Life Cycle Environmental Impact Assessment of a Residential Building in Bangladesh

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Abstract

The environmental aspects of a product's life cycle contribute remarkably to the globally emerging sustainable construction concept. In order to quantify the environmental effects of construction processes and products, life cycle assessment (LCA) is a technique for systematical analysis of any material from raw material extraction, processing, production, construction, operation, maintenance to the end-of-life, i.e. demolition. This study quantifies the significant environmental impacts of a suburban residential building with a plinth area of 80.82 m^2, having a service life of 50 years in Rajshahi, Bangladesh. An LCA model for that residential building was developed using One-Click LCA in this study. Impact categories were selected like Global Warming Potential (GWP) through carbon emission in the functional unit of "meter-square of the building". The findings suggest that the materials used in the construction of floor slabs, walls, roofing decks, beams, and roofs account for the majority of carbon emissions in typical suburban residential buildings with no more than three floors. This case study will aid professionals to understand which part of the building has the most GWP, what the traditional designs bring in terms of material usage per plinth area, and CO_2 emission per plinth area.

Keywords: *Life Cycle Assessment (LCA); Carbon Emission; One Click LCA; Residential Building; Bangladesh.*

1. Introduction

From the global CO_2 emission, buildings account for 6% of the total share in terms of dividing it into economic sectors since 2011 (Intergovernmental panel on climate change - IPCC, 2014). The huge impact on the environment in producing materials for building construction, maintenance, and energy consumption has been ever-growing since. The impact on the environment does not only happen when the construction materials are produced, transported, and cast rather throughout the whole life span of the building structure relating to maintenance and energy consumption. These impacts can be measured by analyzing individual materials in terms of GWP, CO_2 emissions, etc. To make the industry more efficient, lowering these impacts by choosing sustainable materials is essential. In this situation, life-cycle assessment (LCA) incorporation in the design phase of construction and material selection can play a crucial role. LCA usage will ensure optimization in environmentally friendly material selection for residential wellbeing and environmental sustainability. LCA assessment has even made designers and researchers look into CLT (cross-laminated timber) over concrete as a more potentially environmentally sustainable material which seemed quite counter-intuitive at first (Pierobon et al., 2019). For buildings up to three stories high, timber frames are appearing to be more sustainable in the structural concepts because of LCA-based analysis. In many non-renewable (steel, masonry, concrete) versus renewable (wood) construction material studies, researchers assigned better results to wooden structures as wood being easier to manipulate and being a low CO_2 emitter as steel and concrete have huge carbon emissions in their production process (Cole and Kernan, 1996; Gerilla et al., 2007; Mithraratne and Vale, 2004). And a study also represents the net positive outcomes of using walls made from buildings that are transformable and reversible with a design conforming to circular building principles typically lasts longer with less waste even when transforming and aging (Androsevic et al., 2019). So actually, new and dynamic concepts and insights wait in material selection in construction through the LCA-based analysis approach. However, in Bangladesh, research on this potentially lucrative method of material selection evaluation and the analysis of their environmental impact has not been done in a standardized way. This paper aims to address that. This will help researchers in focusing on what materials are needed to be adjusted in Bangladeshi building construction to combat climate change and ensuring sustainable housing. By using LCA, several studies have found that the major contributing factor in building construction varies with local climate and cultural design preferences thus implying different approaches in material selection for different segments of the building. A study in Sweden showed that major GWP contributors are typically channeled in the foundation construction of the building and parts that are to be replaced take up about half of the net total environmental impact over a 100-year period. Also, the usage of untreated wood and cellulose insulation is closer to green construction than thermos-treated wood (Petrovic et al., 2019). The software to be used in this paper is One Click LCA as their analysis is based on authorized verifiable data and fully standardizes up to regulatory policies, which will give researchers confidence to analyze and look into further studies. There are several life-cycle stages but this study focuses on the raw material supply and the production of materials used in a three-story residential building in Rajshahi, corresponding to the data that is available in Bangladesh from the authorities.

Table 1. Life-cycle stages according to EN 15978 and EN 15804 standards

Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage				Benefits and loads beyond the system boundary		
Raw material Supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolitio	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D

Thus A1 and A3 will be thoroughly looked into and analyzed by the study, where LCA of the ready mix concrete, reinforced steel, cement, and glass that is used in the construction will be measured against their environmental impact parameter GWP on the scale of CO_2 emission. The emission will also be classified on the basis of what material is used in which part of the building by holding the material’s weight and the building area as a reference.

This is a preliminary study that shows the environmental impact of building materials, without considering energy use and water consumption as these data are not available from the Bangladeshi authorities. However, further research will be continued based on experiments and usage data collection of the residence of this three-story residential building from the authorities to gain full spectrum LCA.

2. Methodology

The building to be analyzed is located in the town of Hat Khuipur, Bagmara, Rajshahi. The three-story building is located in a residential neighborhood with dense vegetation surrounding the plot area where it has access to relatively good transportation hence lowering the carbon emission relating to cooling and material transport. This is why this case study was chosen to reflect the closest data that will be obtained in further experimental studies.

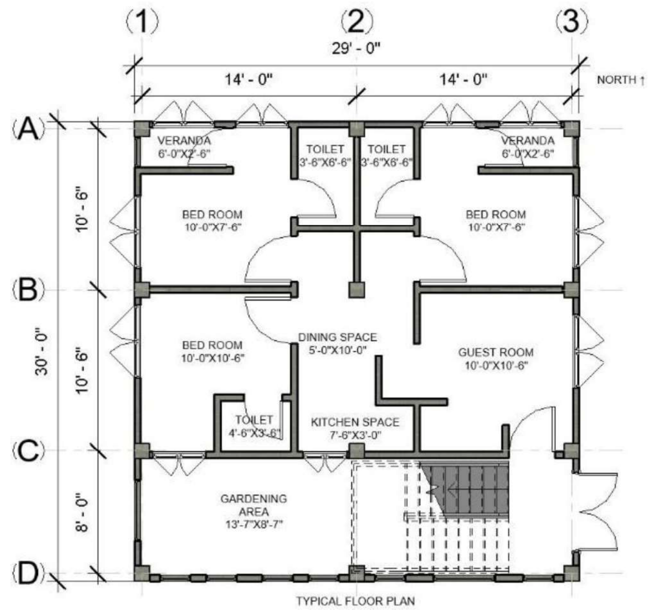

Figure 1. Floor plan of the building

The material used in constructing the building was fed into One Click LCA modeled by Bionova Ltd., One Click LCA software is EN 15978 standard-compliant in all analyses. This software takes in the type of material used in constructing different segments of the building and their quantities and analyzes the data sets to report on the opportunities to reduce environmental impacts. It uses factors in the material production phase, usage phase until end-of-life i.e. cradle to gate phase.

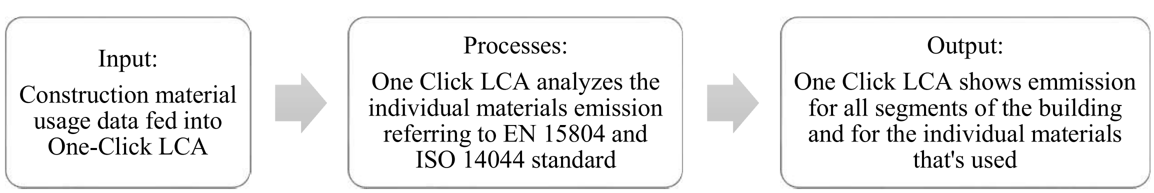

Figure 2: Research methodology

One Click LCA follows the Environmental Product Declarations (EPDs) based upon EN 15804 and ISO 14044 and standard. EPD is a verified detailed dataset of the environmental profile of registered products based on LCA calculation according to the standards of ISO14044, ISO

14040, and EN 15804. Registered materials, over their life span, have an EPD connected to them representing their environmental performance over their life-cycle. One Click LCA uses these data sets with the volume and types of materials given in as inputs, analyzes, and makes a report on which materials cause what levels of carbon emission.

Table 2. One Click LCA Planetary results summary after inputting main construction materials

Result Category	Tons CO_2 Emitted (t CO_2e)	CO_2 Emission per plinth area (kg CO_2e/m^2)	Input Data: Mass of raw materials used (tons)	Mass of raw materials per area (kg/m^2)
Ready mix concrete	41	511	275	3401
Cement	7	82	8	94
Steel	43	534	15	184
Glass	1	6	0	5
In the scale of total construction material	92	1133	298	3685

3. Results and Discussions

The results were divided into basically three points of reference shown in tables 3, 4, and 5. The first reference is towards the construction materials used and their emissions:

Table 3. Carbon emission by construction material category

Construction material	Carbon emission (t CO2e)
1 Ready mix concrete (A1-A3)	41.28
3 Cement (A1-A3)	6.63
4 Steel (A1-A3)	43.13
7 Glass (A1-A3)	0.51

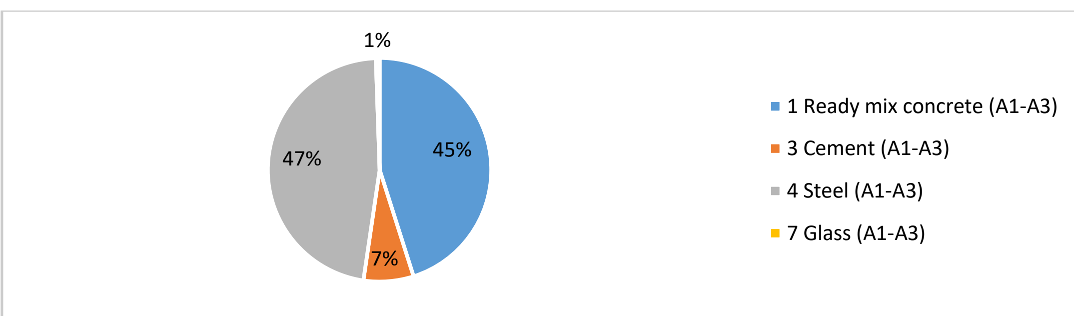

Figure 3. Total carbon emission by construction material category in percentage

From figure 3, most emission caused in terms of construction material category is steel at 47% followed closely by ready mix concrete at 45%. Cement contributes 7% in terms of plastering and mortars, whereas miscellaneous materials like glass used in windows have the least impact on the emission but when compared to usage per plinth area, more insight can be gained.

The second reference is towards the raw materials that are individually behind the emissions:

Table 4. Comparison of emission and usage of materials

Item	Mass of raw materials used per plinth area (kg/m^2)	CO_2 Emission per plinth area (kg CO_2e/m^2)
Ready mix concrete	3401	511
Cement	94	82
Steel	184	534
Glass	5	6

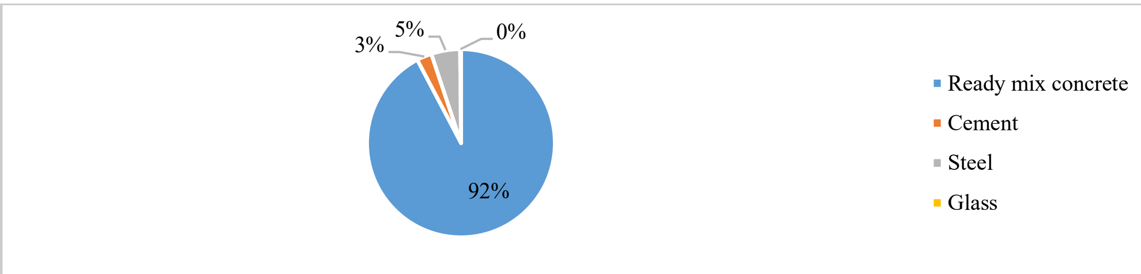

Figure 4. Material usage per plinth area

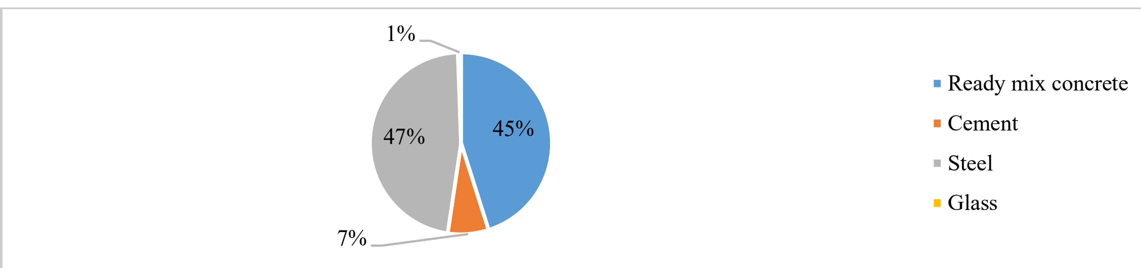

Figure 5. Material's share of emissions per plinth area

Despite figure 4 presenting that the most material amount usage by per plinth area is Ready mix concrete at 92% followed by steel at 5%, interestingly emission per plinth area data from figure 5 puts steel as the most contributor at 47% followed by Ready mix concrete at 45%. While glass showing more share of emission per plinth area despite its insignificant usage per plinth area.

The final reference is towards emission shares by individual segments of the building:

Table 5. Carbon emission by building segments

Category	Carbon emission (t CO2e)
Floor slabs, ceilings, roofing decks, beams, and roof	60.34
Foundation, sub-surface, basement, and retaining walls	14.64
Columns and load-bearing vertical structures	9.44
Internal walls and non-bearing structures	6.63

However, in terms of portions of the building that is responsible for the most carbon emission is horizontal structures (slab, beam ceilings) at 66% followed by foundations and sub-surface structures (substructures) at 16% while columns and load-bearing vertical structures are responsible for 11% of the total emission. The building has a total of 92 tons of CO_2 emissions.

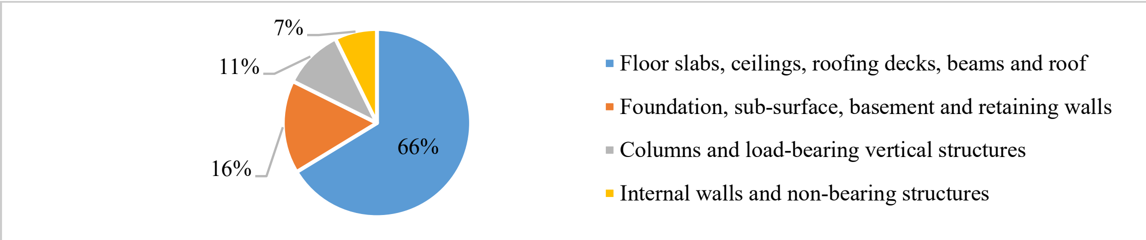

Figure 6. Carbon emission by different segments of the building

4. Conclusions

The analysis reveals that in the case of typical Bangladeshi suburban residential buildings, not exceeding three stories, most of the carbon emission happens due to the materials used in the construction of floor slabs, ceilings, roofing decks, beams, and roofs. However, in the case of a high-rise, this percentage may go down as the foundation require more materials corresponding to building load and soil behavior. The overall data also indicates that if research is focused on developing alternative and or modified materials that allow the lowering of steel usage and that can construct the horizontal segments of building structures with lower environmental impact, it will bring huge leverage in the fight towards environment-friendly sustainable housing regarding medium-sized suburban homes of low rise residential building, which is the most constructed building type in Bangladesh as a huge percentage of the lower-middle class and middle-class segments of the population rely on these types of buildings for residence. Implementation of this study during a building's early design stages will assist in assessing the GWP potential of the building and considering different designs and materials that can reduce the GWP like vernacular design processes and CLT-based materials that are renewable.

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