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Assessing the Environmental Impact of the Proposed Alturas Mall in Ubay, Bohol Through Life Cycle Assessment

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Abstract

This study presents a whole-building Life Cycle Assessment (LCA) of a proposed large-scale commercial mall in a tropical emerging-economy context, addressing the limited application of LCA in the Philippine construction sector. Using One Click LCA software, the environmental impacts of the proposed Alturas Mall in Ubay, Bohol, were assessed across selected life-cycle stages. Results indicate that operational energy use (B6) dominates total life-cycle carbon emissions, accounting for 96.82% of total CO_2e, reflecting the fossil-fuel-dependent electricity mix of the Philippines. The calculated embodied carbon was 414.73 kg CO_2e/m^2, which falls below international benchmark thresholds. This study contributes empirical whole-building LCA evidence for large-scale commercial buildings in tropical emerging economies, a context that remains underrepresented in current literature. Transportation (A4) and selected maintenance stages (B1–B5) were excluded due to data limitations at the design stage, and embodied carbon results should therefore be interpreted as conservative estimates, particularly in archipelagic contexts such as the Philippines. The findings highlight the critical need to prioritize operational energy efficiency alongside material optimization in tropical commercial buildings and support the early integration of LCA into architectural decision-making.

1.0 INTRODUCTION

Humans continuously modify the natural environment to improve their living status and quality of life (Mbala, Aigbavboa, & Aliu, 2019). Infrastructure projects, construction of buildings, and developments in the built environment are widely considered indicators of economic progress (Balaban, 2012). However, the rapid pace of urbanization and the increasing demand for commercial developments have raised environmental concerns (Minde, Patvekar, Mokashi, Bulchandani, & Desale, 2023). Globally, buildings are responsible for approximately 30-40% of primary energy consumption and contribute to about 40% of greenhouse gas emissions (Dixit, Culp, & Fernández-Solís, 2013). The construction process also plays a major role in the extraction of raw materials (Bribián, Capilla, & Usón, 2011), which, if not managed sustainably, can lead to severe environmental degradation. Throughout a building's life span, extensive energy and resource usage result in detrimental impacts such as resource depletion, climate change, and biodiversity loss (Dahiya & Laishram, 2024; Watson, et al., 2019). To address these issues and maintain a balance between development and environmental preservation, the implementation of environmental assessments, such as Life Cycle Assessment (LCA), becomes essential. Recent studies emphasize that sustainability assessment in the built environment must adopt integrated, systems-based approaches that account for life cycle impacts and resource interdependencies, rather than focusing solely on isolated performance indicators (Halog, 2011). LCA is a systematic method used to evaluate the environmental impacts of a product, process, or building across its entire life cycle (Barbhuiya & Das, 2023; Abd Rashid & Yusoff, 2015), contributing to the goal of sustainable development by ensuring the needs of the present generation are met without compromising those of future generations (Zahedi, 2019).

The increasing demand for economic growth has led to a rise in the construction of commercial developments, including shopping malls, which play a vital role in urban economies (Çavka, 2023). In the Philippines, the construction of commercial malls has become closely associated with development and serves as a visible indicator of economic progress. The proliferation of shopping malls reflects the country's evolving economic landscape, positioning the Philippines as a competitive force in global retail (Rico & de Leon, 2017). While these establishments drive economic growth and meet consumer needs (Lin, Shih, & Perng, 2020), their environmental implications should not be overlooked. Alarmingly, in areas like Metro Manila, commercial malls outnumber parks, contributing to ecological imbalance and urban environmental stress (Rico & de Leon, 2017). Without proper intervention, this disproportion between built environments and green spaces can lead to irreversible environmental consequences, including climate change and biodiversity threats (Röck, Passer, & Allacker, 2024). The Philippines is already experiencing environmental challenges such as intensified typhoons, flooding, and extreme weather conditions, which affect social, environmental, and economic systems (Rincón & Virtucio, 2008).

In recent years, the Province of Bohol has experienced a surge in infrastructure and commercial development. As a first-class province with growing economic potential, Bohol has seen an increase in retail and tourism-related establishments. Among its rapidly developing areas is the Municipality of Ubay, which spans approximately 20,755 hectares (PGBh, 2024) and is recognized as a first-income class municipality. The Alturas Group of Companies, a prominent local business, is planning to build a three-storey commercial mall in Ubay with a floor area of approximately 32,000 square meters. The mall's ground floor is designated for commercial space, a supermarket, and a department store, while the upper floors will house support services and administrative offices. A solar farm will be integrated into the roof deck on the second floor as part of the company's efforts to pursue renewable energy solutions. Although such developments bring economic advantages such as job creation and increased revenue, they also pose potential environmental risks that must be carefully assessed to ensure sustainable urban growth. Although a roof-deck solar farm is proposed as part of the architectural design, renewable energy generation was not included in the present LCA simulation, which represents a baseline grid-dependent operational scenario. Future scenario-based analyses may assess the potential reduction in operational emissions from on-site renewable energy integration.

The growing concern over the environmental impacts of buildings motivated this study, which aims to assess the potential ecological effects of the proposed Alturas Mall in Ubay, Bohol, through a comprehensive Life Cycle Assessment. LCA evaluates the environmental performance of a product or structure from cradle to grave, considering all stages of its life span (Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014). While numerous LCA studies have been conducted globally, limited research exists in emerging economies such as the Philippines, where LCA practices are still in their infancy (Salzer, Wallbaum, Ostermeyer, & Kono, 2017). Understanding the environmental impacts of the proposed development is crucial in informing sustainable design decisions and mitigating harmful ecological consequences. The study aims to analyze the building's architectural and structural materials—since only these were finalized during the study period—and evaluate their environmental performance using the One-Click-LCA software (One-Click-LCA, 2015). The LCA covers stages A1–A3 (product phase), A5 (construction process), B6–B7 (use phase), and C1–C4 (end-of-life phase), while excluding phases A4, B1–B5, and B8 due to data unavailability. The environmental impact will be measured across several categories, including global warming potential (CO_2 eq.), ozone depletion (CFC-11 eq.), acidification (SO_2 eq.), eutrophication ($(PO_4)^{3-}$ eq.), photochemical ozone creation (C_2H_4 eq.), and abiotic resource depletion (Sb eq. & MJ net calorific) (En-C.E.N., 2011). This study is positioned within the broader framework of sustainable building performance assessment, where Life Cycle Assessment is employed as a decision-support tool for evaluating long-term environmental impacts of buildings. Specifically, the study aims to: (1) quantify the life cycle environmental impacts of a proposed commercial mall in a tropical, emerging-economy context; (2) identify building materials and elements with the highest embodied carbon contributions; and (3) evaluate the relative contribution of operational energy use to total life cycle emissions in order to inform sustainable design and policy decisions.

1.1 Life Cycle Assessment on Building Sector

Life Cycle Assessment (LCA) is a methodological framework used to evaluate the environmental impacts of buildings across their entire life span, including raw material extraction, manufacturing, construction, operation, maintenance, and end-of-life processes (Basbagill, Flager, Lepech, & Fischer, 2013). Owing to the inherent complexity of building systems and limitations in available data, LCA practitioners commonly define simplified system boundaries that exclude selected life-cycle stages while maintaining analytical reliability and interpretability (Hernandez, Oregi, Longo, & Cellura, 2019).

Integrating LCA during the conceptual and preliminary design stages enables the comparison of material and design alternatives, supports environmentally informed decision-making, and allows prediction of potential ecological impacts prior to construction (Cusenza, Guarino, Longo, & Cellura, 2022; Hassan, Megahed, Eleinen, & Hassan, 2022; Hollberg, et al., 2021; Meex, Hollberg, Knapen, Hildebrand, & Verbeeck, 2018; Norouzi, Colclough, Jiménez, & Boer, 2022; Arvizu-Piña, López, González, & Alarcón, 2023) By enabling the evaluation of alternative design strategies before implementation, early-stage LCA contributes to reducing long-term environmental burdens and strengthening sustainable development outcomes in the built environment.

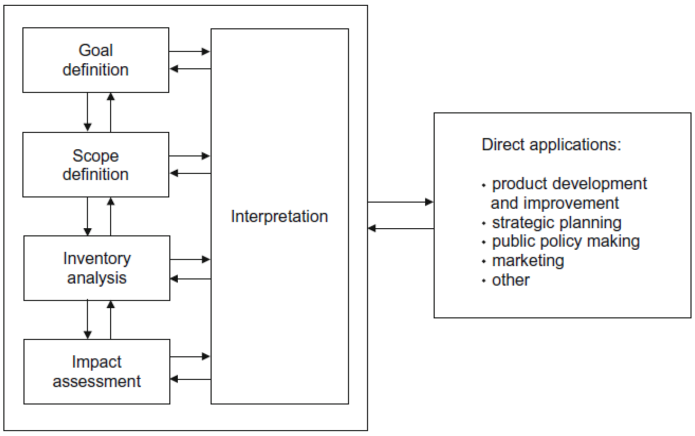

Figure 1. Life Cycle Assessment Framework.

1.2 Methodological Framework of Life Cycle Assessment

The conduct of a Life Cycle Assessment involves four main stages: goal and scope definition, Life-Cycle Inventory (LCI), Life-Cycle Impact Assessment (LCIA), and interpretation of the results (Bowyer, Howe, Guillery, & Fernholz, 2005). When performing an LCA, it is essential to define the goal and scope to ensure a clear understanding of the study's objective. To ensure the assessment goal is achieved, it is vital to clearly define the scope of the investigation (Hernandez, Oregi, Longo, & Cellura, 2019). The Life-Cycle Inventory (LCI) is the next stage of an LCA. In this phase, data are collected (Hauschild, Rosenbaum, & Olsen, 2018) and serve as inputs and these inputs will then be converted to equivalent outputs (Ong, Arcilla, & Oreta, 2017). During the Life-Cycle Impact Assessment (LCIA) stage, the recorded data obtained from the LCI will be quantitatively correlated with several impact categories. (Ong, Arcilla, & Oreta, 2017). Lastly, the analysis of the results is connected to the findings derived from the LCI and LCIA and to the evaluation objective (Hollerud, Bowyer, Howe, Pepke, & Fernholz, 2017). Figure 1 presents the rubric for the LCA framework diagram, as defined by ISO 14040 (ISO-14040, 2006).

1.3 Tools for Life Cycle Assessment

Performing Life Cycle Assessment (LCA) in the construction industry is predominantly difficult because of the enormous amount of components that are included in the building's whole life span (Hernandez, Oregi, Longo, & Cellura, 2019). Traditional Life Cycle Assessment tends to be complicated and requires a significant investment of time and effort (Soust-Verdaguer, Llatas, & García-Martínez, 2016). The inadequate use of LCA in the building industry can be attributed to challenges connected to users, namely, inadequate expertise in LCA among professionals like architects. (Meex, Hollberg, Knapen, Hildebrand, & Verbeeck, 2018).

Several studies have inspected the features of the applied LCA in buildings utilizing different programs and software (Meex, Hollberg, Knapen, Hildebrand, & Verbeeck, 2018), (Basbagill, Flager, Lepech, & Fischer, 2013), (Rodríguez, et al., 2023). The Athena Eco Calculator was used in conducting a Life Cycle Assessment for residential dwellings (Esteghamati, et al., 2022), (Basbagill, Flager, Lepech, & Fischer, 2013). The IMPACT database and software were also used, which can be integrated with building information modeling software to comprehensively assess environmental impact and building performance (Azzouz, Borchers, Moreira, & Mavrogianni, 2017). A tool specifically designed for the Latin America region, called EVAMED, was used on the Life Cycle Assessment of buildings (Arvizu-Piña, López, González, & Alarcón, 2023). OpenLCA software and *ecoinvent* database were also used by different authors in the conduct of environmental impact assessment on buildings (Ong, Arcilla, & Oreta, 2017), (Rezaei, Bulle,, & Lesage, 2019), (Ryberg, Ohms, Møller, & Lading, 2021), (Pamu, Kumar, Shakir, & Ubbana, 2022).

Other Life Cycle Assessment software like GaBi and SimaPro, which are some of the widely used Life Cycle Assessment tools around the globe (Hollerud, Bowyer, Howe, Pepke, & Fernholz, 2017), can also be used in the calculation of ecological impacts for the construction sector. One Click LCA tool (One-Click-LCA, 2015) It is a cloud-based program specifically designed for the construction and building industry, and also has a database around the world. This software can also be used globally. Different Life Cycle Assessment studies also used One Click LCA (One-Click-LCA, 2015) in determining the ecological effects of different building types (Petrovic, Myhren, Zhang, Wallhagen, & Eriksson, 2019), (Vigovskaya, Aleksandrova, & Bulgakov, 2018), (Morsi, Ismaeel, Ehab, & Othman, 2022).

In conducting a Life Cycle Assessment using LCA software or tools, it is important to determine the geographic applicability of the software to have a comprehensive and reliable result. Table 1 shows the different Life Cycle Assessment tools and their geographic applicability (Arvizu-Piña, López, González, & Alarcón, 2023).

Table 1. Different Tools and their Geographical Applicability (Arvizu-Piña, López, González, & Alarcón, 2023).

LCA Tool	**Geographic Applicability**
SimaPro	Global
Gabi	Europe
OpenLCA	Global
Ecosoft	Global
Equer	France
Athena	USA
Legep	Germany
Elodie	France
Envest	Global
SBS Building Sustainability	Germany
eTOOL	Global
GreenCalc	Europe
CoconBIM	France, Europe
Tally	USA
One Click LCA	Global
Eco-bat	Europe
BeCost	France
Eco Quantum	Global

2.0 METHODS

This study employed a quantitative, simulation-based research design. The first step in conducting the study was obtaining approval to use the plans for the proposed Alturas Mall. Permission for the use of plans was obtained from the head architect and the structural designer of the Planning, Design, and Construction department of Alturas Group of Companies as well as the general manager or the owner of the building. After obtaining the necessary plans for the proposed mall, the next step was to identify and document the architectural and structural building materials for the development. These materials were estimated and quantified to produce the bill of materials. The expertise of a quantity surveyor was consulted during the quantification and estimation of various architectural and structural building materials to obtain more accurate data. The data collected were treated with utmost confidentiality since the plans were the intellectual property of the designing architect and structural engineer. The gathered data were stored in a hardware storage and in an online password-encrypted storage drive to ensure that the data is protected. Two years after the conduct of the study, all electronic and printed data gathered will be irreversibly deleted or hard deleted from both the hardware and the online storage drive.

The study used a Life Cycle Assessment software. Acquiring a license for the software was necessary to have a reliable and valid result. The study used the One Click LCA tool (One-Click-LCA, 2015), an LCA software intended for the construction and building sector. A student license for the software was acquired to access its features and database. The software's simulation process followed the framework in conducting an LCA as set by ISO 14040 (ISO-14040, 2006). Table 2 presents the simulation process.

Table 2. Simulation Process.

Goal and Scope	Input of the building area of the proposed development
	Input of the calculation period of the building. For this study, a 60-year calculation period was used as set by EN 15978 (BRE-Global, 2018).
	The functional unit of the study is one square meter of gross floor area over a 60-year reference study period, in accordance with EN 15978.
Life Cycle Inventory (LCI	Selection and input of materials from the software's database that matched the architectural and structural building materials of the proposed Alturas Mall, together with their corresponding quantities estimated from the plans
	Input of potential annual electricity (Inquirer, 2012) of the proposed mall
	Input of potential water consumption (Seneviratne, 2007) of the proposed development
	Selection of generic data for the construction scenarios from the software's database was done to determine the potential impact of the on-site processes stage of the proposed development's life cycle.
	Selection of deconstruction or demolition scenario data from the software's database was also performed for the end-of-life stage of the project
	Operational energy and water consumption were estimated using benchmark data for Philippine commercial buildings, assuming full occupancy, standard commercial operating hours, and conventional HVAC systems designed for tropical climatic conditions. Electricity supply was modeled based on the national grid mix, which remains predominantly fossil-fuel-based. Water use assumptions reflect typical commercial demand patterns and were applied consistently throughout the reference study period.
Life Cycle Impact Analysis	Impact categories as set by EN 15978 (En-C.E.N., 2011) such as global warming potential, ozone depletion, acidification, eutrophication, photochemical ozone creation, and abiotic resource depletion, were evaluated. These environmental impact categories were simulated and analyzed using the One Click LCA software.
Interpretation	Outputs from the software were interpreted to produce a report on the potential environmental effects of the proposed development.

Life cycle stages A4 (transport to site), B1–B5 (maintenance and replacement), and B8 were excluded due to the lack of reliable, project-specific data at the design development stage. These exclusions introduce uncertainty, particularly in the estimation of embodied impacts, as transport and maintenance activities can contribute additional emissions. As such, the embodied carbon results should be interpreted as conservative estimates. Nevertheless, exclusion of these stages is common in early-design LCAs and does not undermine the study's ability to identify dominant impact phases.

The system boundary of this study includes the product stage (A1–A3), construction stage (A5), operational energy and water use (B6–B7), and end-of-life stages (C1–C4). The transportation phase (A4), maintenance and replacement stages (B1–B5), and operational energy for user transport (B8) were excluded due to the absence of reliable, project-specific data at the early design stage. This boundary definition is consistent with previous early-stage whole-building LCA studies, where exclusion of data-intensive stages reduces uncertainty and improves result robustness.

Annual electricity consumption was estimated using benchmark values for Philippine commercial buildings, assuming full operational occupancy, conventional HVAC systems appropriate for a tropical climate, and a grid-dependent electricity supply. The modeled scenario represents a baseline operational condition without advanced energy efficiency measures or high renewable energy penetration. These assumptions were applied consistently across the reference study period to ensure comparability of life cycle stages.

3.0 RESULTS AND DISCUSSIONS

3.1 Building Element with the Highest Environmental Impact

The gathered data on the equivalent building materials and their corresponding quantities were entered in the One Click LCA software. The software calculated the potential environmental impact of the materials and determined the most contributing building material. Table 3 shows the carbon emissions of the top 10 materials with the highest emissions, and their corresponding percentage of the overall emissions of the proposed building. The top 3 most contributing materials were determined to be the ready-mix concrete, followed by the plaster mortar and steel reinforcement or reinforcement bars.

Table 3. Carbon Emissions of Different Building Materials from Cradle to Grave.

Material	Qty	Emission	%
Ready mix concrete	11,717.26	4,064.40	30.476%
Cement plaster	8,712,528.00	3,653.39	27.394%
Steel reinforcement	1,922,640.83	2,316.66	17.371%
Cement mortar	1,476,288.00	451.86	3.388%
Tempered glass	1,440.12	279.19	2.093%
Aluminum cladding	2,454.93	250.42	1.878%
Ceramic tiles	19,074.15	209.51	1.571%
Formworks	310.02	193.74	1.453%
6"concrete hollow blocks	65,639.00	112.42	0.843%
Metal furring	6,788.02	100.91	0.757%

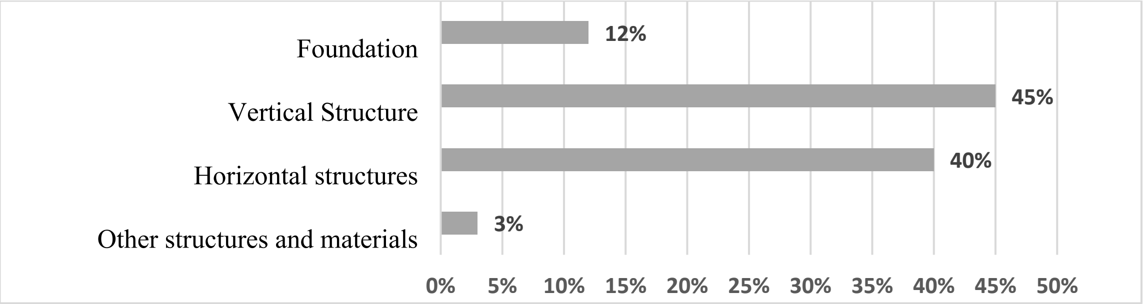

Figure 2. Embodied Carbon by Building Element.

It can be observed in the tabulation that the material with the highest emissions is the ready-mix concrete, which accounts for 30.476% of the overall carbon emissions of the proposed development. The reason for this is the production of cement, which is the primary ingredient in the ready-mix concrete. The manufacturing process of cement involves heating and is an energy-intensive process that typically depends on fossil fuels, resulting in significant carbon dioxide emissions (Worrell, Price, Martin, Hendriks, & Meida, 2001). The ready-mix concrete also contains aggregates, and aggregate extraction is also associated with carbon emissions. The combination of these materials results in high carbon emissions. Another reason why this material ranked as the most contributing material is because of the quantity of ready-mix concrete utilized in the structural component of the proposed development.

The second most contributing material was determined to be the cement plaster, which is responsible for 27.394% of the overall carbon emissions of the proposed building. This material was used as the primary finishing material for the concrete hollow block walls of the proposed mall. Plaster mortar contains cement, and cement production involves high energy consumption; a large quantity of this building material was used in the proposed mall, resulting in substantial carbon emissions. The reinforcement steel ranked as the third most contributing material based on the calculation of the One Click LCA software and also accounts for 17.371% of the total carbon emissions of the proposed building. Similar to cement, the manufacturing and production of reinforcement steel also involve high energy consumption (Tongpool, Jirajariyavech, Yuvaniyama, & Mungcharoen, 2010) from the raw material extraction, melting, and refining. Steel requires another processing, which involves shaping to form a reinforcement bar. This process also produces additional carbon emissions. The proposed building, being designed as a reinforced concrete structural frame, requires a substantial amount of reinforcement bars, thus resulting in a higher carbon dioxide emission compared to other materials used in the proposed mall.

Figure 2 illustrates the percentage of the embodied carbon associated with the building elements of the proposed Alturas Mall. As shown in the figure above, the building element with the highest percentage of embodied carbon was the vertical structure, which constitutes 45% of the total embodied carbon of the proposed building. This building element comprises various sub-elements, including columns, load-bearing and non-load-bearing walls, and façade elements. This building element exhibited the highest embodied carbon due to the different sub-elements that also have various building materials, contributing to the overall carbon emission. The horizontal structures, which include beams, slabs, and roofing sub-elements, constitute 40% of the building's overall embodied carbon. This building element was classified as the second highest due to the use of ready-mix concrete and reinforcement bars as the main materials. The foundation, consisting of column footing, tie beam, and wall footing, accounts for 12% of the overall embodied carbon of the proposed development. Other building materials, such as doors and finishes, contributed to 3% of the embodied carbon of the proposed building.

3.2 Potential Environmental Impact

The potential environmental impact of the proposed Alturas Mall was calculated and analyzed using the One Click LCA program, aligning with the impact categories set by EN 15978. Global warming potential, ozone depletion, acidification, eutrophication, photochemical ozone depletion, and abiotic resource depletion for both non-fossil and fossil resources (En-C.E.N., 2011) were the environmental impact categories that were assessed. The life cycle stages that were included in the analysis were the product phase (A1-A3), construction phase (A5), the operational energy consumption (B6), the operational water usage (B7), and C1-C4 or the end-of-life phase.

The results obtained from the One Click LCA program were normalized to have a clearer visualization of the different environmental impacts throughout the whole life cycle of the building. Data normalization helps in comparing different datasets to a common range across different categories and units (Sousa, Soares, Moreira, Severis, & de Santa-Eulalia, 2021). It was necessary to normalize the data because there were significant differences in the ranges in the results of the different environmental impact categories. The data were normalized to express the different results of the environmental impact categories in a manner that relates to how they contribute to the overall impact of the proposed building.

Figure 3 shows the graph depicting the consolidated potential environmental impact of the proposed Alturas Mall throughout its entire life cycle. It can be observed, as shown in the result of the analysis from the One Click LCA software, that almost all of the impact categories revealed a very high environmental impact during the B6 or the operational energy use phase of the building. The main reason for this is that the building uses energy daily throughout its entire life cycle. A large portion of the energy generation comes from fossil fuels, and burning fossil fuels entails significant carbon dioxide emissions. The only impact category that exhibited a low environmental impact during the B6 phase is the abiotic resource depletion (non-fossil). The main reason for this is that B6 is primarily about energy usage, and during this phase, the use or consumption of materials is lesser compared to the product phase. This can be verified from the results shown in Figure 3 below, where the abiotic resource depletion (non-fossil) impact category exhibited a very high result during the A1-A3 or the production phase.

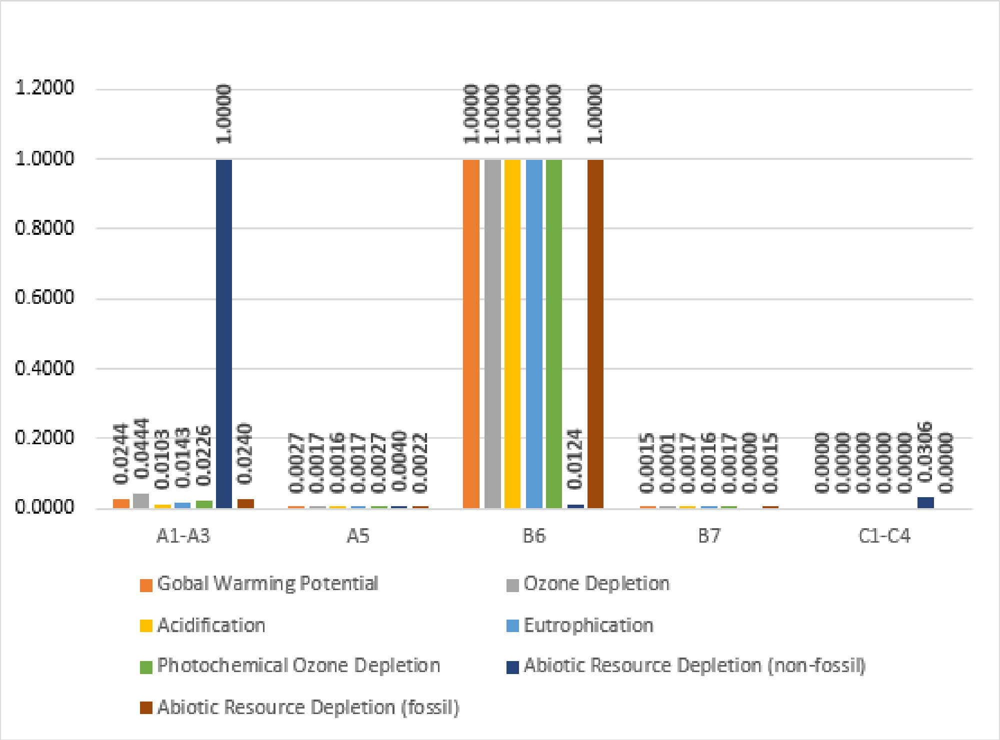

Figure 2. Potential Environmental Impact of the Proposed Alturas Mall.

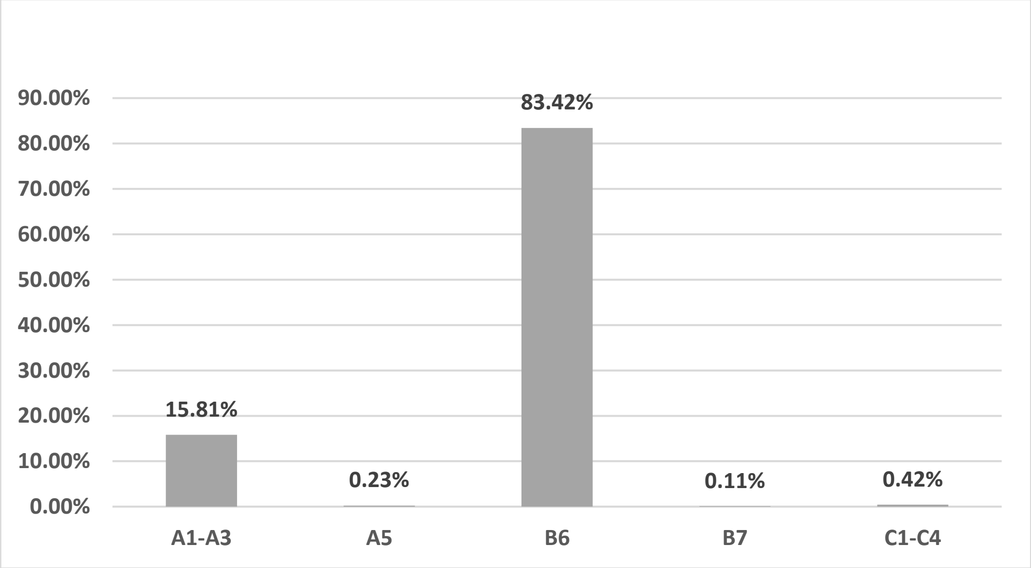

Figure 3. Percentage Contribution of Environmental Impact by Life Cycle Stage.

Table 4. Total Carbon Emission

	Total Carbon Emission	
Life Cycle Stage	**Emissions (tonnes CO_2e)**	**Percentage of Total**
A1-A3	11,131.14	2.46%
A5	1,670.10	0.37%
B6	438,068.74	96.82%
B7	1,137.98	0.25%
C1-C4	469.97	0.10%
Total	**452,477.93**	**100.00%**

Figure 4 presents the percentage distribution across the different life cycle phases of the proposed Alturas Mall. It was observed that among the different life cycle stages, the operational energy usage (B6) exhibited the highest contribution, accounting for 83.42% of the overall impact of the proposed building. This result indicated that this life cycle phase dominated the overall environmental impact of the proposed building due to the use of energy during the operation of the building throughout its entire lifespan. The second highest contribution was the production phase (A1-A3) at 15.81%. This phase was associated with the extraction and processing of the different building materials used in the construction of the proposed building. Minor percentages were observed for A5, B7, and C1-C4 at 0.23%, 0.11%, and 0.42%, respectively. This result indicated that these stages contribute relatively less to the overall environmental impact of the proposed Alturas Mall.

Table 4 displays the tabulation of the carbon emissions across the entire life cycle of the proposed Alturas mall. The B6, or the operational energy usage, accounts for 96.82% of the total carbon emissions of the proposed building. The production phase (A1-A3) was responsible for 2.46% of the total carbon emissions. The construction phase (A5), operational water usage (B7), and end-of-life phase (C1-C4) account for 0.37%, 0.25%, and 0.10% carbon emissions. The total carbon emission of the proposed development was 452,477.93 tonnes of CO_2e. It is important to distinguish between the two reported B6 contribution values presented in this study. The value of 96.82% represents the contribution of operational energy use to total life-cycle carbon emissions (global warming potential, CO_2e). In contrast, the value of 83.42% refers to the contribution of B6 to the total normalized environmental impact across multiple impact categories evaluated under EN 15978. This distinction is necessary to prevent misinterpretation, particularly for readers less familiar with normalization procedures in life-cycle assessment.

Table 5 presents the tabulation of the potential carbon footprint of the proposed Alturas Mall. The proposed development has a potential carbon emission of 14,139.94 kg CO_2e per square meter and embodied carbon of 414.73 kg CO_2e per square meters.

The dominance of the operational energy use phase (B6), accounting for 96.82% of total carbon emissions, is inherently sensitive to assumptions regarding annual electricity consumption, occupancy conditions, and system efficiency. Variations in actual building operation could influence the absolute magnitude of emissions. However, regional and international life-cycle assessment studies of commercial buildings in tropical and developing-country contexts consistently identify operational energy as the primary environmental burden, particularly in regions where electricity generation remains highly dependent on fossil fuels. Consequently, while absolute emission values may vary, the relative dominance of operational energy impacts remains robust.

The proposed Alturas Mall has a potential embodied carbon of 414.73 kg CO_2e per square meter. As displayed in Figure 5 and based on the One Click LCA's calculations and analysis, this carbon emission was classified and belongs to the category "B," benchmark, which indicates that the embodied carbon emission of the proposed building is below average and is below 500 kg CO_2e per square meter, which is the international best practice for carbon emissions (One-Click-LCA, 2015).

Table 5. Potential Carbon Footprint of the Proposed Alturas Mall.

	Carbon Emission	**Unit**
Total Carbon Emission	14,139.94	kg CO_2e per m^2
Embodied Carbon	414.73	kg CO_2e per m^2

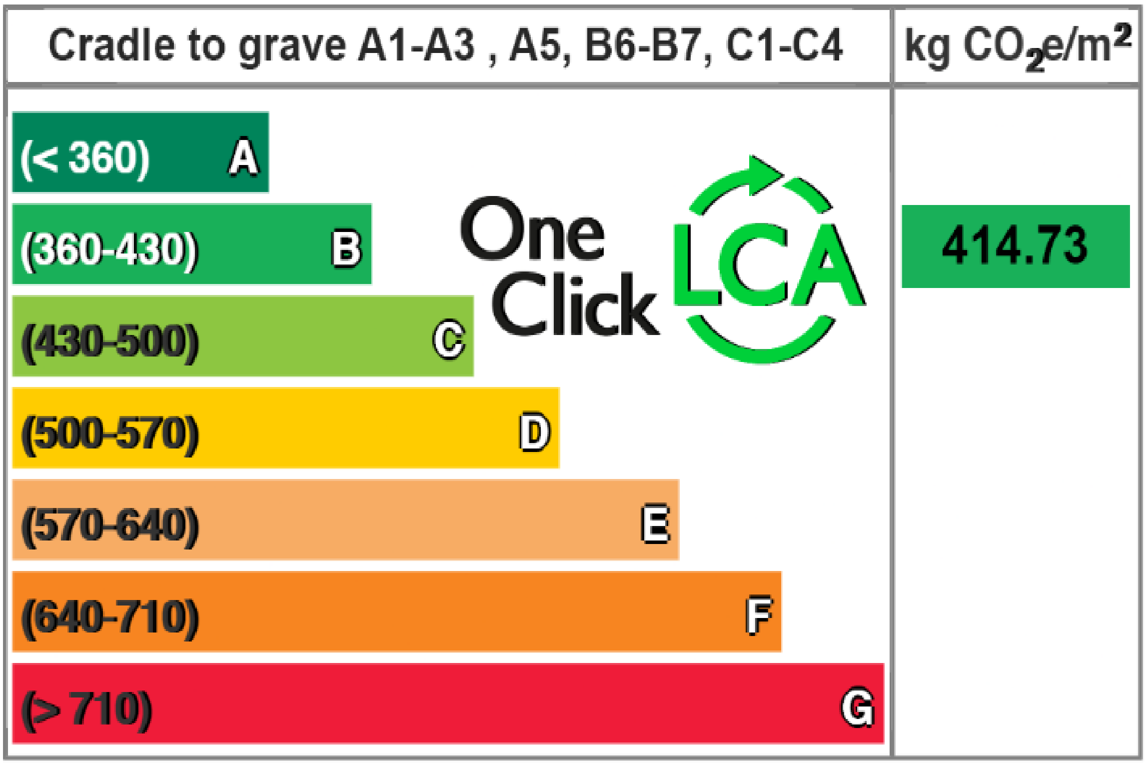

Figure 4. Embodied Carbon per square meter of the Proposed Alturas Mall

3.3 Limitations and Interpretation of Results

The exclusion of the transportation phase (A4) represents a key limitation of this study, particularly in the Philippine context, where construction materials are often transported over long distances through combined land and maritime logistics. As an archipelagic nation, transport-related emissions can be significant, especially for carbon-intensive materials such as cement and steel. As such, the embodied carbon results presented in this study should be interpreted as conservative estimates. Nevertheless, the exclusion of A4 does not compromise the primary conclusion regarding the dominance of operational energy impacts, which are driven by long-term electricity consumption rather than material logistics

3.4 Suitability of Database Emission Factors for Philippine Conditions

This study relied on global and regional emission factor datasets embedded in the One Click LCA database, which are primarily derived from internationally recognized sources such as Ecoinvent and regionally averaged industry data. At present, Philippine-specific environmental product declarations (EPDs) and localized life cycle inventory data for construction materials, particularly cement, steel, and finishing products, remain limited or unavailable. As a result, emission factors used in this study may not fully reflect local manufacturing efficiencies, fuel mixes, or production technologies employed in the Philippines.

In particular, cement and steel production in the Philippine context may involve higher carbon intensity due to reliance on fossil fuels and imported raw materials, while electricity-related emission factors are influenced by a national grid mix that remains predominantly fossil-fuel-based. These factors introduce uncertainty in the absolute magnitude of calculated emissions. However, because consistent datasets were applied across all life cycle stages and materials, the relative comparison of impact contributions, particularly the dominance of operational energy use (B6), remains robust. The results therefore provide reliable directional insights for early-stage design decision-making, even though absolute values should be interpreted with caution.

4.0 CONCLUSIONS

The result of the analysis in the One Click LCA showed that the building materials with the highest emissions or environmental impact were identified as ready-mix concrete, followed by the cement plaster. The primary reason for the finding was the use of cement as the main ingredient for these materials. Cement process and production entail high energy usage and energy generation, constituting the burning of fossil fuels, which have significant carbon emissions. This high energy usage was also true with the production of steel; that's why the reinforcement steel ranked as the third material with the highest emissions based on the simulation done by the software. The LCA software also identified which building element has the highest emission. The vertical structure building element, which comprises the columns, walls, and façade, constitutes 45% of the total carbon emission of the proposed building. The horizontal structures of the proposed mall accounted for a total of 40% carbon emissions. Slabs, beams, and roofing systems were the building parts that were included in the horizontal structure building element. The foundation and sub-structure building element was responsible for the 12% total carbon emission, while other building elements such as paints and other finishing materials contributed 3% of the total carbon emission of the proposed building.

The software's analysis also revealed the potential environmental impact of the proposed Alturas Mall in terms of the different environmental impact categories throughout its entire life cycle. The result showed that during the operational energy phase, or B6, almost all of the impact categories exhibited a high result except for the abiotic resource depletion (non-fossil) impact category. The main reason for having a high result was due to the use of electricity over the entire lifespan of the building. The software included in its analysis the energy generation in the Philippines, where power generation relies primarily on burning fossil fuels. This life cycle accounted for 83.42% of the total environmental impact of the proposed building. The abiotic resource depletion (non-fossil) impact category exhibited a high result during the production phase due to the process of producing the different building materials, which involves raw material extraction, processing, and refining of these raw materials. The production phase (A1-A3) constitutes 15.81% of the total environmental impact.

Based on the analysis performed in the One Click LCA, the proposed Alturas Mall had a potential total carbon emission of 452,477.93 tonnes of CO_2. The operational energy use phase (B6) of the proposed building accounts for 96.82% of the total carbon emissions, seconded by the production phase (A1-A3) at 2.46%. The proposed building had a potential total carbon emissions of 14,139.94 kg CO_2e per square meter and embodied carbon of 414.73 kg CO_2e per square meter. This value falls in the category "B" on the software's rubrics, which indicates that the proposed building's carbon emission falls below average. This result also indicated that the potential environmental impact of the proposed mall is within the international best practice in terms of embodied carbon. The result can still further be improved by applying different sustainable strategies and design recommendations.

This study is subject to limitations arising from the exclusion of transportation and maintenance-related life cycle stages (A4, B1–B5), which may underestimate embodied carbon impacts in the Philippine construction context. Despite these limitations, the findings clearly demonstrate that operational energy use is the dominant contributor to life cycle carbon emissions. This underscores the need for green building strategies in the Philippines to move beyond material optimization and aggressively prioritize operational energy efficiency, particularly in commercial developments within fossil-fuel-dependent energy systems.

5.0 RECOMMENDATIONS

The result of the LCA provided an insight on the potential environmental effect of the proposed Alturas Mall in Ubay, Bohol. Figure 6 shows the design recommendations that can be applied to further improve the result or reduce the potential ecological impact of the proposed development or other similar buildings.

While the design recommendations presented focus on reducing environmental impacts across life cycle stages, their economic feasibility was not assessed in this study. A comprehensive life cycle cost analysis (LCCA) is recommended to evaluate the cost–benefit performance of the proposed annual electric strategies. Given the dominance of operational energy emissions, interventions targeting energy efficiency and renewable energy integration are expected to yield the highest environmental return relative to investment.

Figure 5. Design strategies for minimizing environmental impacts across building life-cycle stages; economic feasibility and cost–benefit performance requires further evaluation through life-cycle cost analysis.

Further studies can be conducted to refine and expand knowledge of performing a whole-building Life Cycle Assessment. A whole building Life Cycle Assessment that evaluates all the life cycle stages, including transport of materials to the site during the construction phase (A4) and other stages in the use phase (B1-B5, B8), and also includes other building materials for electrical, mechanical, HVAC, plumbing, sanitary, and fire protection on the assessment can be conducted. A comparative LCA study can also be conducted between a baseline building and a building incorporating sustainable recommendations, both of the same size and use, located in the Philippines, to determine the potential improvements achievable. A Life Cycle Assessment for other types of buildings in the Philippines can also be conducted. Another study comparing the results of two LCA software programs for a building in the Philippines can also be conducted.

Data Availability Statement

The data supporting this study's findings are not publicly available due to privacy and ethical restrictions. The data include sensitive participant information and are therefore only accessible under strict confidentiality agreements. Data may be available upon reasonable request to the corresponding author, subject to approval from the relevant ethical review board.

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