodied energy have been carried out in developed countries, and you need help finding them in the Philippines.

One of the numerous issues that any nation, including the Philippines, has in the modern era is addressing the issue of climate change through regulating carbon emissions and embodied energy. Although the existing residential building stock is responsible for releasing a significant amount of CO2 into the atmosphere, the market's new construction activity rate is only about 2% each year [14]. Vulnerable houses are also affected by their high embodied energy due to frequent repairs during a disaster. This study will investigate the ecological consequences of constructing housing units along rivers by contrasting a typical residential dwelling in the context of Davao City. The embodied energy will be used as a measurement index to identify areas of potential improvement that could be addressed by implementing novel approaches. This study aims to compare the Embodied Energy (EE) using Life Cycle Analysis (LCA) of a Row House model and a Walk-up Apartment model housing in the riverine area of Davao River.

2 CONCEPTUAL STUDY AREA

This Ecological Footprint assessment will be demonstrated for a residential dwelling prone to riverine flooding. The building is a two-story residential structure made of reinforced concrete.

Fig. 1 Study area: Identified Riverside Dwellings Vulnerable to Flooding in Barangay Bucana (Source: Google Earth)

Fig. 2 Aerial View of the Study Area (Source: Google Earth)

Fig. 3 Existing Residential Dwellings in the study area

3.1 Embodied Energy in the Built Environment

The term "embodied energy" refers to the total amount of energy that goes into making, maintaining, and getting rid of a manufactured product [15]. Many different kinds of building materials can be used to build a building, and each needs energy to be made, used, and taken apart. These stages include getting the raw materials, transporting them, making them, putting them together, putting them in place, and taking them apart, taking them apart, and breaking them down. The energy used to make something (in conversion and flow, as Koskela [16] suggests) is called the material's "embodied energy," and it is a concern for both energy use and carbon emissions. Gonzales and Navarro [17] say that building materials with a lot of embodied energy could cause more carbon dioxide to be released than materials with a low amount of embodied energy.

3.1.1 Embodied Energy

The energy used directly in all on-site and off-site construction, transportation, management, and consulting operations is the direct energy embodied in a building [18]. The direct embodied energy component, mainly connected to the construction phase, has been thoroughly examined in studies like those by Shrivastava and Chini. According to Shrivastava and Chini [19], setting up the on-site management, using tools and equipment for construction, and getting people, supplies, and equipment to a job site all use the majority of direct energy. Using materials, assemblies, and equipment installed in a building consumes indirect embodied energy because each item requires energy during production and delivery to a job site. Some studies explained how shape affects the embodied energy of the houses. The research carried out by Zegarac Leskovar et al. [20] used a small residential construction typology made of cross-laminated timber, which was analyzed and compared. Different types of detached, semi-detached, terraced, two-story, and three-story homes were included in these residential typologies. It was shown that there is a clear linear link between the geometry of a building and its environmental performance. With increasing building height, the environmental impact of structures, both when they were embodied and operating, was found to diminish. This link was discovered as a result. According to the findings, single-story building typologies with high shape factors—such as the ratio of the base size to the floor area—should be avoided. This is because foundations comprise a significant percentage of a structure's embodied influence. Cali et al. 2006 [21] reached similar conclusions in their research. They discovered that the total LCE efficiency of a building increases as the number of levels and floor area increase.

3.2 Life Cycle Analysis of Buildings

An in-depth method that estimates the total amount of energy that goes into, comes out of, and flows through a structure during its entire lifespan is called a life cycle energy study (Fig. 5). The boundaries of the system are broadened so that it may take into consideration a building's running energy as well as its embodied energy. The energy needed for the building's heating, cooling, ventilation, domestic hot water, lighting, and other auxiliary facilities and appliances is referred to as the operating energy [22].

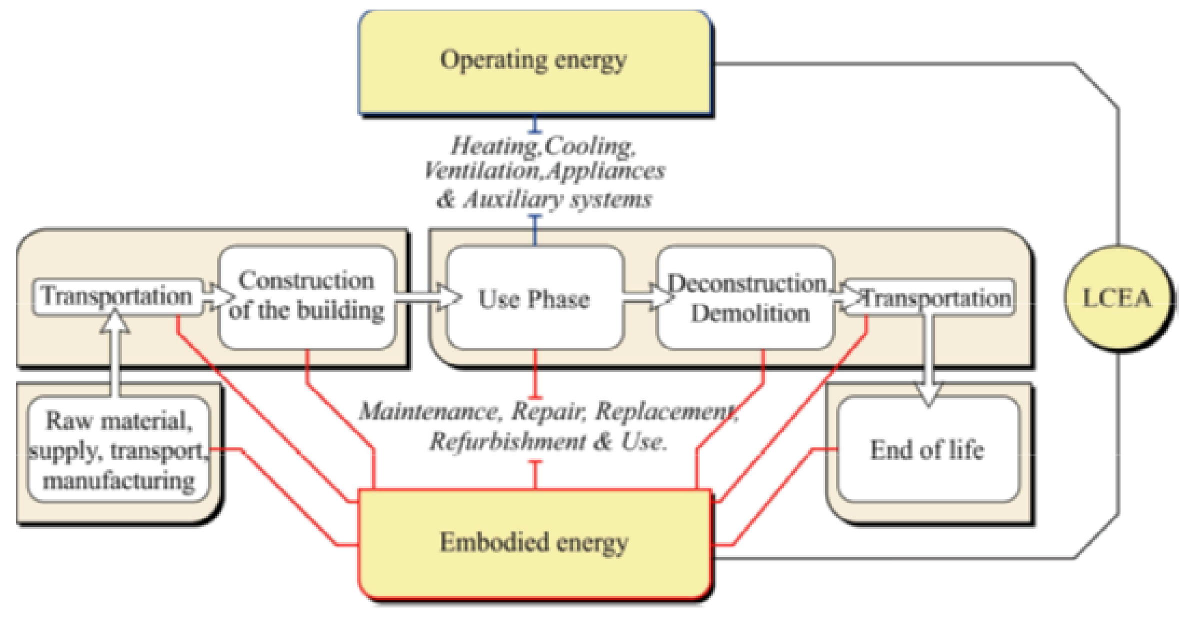


Fig. 4 Boundaries of the system, inputs, output and flows in Life Cycle Energy Analysis (Chastas et al., 2016)

Embodied energy and operating energy are components of the overall amount of energy that a structure uses over its lifetime. Embodied energy (EE) is stored in the building materials throughout production, on-site construction, and final demolition and disposal. Operating energy (OE) is the energy expended in maintaining the environment inside the building through processes such as heating and cooling, lighting, and operating appliances. Embodied energy is also known as embodied energy.

3.2.1 Method of Embodied Energy Calculation

The main ways to figure out embodied energy are input-output (IO), process-based, hybrid, and statistical analysis. Each method has its limits and levels of accuracy [23].

3.3 Embodied Energy and Urban Sprawl

Multiple facets of urban planning are affected by infrastructure decisions that have a locking-in effect on CO2 emissions and prolong their duration [24]. Per capita, compact communities may require fewer resources, including surface area, water supply and wastewater removal pipelines, and transportation and communication infrastructure [25]. Aside from climatic effects, there is a decline in economic output caused by sprawl. According to a study of the Beijing metropolitan area, urban congestion and environmental damage reduce the region's economic output by 7.5% to 15% [26]. Moreover, the built environment density in urban areas enables more excellent options for district heating and cooling networks [27], preferably based on 100 percent renewable energy at the city level and the utilization of residual energy [28], including from wastewater treatment plants [29].

Local governments and institutions have unique opportunities to engage in urban mitigation activities, and local mitigation efforts have been overgrown recently [24]. Nonetheless, there needs to be a more systematic evaluation of the extent to which cities implement mitigation policies, achieve emission reduction targets, or reduce emissions. Climate action plans contain a variety of cross-sectoral initiatives, with an emphasis on energy efficiency as opposed to more effective land-use planning strategies and cross-sectoral measures to decrease sprawl and encourage transit-oriented development [30].

4 THEORETICAL FRAMEWORK

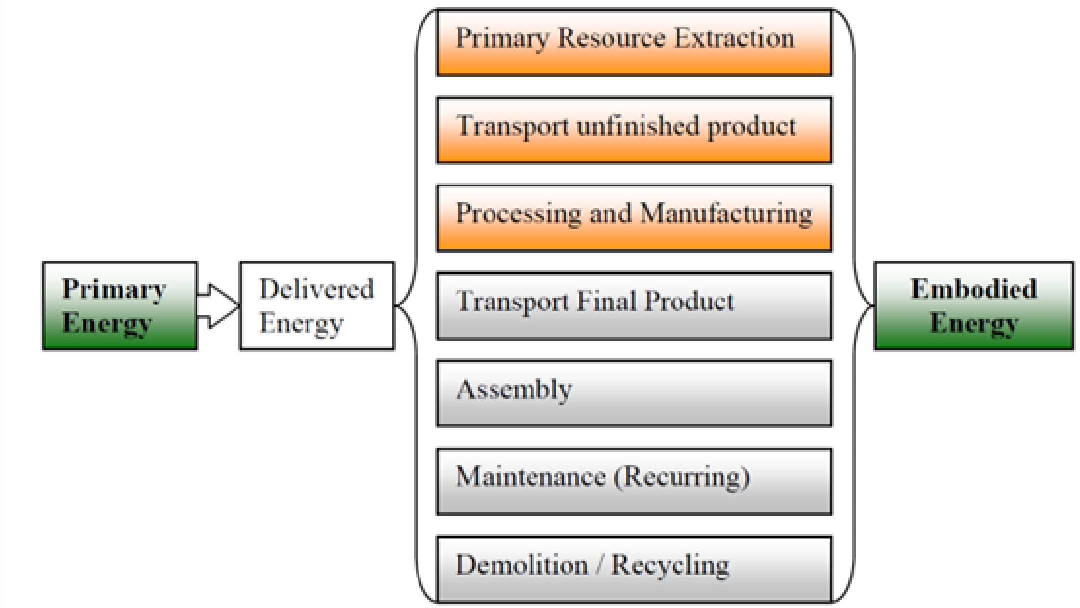


Fig 5. Embodied Energy Calculation

5 MATERIALS AND METHODS

Assessment of the tool's life cycle is the research approach used for this investigation (LCA). A life cycle perspective can be helpful in several situations, including but not limited to better appreciating the potential benefits of the repurposing project and its impacts on the environment and providing information for future building stock management.

5.1 Life Cycle Assessment Tool

The Athena Institute for Sustainable Development, a research organization headquartered in Toronto, Canada, is responsible for developing the Athena Impact Estimator for Buildings instrument. The tool aims to provide construction industry experts and policymakers with assistance in better understanding the effects of various building materials and design decisions on the surrounding environment. The Athena Impact Estimator for Buildings uses life cycle assessment (LCA) approaches to evaluate the effects of building materials and systems on the environment throughout their life cycles. This comprises activities such as the extraction and processing of raw materials, manufacture, transportation, usage, and waste disposal or recycling of resources. Users can evaluate the impact on the environment of various systems and materials and then make educated selections about which systems, materials, and design choices are the most environmentally friendly. The Architectural Information Exchange for Buildings (AIE4B) was developed as a decision-making tool for building professionals and policymakers. It is possible to include it in the design, construction, and operation of buildings to lessen the negative impact those structures have on the surrounding environment.

The Athena Impact Estimator for Buildings 5.4 was used for this life cycle assessment's residential building assembly considerations (AISM, 2015). The data it uses comes from a separate application, the Athena Impact Estimator. The same organization in Ottawa, Athena Sustainable Materials, developed this application for buildings. Users pick building assemblies from within the calculator itself and then enter inventory amounts in the form of the square footage of the selected building assemblies. The stages of a structure's life cycle that the calculator accounts for are its construction, as well as its disposal, maintenance, repair, replacement of building assemblies, and resource extraction. The Eco-Calculator does not evaluate the damages caused by operating energy consumption. Even though this instrument will not consider the energy consumption during the use phase, it is still sensible to use it because the study's primary goal is to produce rapid directional results on the material dimension of the structure. The Impact Calculator is a tool for conducting a midpoint impact assessment, and it takes into account the following seven environmental impact categories: fossil fuel consumption (FFC), global warming potential (GWP), acidification potential (AP), human health criteria (HHC), eutrophication potential (EP), ozone.

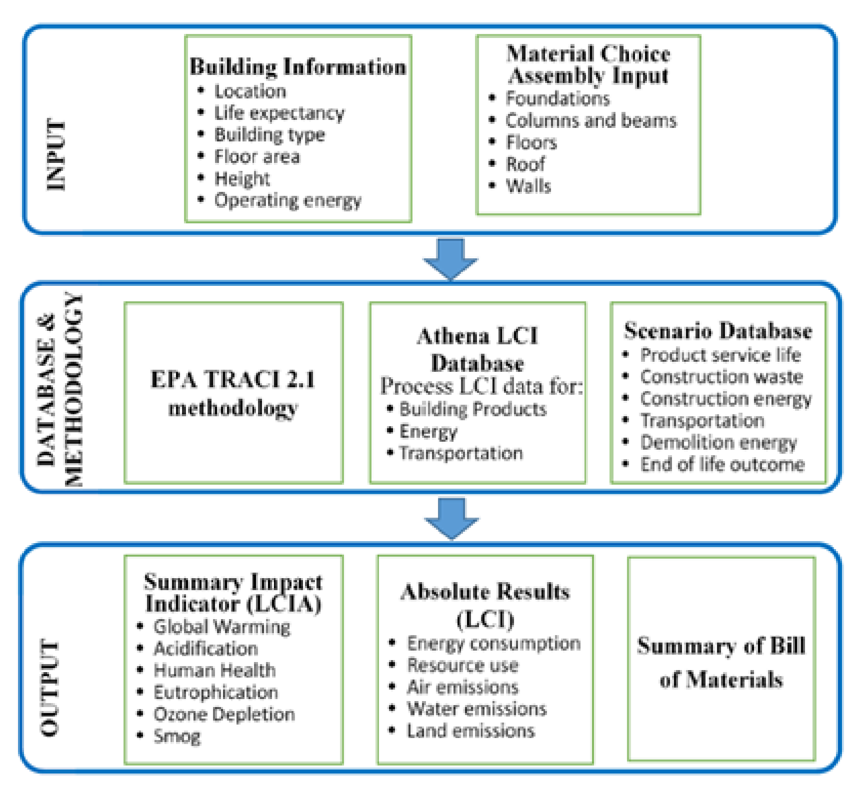


Fig.6 Athena Impact Estimator for Buildings (IE4B) calculation process based on ASMI (2019).

5.2 Limitations of the Study

This study will utilize Athena Impact Estimator for Buildings (Athena IE4B), a free software developed in North America, to evaluate whole buildings and assemblies based on internationally recognized life cycle assessment (LCA) methodology. The settings used in this study were based in Atlanta, a subtropical state in the United States of America, since it is the nearest option available for the researcher in the context of the Philippine Setting. The researcher set the Single-Family Residential building type for Row Housing and Multi-Unit Owner- Occupied for Walk-Up Housing. Both building types utilized 60 years as their Building Life expectancy and used the International System of Units (SI), commonly known as the metric system, for the dimensions needed. The available specifications also substituted the building materials through cradle-to-grave life-cycle inventory (LCI) established by industries related to construction in North America.

5.3 *Case Study Description*

The purpose of this project is to conduct a conceptual examination of two case scenarios on a building model for a vulnerable location. Assuming that the location will be in Barangay Bucana, which is located in Davao City and is home to the Davao River Basin. The Mindanao and the Agusan Rivers are the two major rivers in Mindanao. The Davao River is the third largest river in Mindanao. The primary river has a length of 86 kilometers and drains an area that is approximately 175,960 hectares in size. The Davao River Basin (DRB) is one of the 18 major river basins in the country that are given priority for master planning. This is due to the size of the Davao River Basin, its economic significance to the Davao region, and its potential to provide for the water security of Davao City.

5.4 *Analyzed Models*

The existing vulnerable houses along the riverine area of the Davao River served as the basis for the measured models. The first scenario depicts a home fortified to withstand the effects of water. The second scenario is the upkeep of a residential dwelling in an area prone to flooding by employing the usual building methods.

Case Model A: A Riverside Rowhouse building

In this scenario, the dwelling is a Row House. Every single dwelling has a window-to-wall ratio of 10%. The main wall is made of concrete, and the interior walls will use plywood. There will be a total of 15 units for this model. The flooring is a concrete slab using a pier and beam foundation. For this structure:

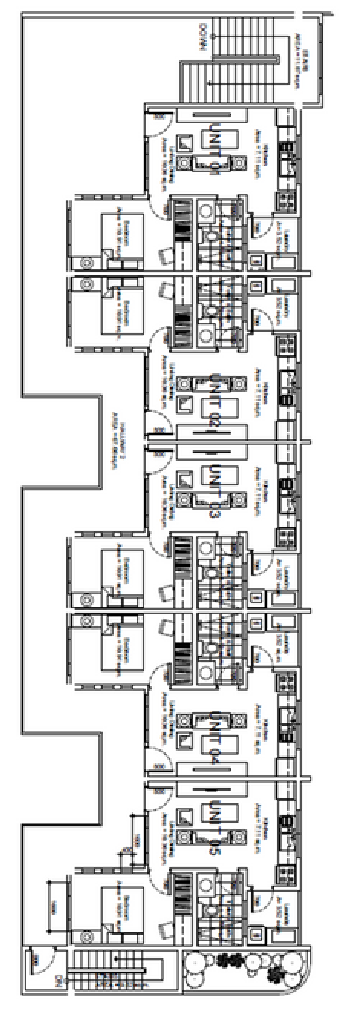


Fig. 7 Entire story of a Walk-up Residential Dwelling

Case Model B: A Walk-Up Building

In this scenario, the dwelling is a Walk-up Apartment model. The Walk-up apartment comprises 15 units, with five on every floor level. Each floor level of the dwelling has a window-to-wall ratio of 10%. The main wall is made of concrete. The flooring is a concrete slab using a matt foundation. For this structure:

The foundation and structural assemblies are using Matt Foundation.

Same Roofing material is the same as model A.

Additional information pertaining to the building systems of the model units can be found in Table 1

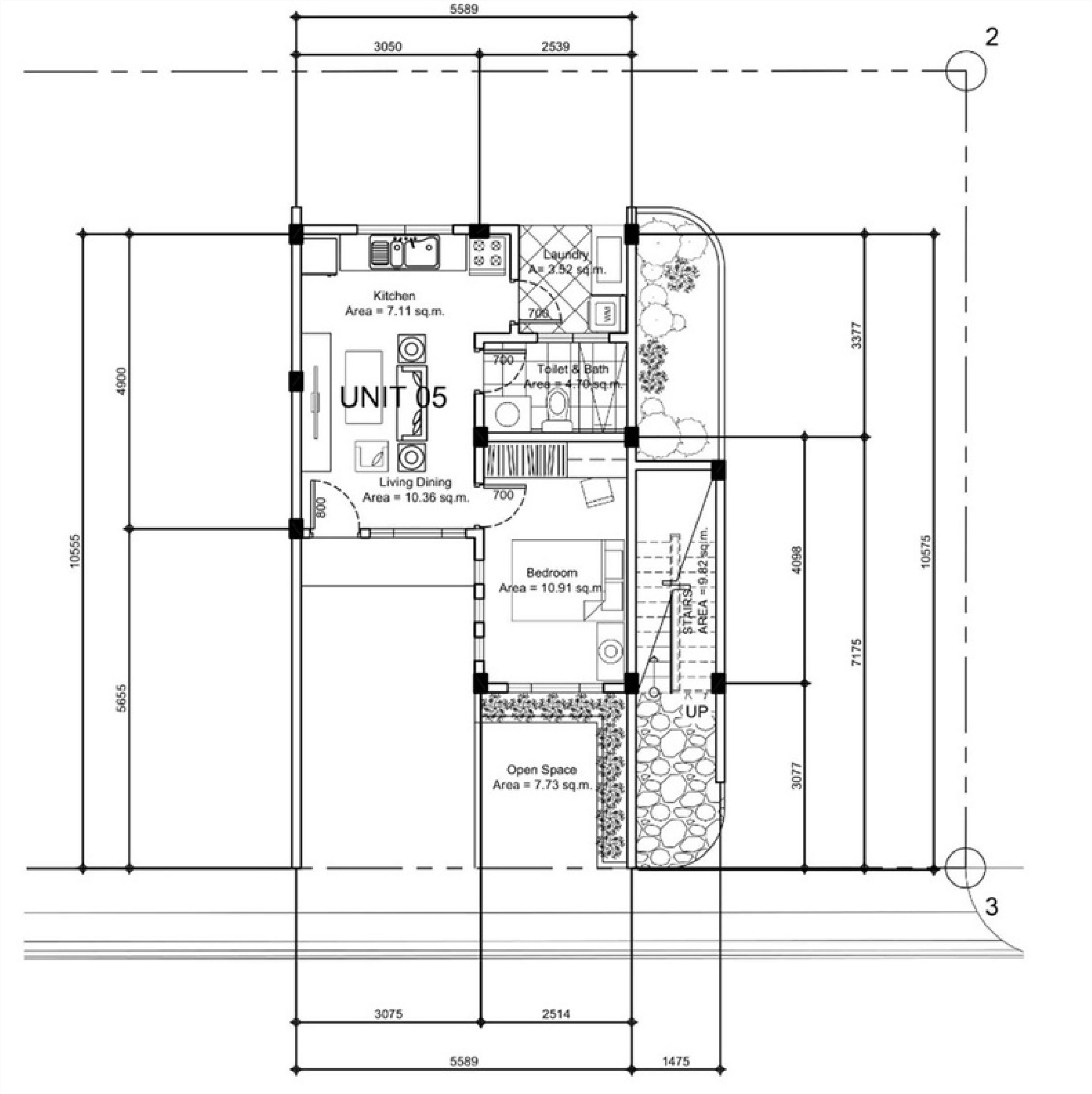
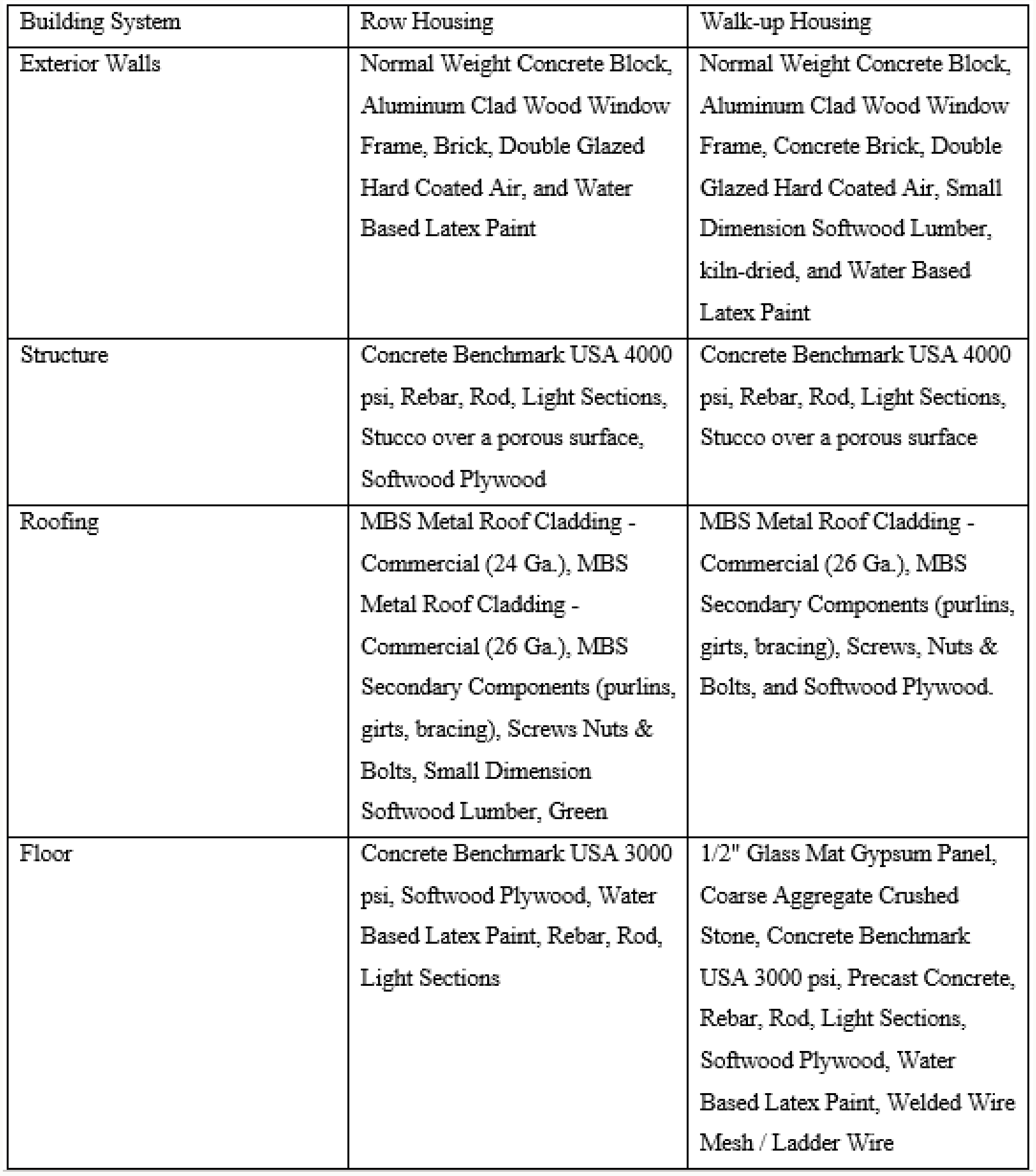


Fig. 8 Average Size of the Model Unit for RROW House

Table 1 Building System Details



Building System	Row Housing	Walk-up Housing
Exterior Walls	Normal Weight Concrete Block, Aluminum Clad Wood Window Frame, Brick, Double Glazed Hard Coated Air, and Water Based Latex Paint	Normal Weight Concrete Block, Aluminum Clad Wood Window Frame, Concrete Brick, Double Glazed Hard Coated Air, Small Dimension Softwood Lumber, kiln-dried, and Water Based Latex Paint
Structure	Concrete Benchmark USA 4000 psi, Rebar, Rod, Light Sections, Stucco over a porous surface, Softwood Plywood	Concrete Benchmark USA 4000 psi, Rebar, Rod, Light Sections, Stucco over a porous surface
Roofing	MBS Metal Roof Cladding - Commercial (24 Ga.), MBS Metal Roof Cladding - Commercial (26 Ga.), MBS Secondary Components (purlins, girts, bracing), Screws Nuts & Bolts, Small Dimension Softwood Lumber, Green	MBS Metal Roof Cladding - Commercial (26 Ga.), MBS Secondary Components (purlins, girts, bracing), Screws, Nuts & Bolts, and Softwood Plywood.
Floor	Concrete Benchmark USA 3000 psi, Softwood Plywood, Water Based Latex Paint, Rebar, Rod, Light Sections	1/2" Glass Mat Gypsum Panel, Coarse Aggregate Crushed Stone, Concrete Benchmark USA 3000 psi, Precast Concrete, Rebar, Rod, Light Sections, Softwood Plywood, Water Based Latex Paint, Welded Wire Mesh / Ladder Wire

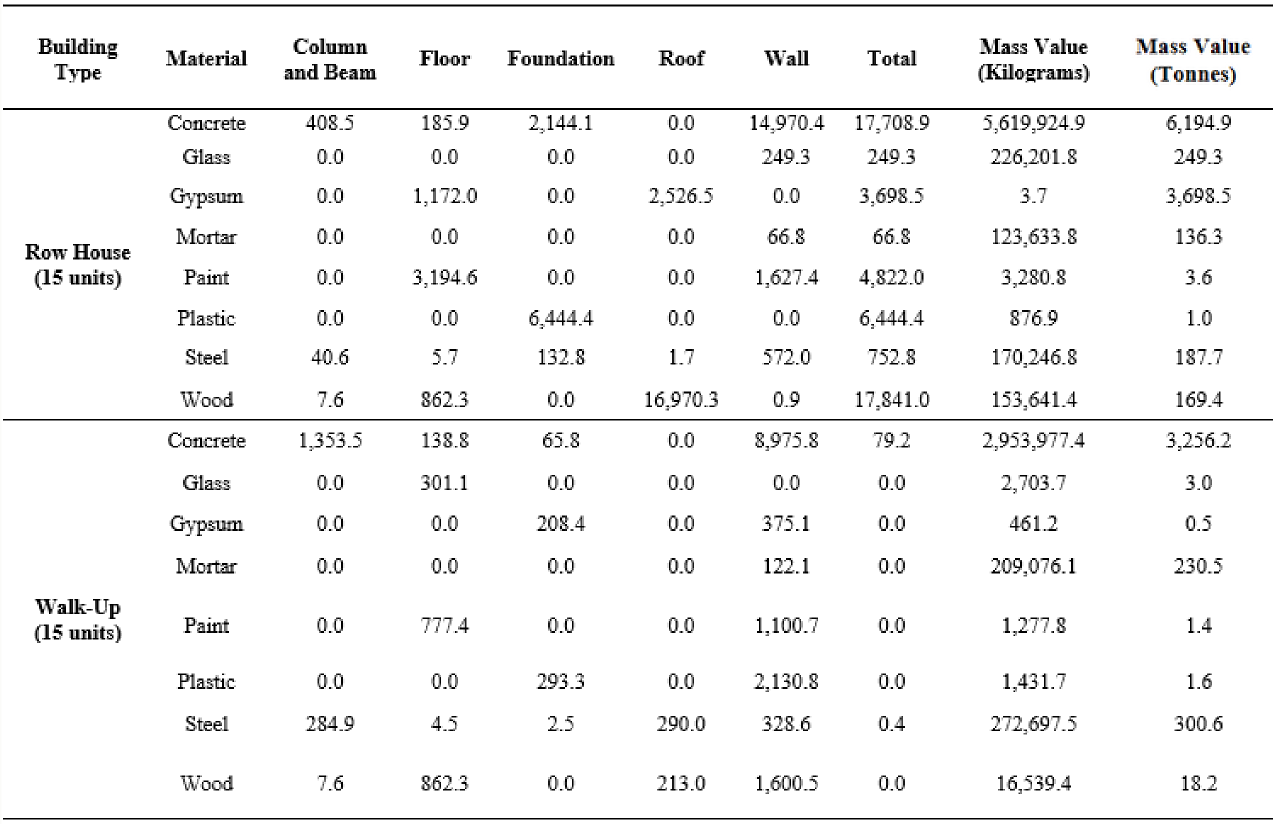
6 RESULTS AND DISCUSSION

6. 1 Bill of Materials

The researcher conceptualized the building's design, which served as the source of the material inputs for the life cycle assessment of the building. Walk-ups and the Row Housing Development can be found here. To conduct an objective comparison, the houses were created to have the same level of functionality. A summary of the building materials discovered by the researcher is provided in Appendix A. The fifteen units (15) of the Row House Building had a total mass of the major (structural) materials that came in at 6.30 106 kilograms, while the fifteen (15) Row Housing came in at 3.46 106 kilograms.

The components of the walk-up model and the row housing model's materials Different building assemblies, such as ceilings and roofs, floors and foundations, columns and beams, and walls, were created for the dwelling model structures that were joined collectively (Appendix A). Based on the summary of the bill of materials (BOM) used in both buildings, the materials are broken down into steel, wood, paint, concrete, gypsum board, and mortar in Table 2. The other elements are categorized as others.

Table 2 Bill of Materials Summary for Row Housing

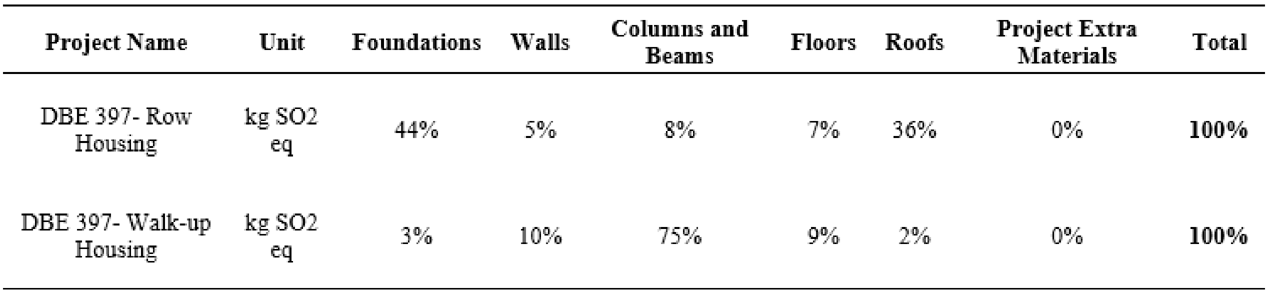


Building Type	Material	Column and Beam	Floor	Foundation	Roof	Wall	Total	Mass Value (Kilograms)	Mass Value (Tonnes)
Row House (15 units)	Concrete	408.5	185.9	2,144.1	0.0	14,970.4	17,708.9	5,619,924.9	6,194.9
	Glass	0.0	0.0	0.0	0.0	249.3	249.3	226,201.8	249.3
	Gypsum	0.0	1,172.0	0.0	2,526.5	0.0	3,698.5	3.7	3,698.5
	Mortar	0.0	0.0	0.0	0.0	66.8	66.8	123,633.8	136.3
	Paint	0.0	3,194.6	0.0	0.0	1,627.4	4,822.0	3,280.8	3.6
	Plastic	0.0	0.0	6,444.4	0.0	0.0	6,444.4	876.9	1.0
	Steel	40.6	5.7	132.8	1.7	572.0	752.8	170,246.8	187.7
	Wood	7.6	862.3	0.0	16,970.3	0.9	17,841.0	153,641.4	169.4
Walk-Up (15 units)	Concrete	1,353.5	138.8	65.8	0.0	8,975.8	79.2	2,953,977.4	3,256.2
	Glass	0.0	301.1	0.0	0.0	0.0	0.0	2,703.7	3.0
	Gypsum	0.0	0.0	208.4	0.0	375.1	0.0	461.2	0.5
	Mortar	0.0	0.0	0.0	0.0	122.1	0.0	209,076.1	230.5
	Paint	0.0	777.4	0.0	0.0	1,100.7	0.0	1,277.8	1.4
	Plastic	0.0	0.0	293.3	0.0	2,130.8	0.0	1,431.7	1.6
	Steel	284.9	4.5	2.5	290.0	328.6	0.4	272,697.5	300.6
	Wood	7.6	862.3	0.0	213.0	1,600.5	0.0	16,539.4	18.2

The Row Housing and Walk-up buildings extensively used concrete, glass, steel, and wood. Meanwhile, the Walk-up building also extensively used concrete, steel, and mortar. As per Table 2, the Walk building utilized 1.37 106 kg more wood than the Rowhouse building. On the other hand, the Row Housing development utilized 2.67 106 and 2.23 106 more kilograms of concrete and glass, respectively. On the other hand, 1.02 106 kg more steel will be used for the walk-up building. For the Walk-up Building, an additional 4.58 102 kg gypsum board was installed, assuming that it would provide comfort for the users; as a result, the LCA results for the Walk-up Building included an increased number of environmental burdens.

6.2 Life-Cycle Assessment Comparison of Assembly Group Embodied effects of the Two Buildings

Table 3 Acidification Potential Compared Across Assembly Types A to D



Project Name	Unit	Foundations	Walls	Columns and Beams	Floors	Roofs	Project Extra Materials	Total
DBE 397- Row Housing	kg SO2 eq	44%	5%	8%	7%	36%	0%	**100%**
DBE 397- Walk-up Housing	kg SO2 eq	3%	10%	75%	9%	2%	0%	**100%**

The comparison of row houses and walk-up housing in terms of their acidification potential is presented in Table 3, which covers the entire life cycle. According to the findings, the foundation of row housing contributes the most to acidity, whereas walk-up housing's most critical elements are its columns and beams.

Table 4 Eutrophication Potential Compared Across Assembly Types A to D

Project Name	Unit	Foundations	Walls	Columns and Beams	Floors	Roofs	Project Extra Materials	Total
DBE 397- Row Housing	kg N eq	66%	3%	10%	8%	13%	0%	**100%**
DBE 397- Walk-up Housing	kg N eq	6%	11%	73%	9%	1%	0%	**100%**

The potential for eutrophication is assessed in Table 4, which compares row houses and walk-up housing on a measure from A to D. According to the findings, the Foundation of Row Housing contributes the most to acidity. However, Walk-up Housing's columns and beams are responsible for the most acidity production. The walls and roofing of row housing and walk-up housing had the most negligible impact on eutrophication, respectively. This was the case for both types of housing.

Table 5 Fossil Fuel Consumption Compared Across Assembly Types A to D

Project Name	Unit	Foundations	Walls	Columns and Beams	Floors	Roofs	Project Extra Materials	Total
DBE 397- Row Housing	MJ	40%	4%	8%	4%	43%	0%	**100%**
DBE 397- Walk-up Housing	MJ	3%	10%	79%	6%	2%	0%	**100%**

Table 5 presents a comparison between row houses and walk-up housing concerning the amount of fossil fuel consumed by the assembly group, commencing from A to D. According to the findings, the Foundation and Roofing of Row Housing have the most significant contribution to Fossil Fuel Consumption, with 40% and 43% respectively. In contrast, the Columns and Beams of Walk-Up Housing have the highest contribution to FFC. On the other hand, the base and roof of walk-up housing contributed the least to the consumption of fossil fuels, while the walls of row housing contributed the least to the use of fossil fuels.

Table 6 Global Warming Potential Compared Across Assembly Types A to D

Project Name	Unit	Foundations	Walls	Columns and Beams	Floors	Roofs	Project Extra Materials	Total
DBE 397- Row Housing	kg CO2 eq	50%	4%	9%	5%	33%	0%	**100%**
DBE 397- Walk-up Housing	kg CO2 eq	4%	7%	81%	6%	1%	0%	**100%**

Table 6 compares row houses and walk-up housing regarding the potential for global warming for each of the four assembly groups (A through D). Row Housing's Foundation and Roofing Have the Highest Contribution to Fossil Fuel Consumption The results showed that Row Housing's Foundation and Roofing Have the Highest Contribution to Fossil Fuel Consumption with 50% and 33%, respectively, in walk-up Housing, Columns and Beams Still Have the Highest Contribution to GWP (81%) In contrast, the Walls and Roofing of Row Housing had the most negligible contribution to GWP (4% and 5%). In comparison, the roof (1%) and foundation (4%) of Walk-up Housing contributed the least influence toward Global Warming Potential.

Table 7 HH Particulate Compared Across Assembly Types A to D

Project Name	Unit	Foundations	Walls	Columns and Beams	Floors	Roofs	Project Extra Materials	Total
DBE 397- Row Housing	kg PM2.5 eq	52%	3%	13%	6%	26%	0%	**100%**
DBE 397- Walk-up Housing	kg PM2.5 eq	2%	6%	87%	4%	1%	0%	**100%**

Table 7 compares row houses and walk-up housing concerning the Human Health Particulate emitted by each of the four Assembly groups. According to the findings, the Foundation, Roofing, Columns, and Beams of Row Housing contribute the most to Fossil Fuel Consumption, with 52%, 26%, and 13%, correspondingly. However, the Columns and Beams still contribute (87%) to HH Particulate in walk-up housing. On the other hand, the Walls and Flooring of Row Housing had the most negligible contribution to GWP (3% and 6%). In contrast, Walk-up Housing's roof (1%), floors (4%), and foundation (2%) contributed the least to the impact on human health particles.

Table 8 Non-Renewable Energy Compared Across Assembly Types A to D

Project Name	Unit	Foundations	Walls	Columns and Beams	Floors	Roofs	Project Extra Materials	Total
DBE 397- Row Housing	MJ	37%	4%	7%	4%	49%	0%	**100%**
DBE 397- Walk-up Housing	MJ	3%	8%	81%	5%	2%	0%	**100%**

Table 8 compares row houses and walk-up housing regarding the amount of non-renewable energy consumed. The comparison is broken down according to assembly groups A through D. According to the findings, the Roofing of Row Housing contributes the most to non-renewable energy consumption at 49%. The Foundation of walk-up Housing contributes the most at 37%. However, the columns and beams continue to have the most significant contribution, with 81%. Meanwhile, the Walls and Flooring of Row housing had the most negligible contribution to NRE, with 4% apiece. In comparison, Walk-up Housing's Floor (5%), roof (2%), and foundation (3%) contributed the least impact toward the consumption of non-renewable energy.

Table 9 Ozone Depletion Potential Compared Across Assembly Types A to D

Project Name	Unit	Foundations	Walls	Columns and Beams	Floors	Roofs	Project Extra Materials	Total
DBE 397- Row Housing	kg CFC-11 eq	66%	5%	10%	7%	12%	0%	**100%**
DBE 397- Walk-up Housing	kg CFC-11 eq	7%	11%	72%	10%	0%	0%	**100%**

The potential for ozone depletion in the atmosphere is compared between row houses and walk-up housing in Table 9, which is organized from A to D according to the assembly groups. According to the findings, the Foundation of Row Housing contributes the most to ODP with 66%. At the same time, the Columns and Beams of Walk-Up Housing still have the most considerable contribution, with 72% for Ozone Depletion potential. In the meantime, the contribution of Walls and Flooring of Row houses to NRE was the lowest, coming in at 5% and 7%, respectively. While the Floor (10%) and Foundation (7%) of walk-up Housing contribute the least to Ozone Depletion Potential, these two components are nevertheless important.

Table 10 Smog Potential Compared Across Assembly Types A to D

Project Name	Unit	Foundations	Walls	Columns and Beams	Floors	Roofs	Project Extra Materials	Total
DBE 397- Row Housing	kg O3 eq	48%	4%	8%	10%	30%	0%	**100%**
DBE 397- Walk-up Housing	kg O3 eq	4%	10%	73%	12%	2%	0%	**100%**

Table 10 presents a contrast between row houses and walk-up housing in terms of the potential for smog, broken down by each assembly group from A to D. According to the findings, the Foundation of Row Housing contributed the most to SP with 48%. In comparison, roofing contributed the most to SP, with 30%. However, the Columns and Beams contributed the most to SP, with 73% in walk-up housing. Walls, Columns, and Beams for Row Housing Had the Least Contribution to Smog Potential, with 4% and 8%, respectively. Walls and Beams for Row Housing Had the Least Contribution to Smog Potential. Meanwhile, the roof (2% of the total impact) and foundation (4% of the total impact) of walk-up housing contribute the least to smog potential.

Table 11 Total Primary Energy Compared Across Assembly Types A to D

Project Name	Unit	Foundations	Walls	Columns and Beams	Floors	Roofs	Project Extra Materials	Total
DBE 397- Row Housing	MJ	37%	4%	7%	4%	48%	0%	**100%**
DBE 397- Walk-up Housing	MJ	3%	9%	80%	6%	2%	0%	**100%**

Table 11 depicts a comparison between row houses and walk-up housing in terms of the total primary energy required to heat and cool each kind of dwelling, broken down by assembly group from A to D. Following the findings, the Foundation of Row Housing contributed the most to Total Primary Energy with 37%. Roofing contributed the most, with 48%. In contrast, in walk-up housing, the Columns and Beams contributed the most to Total Primary Energy, with 80%. Walls and Floors for row housing had the least contribution to PE, contributing 4% to the total. Meanwhile, the roof (2%), foundation (3%), and walls (9%) of walk-up housing make the slightest contribution towards the creation of total primary energy.

6.3 Detailed Life Cycle Measure by Life Cycle Stages for Both Developments

Table 12. Detailed LCA Measure Table by Life Cycle Stages for Row Housing Development

LCA Measures	Unit	Product (A1 to A3)	Construction process (A4 & A5)	Use (B2, B4 & B6)	End of life (C1 to C4)	Beyond building life (D)	Total effects
Global Warming Potential	kg CO2 eq	94%	7%	1%	4%	-6%	100%
Acidification Potential	kg SO2 eq	76%	14%	2%	11%	-3%	100%
HH Particulate	kg PM2.5 eq	94%	4%	4%	3%	-4%	100%
Eutrophication Potential	kg N eq	87%	9%	1%	5%	-1%	100%
Ozone Depletion Potential	kg CFC-11 eq	95%	4%	1%	0%	0%	100%
Smog Potential	kg O3 eq	60%	21%	3%	17%	-2%	100%
Total Primary Energy	MJ	89%	7%	1%	5%	-2%	100%
Non-Renewable Energy	MJ	89%	7%	1%	5%	-2%	100%
Fossil Fuel Consumption	MJ	89%	9%	1%	6%	-5%	100%

The environmental consequences of Row Housing buildings throughout their entire life cycles (from Module A to Module D) are displayed in Table 12. They account for an average of 86% of the total load from production. The findings indicate that Manufacturing and Transport (A1-A3) in Row House Buildings have the most impact on the environment out of all nine categories, including GW (94%), AP (76%), HHP (94%), EP (87%), ODP (95%), SP (60%), TPE (89%), TPE (89%), NNE (89%), and FFC (89%). Row Housing's Construction Process impacts all nine categories of the Life Cycle, averaging 9%. The Use and Beyond Building Life of Row House buildings had the most negligible impact on all nine categories, ranging from 1% to 4% of the overall impact.

Table 13 illustrates the environmental impacts of the Walk-up Housing building on the entire structure life cycle (from Module A to D). The results illustrate that the walk-up house buildings' Manufacturing and Transport (A1-A3) contributes to the environmental impact averaging 76% of the overall load among all the nine categories with GW (77%), AP (64%), HHP (86%), EP (83%), ODP (95%), SP (49%), TPE (80%), NNE (80%), and FFC (69%). Walk-up building's Construction Process impacts all nine categories of the Life Cycle, averaging 11%. Walk-up buildings' Use and Beyond Building Life had the most negligible impact on all the nine categories ranging from 1-3% of the overall impact.

Table 13 Detailed LCA Measure Table by Life Cycle Stages for Walk-up Housing Development

LCA Measures	Unit	Product (A1 to A3)	Construction process (A4 & A5)	Use (B2, B4 & B6)	End Of Life (C1 to C4)	Beyond Building Life (D)	Total Effects
Global Warming Potential	kg CO2 eq	**77%**	**8%**	**0%**	**4%**	**11%**	**100%**
Acidification Potential	kg SO2 eq	**64%**	**17%**	**2%**	**11%**	**6%**	**100%**
HH Particulate	kg PM2.5 eq	**86%**	**3%**	**2%**	**2%**	**7%**	**100%**
Eutrophication Potential	kg N eq	**83%**	**10%**	**1%**	**4%**	**2%**	**100%**
Ozone Depletion Potential	kg CFC-11 eq	**95%**	**5%**	**0%**	**0%**	**0%**	**100%**
Smog Potential	kg O3 eq	**49%**	**27%**	**3%**	**18%**	**3%**	**100%**
Total Primary Energy	MJ	**80%**	**9%**	**1%**	**5%**	**5%**	**100%**
Non-Renewable Energy	MJ	**80%**	**9%**	**1%**	**5%**	**5%**	**100%**
Fossil Fuel Consumption	MJ	**69%**	**11%**	**1%**	**7%**	**13%**	**100%**

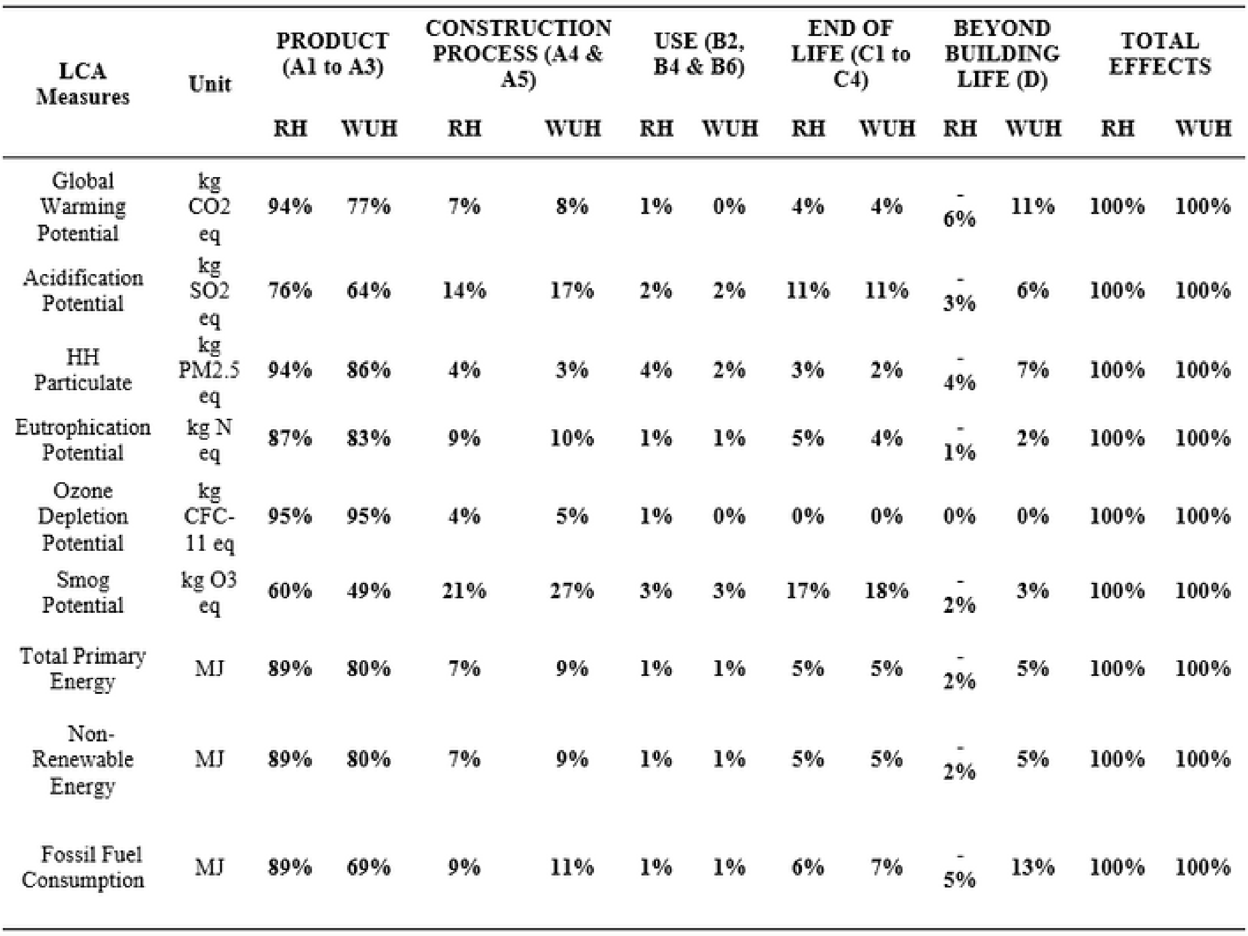
7 CONCLUSION AND FUTURE WORKS

	Building Systems	GWP (kg CO2 eq)	AP (kg SO2 eq)	HHC (kg PM2.5 eq)	EP (kg N eq)	ODP (kg CFC-11 eq)	SP (kg O3 eq)	TPE (MJ)	FFC (MJ)	NRE (MJ)
Foundation	Row Housing	80%	72%	76%	80%	81%	71%	73%	73%	70%
	Walk-up Housing	4%	3%	2%	6%	7%	4%	3%	3%	3%
Walls	Row Housing	3%	5%	2%	2%	3%	3%	4%	4%	4%
	Walk-up Housing	7%	10%	6%	11%	11%	10%	9%	10%	8%
Columns and Beams	Row Housing	3%	3%	5%	2%	2%	3%	4%	4%	3%
	Walk-up Housing	81%	75%	87%	73%	72%	73%	80%	79%	81%
Roofs	Row Housing	1%	2%	4%	0%	0%	1%	9%	9%	10%
	Walk-up Housing	1%	2%	1%	1%	0%	2%	2%	2%	2%
Floors	Row Housing	12%	19%	12%	15%	13%	22%	11%	11%	12%
	Walk-up Housing	6%	9%	4%	9%	10%	12%	6%	6%	5%
Project Extra Materials	Row Housing	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Walk-up Housing	0%	0%	0%	0%	0%	0%	0%	0%	0%

This study used the Athena software for Building Impacts to conduct a comparative LCA assessment. The two scenarios that were evaluated were a Row Housing design and a Walk-up Building. The designs were assumed to be situated on a vulnerable structure on the Davao River riverbanks. The categories assessed were Acidification Potential, Eutrophication Potential, Fossil Fuel Consumption, HH Particulate, and Non-Renewable Energy indicators were reported from the whole-building LCA from the cradle-to-grave analysis. Results showed that each building type produces significant GHG levels in different Life Cycle stages.

In contrast to row housing homes, walk-up housing required significantly less usage and repetition of building materials, including roofing and foundation materials. As a result, the embodied carbon for walk-up housing was 11% less than that of row housing dwellings from Stage A through Stage C. This comparative study demonstrated that walk-up buildings are a preferred building approach for vulnerable dwellings due to their lower Embodied Energy emission compared to the Row Housing approach. This study suggests further inquiry into how land also affects sustainability aside from the building materials of a residential unit.

Row Housing has a higher Production Impact for the Life Cycle Assessment than Walk-up Housing, with more than 10% for Global Warming Potential, Acidification Potential, Smog Potential, and Fossil Fuel Consumption. Walk-up Housing has a higher impact on GHG emissions categories than Row House buildings, ranging from 1-3% higher in terms of GWP, AP, EP, ODP, SP, TPE, NRE, and FFC. For Building Use, the Row Housing type produces more GHG compared to Walk-up housing, specifically AP, HHP, ODP, NRE, and FFC, ranging from 1-2% higher. There is very little difference between the two approaches for C4 (End of the Life cycle), with a -1 to 1% disparity. For category D (Beyond Building Life), Walk-up housing has a higher life cycle potential for the nine categories of GHG. The findings reported in this paper support decision-makers looking for a better choice of building approaches for vulnerable dwellings along the Davao River, whether high-rise development or horizontal development, to minimize environmental liabilities and reduce climate change impacts.



LCA Measures	Unit	PRODUCT (A1 to A3)		CONSTRUCTION PROCESS (A4 & A5)		USE (B2, B4 & B6)		END OF LIFE (C1 to C4)		BEYOND BUILDING LIFE (D)		TOTAL EFFECTS	
		RH	WUH	RH	WUH	RH	WUH	RH	WUH	RH	WUH	RH	WUH
Global Warming Potential	kg CO2 eq	94%	77%	7%	8%	1%	0%	4%	4%	-6%	11%	100%	100%
Acidification Potential	kg SO2 eq	76%	64%	14%	17%	2%	2%	11%	11%	-3%	6%	100%	100%
HH Particulate	kg PM2.5 eq	94%	86%	4%	3%	4%	2%	3%	2%	-4%	7%	100%	100%
Eutrophication Potential	kg N eq	87%	83%	9%	10%	1%	1%	5%	4%	-1%	2%	100%	100%
Ozone Depletion Potential	kg CFC-11 eq	95%	95%	4%	5%	1%	0%	0%	0%	0%	0%	100%	100%
Smog Potential	kg O3 eq	60%	49%	21%	27%	3%	3%	17%	18%	-2%	3%	100%	100%
Total Primary Energy	MJ	89%	80%	7%	9%	1%	1%	5%	5%	-2%	5%	100%	100%
Non-Renewable Energy	MJ	89%	80%	7%	9%	1%	1%	5%	5%	-2%	5%	100%	100%
Fossil Fuel Consumption	MJ	89%	69%	9%	11%	1%	1%	6%	7%	-5%	13%	100%	100%

This merely demonstrates that the Philippines has achieved some sustainability over the past several years; nonetheless, there is still a great deal of work to be done. The reliance of this country on fossil fuels, which has been shown to contribute to both the pollution of the air and the release of greenhouse gases, is a significant cause for concern. When it comes to effectively managing its resources in a way that does not cause damage to the ecological system of the country, the nation needs help. In a hopeful sign, the Philippines has begun to transition toward using renewable energy sources such as solar and wind power. This is a step in the right direction. In addition, the government has established initiatives to safeguard and preserve natural resources, encourage environmentally responsible agricultural and forestry practices, and promote sustainable agricultural and forestry practices. On the other hand, these initiatives have frequently been thwarted by a need for more political will and financial resources.

In general, a clear picture of the sustainability situation in the Philippines needs to be painted. Even though there have been some encouraging breakthroughs, many obstacles still need to be overcome before the country can go forward in an environmentally responsible and sustainable manner.

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