

Article

Estimation of Carbon Footprint of Residential Building in Warm Humid Climate of India through BIM

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Abstract: In recent years Asian Nations showed concern over the Life Cycle Assessment (LCA) of their civil infrastructure. This study presents a contextual investigation of a residential apartment complex in the territory of the southern part of India. The LCA is performed through Building Information Modelling (BIM) software embedded with Environmental Product Declarations (EPDs) of materials utilized in construction, transportation of materials and operational energy use throughout the building lifecycle. The results of the study illustrate that cement is the material that most contributes to carbon emissions among the other materials looked at in this study. The operational stage contributed the highest amount of carbon emissions. This study emphasizes variation in the LCA results based on the selection of a combination of definite software-database combinations and manual-database computations used. For this, three LCA databases were adopted (GaBi database and ecoinvent databases through One Click LCA software), and the ICE database was used for manual calculations. The ICE database showed realistic value comparing the GaBi and ecoinvent databases. The findings of this study are valuable for the policymakers and practitioners to accomplish optimization of Greenhouse Gas (GHG) emissions over the building life cycle.

Keywords: building information modeling; life cycle database; life cycle assessment; carbon footprint



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1. Introduction

1.1. Background

Societies worldwide have a significant unease over emissions of Greenhouse Gases (GHG) causing a boost to earth temperature [1]. One of the predominant causes of climate change and global warming is the increase in carbon emissions [2]. The built environment is accountable for more than 33% of worldwide ozone depleting GHG discharges, and its impact on the environment is exceptionally high [3]. The explanations behind high GHG emanations are energy utilization during construction, operation and destruction of the structure [4]. Carbon emissions estimation for structures is made basically in developed nations like the United States, Sweden and Germany. India has not been quite as engaged with the estimation of carbon emissions attributable to an absence of accurate information databases for all construction materials [5,6].

We are moving towards a crucial stage for worldwide endeavors to handle an environmental emergency such as the climate crisis—an incredible challenge of this time. Natural impacts were an Earth-wide temperature boost and essential energy. The nations that vowed to reach Net-Zero-Emissions (NZE) by mid-century or not long after keep

on developing; however, so do global Greenhouse Gas Emissions. Reducing worldwide carbon dioxide (CO₂) emissions to net-zero by 2050 means restricting the long-period expansion in average worldwide temperatures to 1.5 °C. The nations that have sworn to accomplish net-zero emissions have developed quickly in the course of the last year and around 70% of worldwide emissions of CO₂. In addition, regardless of whether effectively satisfied, the targets would in any case leave around 22 billion tons of CO₂ emissions worldwide in 2050 [7]. Hence, Life Cycle Assessment (LCA) study is essential to finding the carbon emissions generated by the build infrastructure.

Environmental Impact Assessment (EIA) guidelines focus on plan, design and stages and are not associated with the operation activity and maintenance stages [8]. Life cycle assessment can be used to assess the impact of both production and service activities. Use of the LCA method can assess the environmental impact of an activity and/or activities that produce goods or services. The LCA is a prominent tool utilized for carbon footprint computation [4]. The LCA is utilized to figure out carbon emissions (CO₂e) which is a blend of GHG including CO₂, methane (CH₄), nitrogen dioxide (NO₂) [1,5]. LCA estimates the ecological effect of a specific material of the overall building life cycle [6]. The International Organization for Standardization (ISO) 14040 series standards address quantitative assessment methods for the assessment of the environmental aspects of a product or service in its entire life cycle stages within system boundaries and functional units [9]. The information about the products is gathered from the Environmental Product Declarations (EPD's) strategy is based on LCA energized by ISO principles which have subtleties and exact cycles included. LCA has four strategies as indicated by ISO 14040 [9]:

- Scope definition and objective;
- Analysis of inventory;
- Environmental impact assessment;
- Results and interpretations.

1.2. Motivation

A significant contributor to the country's economy is the investment led sector; the construction industry in India has played a significant part by adding over 5% to India's Gross Domestic Product (GDP). The Indian built environment area is facing a lot of difficulties at present. This can be significantly credited to the current work inefficiency and absence of data sharing between industry partners. Therefore, a need to adopt Building Information Modeling (BIM) in the construction industry has become vital. BIM fundamentally defines the utilization of project three-dimensional (3D) model to improve its plan, development, activity and maintenance [10]. The BIM-LCA adoption rate differs around the world. India being the lowest in BIM-LCA, with an adoption rate 10–18% as compared with 71% of BIM clients in United States alone, it may not actually be appropriate to apply the past discoveries and information to the context of India.

The computation of LCA carbon footprint will cost additional time. The time and exertion can be decreased to oversee BIM information in LCA. BIM can create rich information sources like material amounts [4]. The capability of BIM is to such an extent that the entire structure LCA is worked with. The physical qualities of a structure are addressed in advanced BIM. BIM offers virtual coordination incitement, augmented perception and upgrade. A few examinations say that BIM and LCA, the software, will have upgrade requirements for contributing information which is done manually, so the LCA model is set up [4]. The different information about development stages such as utilization of machines and materials is taken in an amounts estimation sheet [5]. BIM has information regarding building climatic conditions, requirements of comfort, schedules of operations, and integrated BIM-LCA software's tools.

2. Review of Literature

2.1. LCA Phases and Building Application

LCA is applied to sustainable green building rating and energy assessment of buildings for building maintainability and essential energy optimization. LCA assesses the effects of crude material extraction, manufacturing, construction, operation, maintenance, repair, replacement and demolitions. The stages of LCA are the product stage, transportation stage, operational stage and end of life stage as shown in Figure 1. Product stage incorporates the creation of raw material to products, transportation and onsite construction. The area of building tools for transport environmental conditions, size of building life expectancy of the structure and strategies for materials produces construction techniques. During the operational stage, energy utilization from warming, cooling ventilation, AC, water supply, and use of other equipment are considered. Life cycle assessment is attributed to the environmental and ecological factors and other innovative strategies to deal with the energy consumption during its operational stage and finally end of life stage.

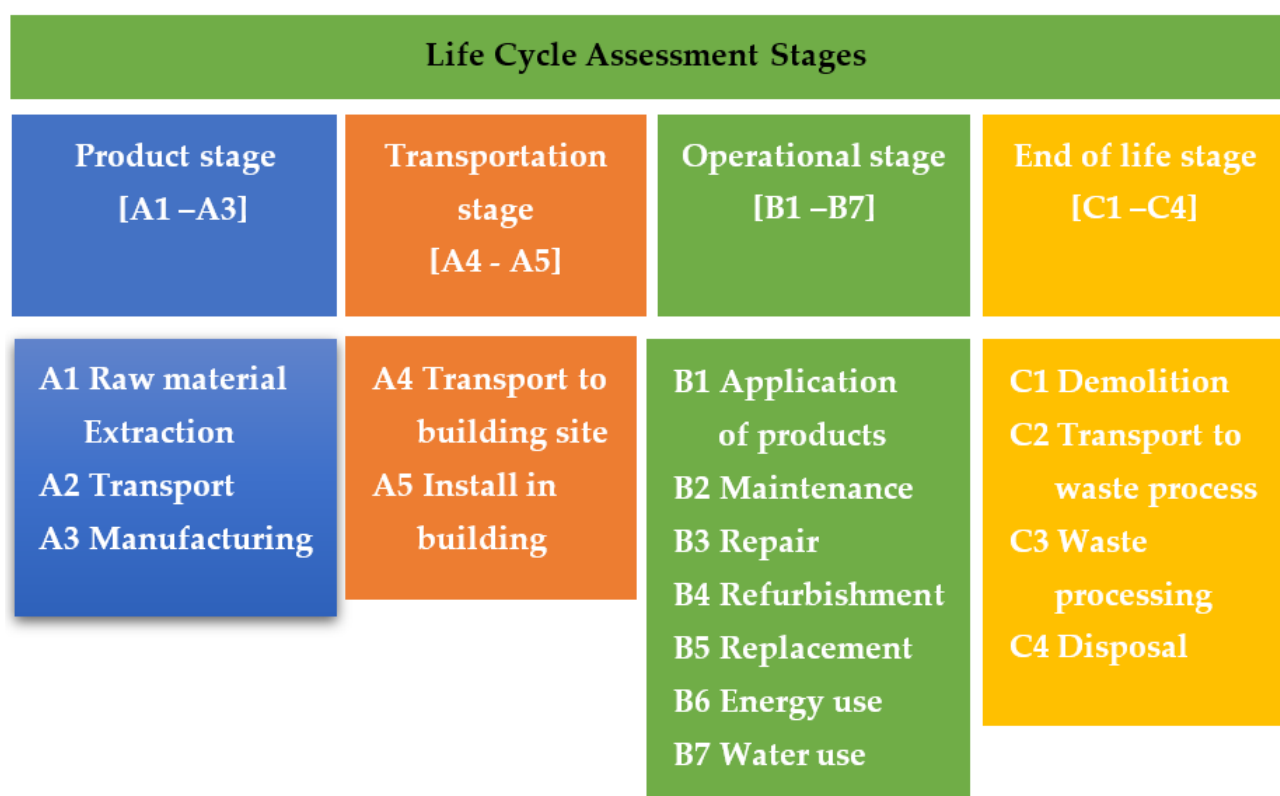


Figure 1. Life cycle assessment stages.

The study carried by Cheng et al. shows that a rich source of information is provided by BIM for LCA [11]. The operational stage assumes the main part of optimizing the GHG of a structure through the entire life cycle of the building [11]. Xu et al. evaluated exact building energy performance estimated in BIM, which is a powerful innovation [12]. Yang et al. calculated that the operation phase accounts for about 69% of total carbon emissions, while 24% is contributed from the building material production where concrete produces 82% and is the most used construction material [13]. The researchers conducted a comparison of LCA databases, and the results commonly indicate fundamental gaps in the methodologies used, which sometimes result in significant differences in the assessment results [14,15]. The impact of the LCA results calls for a distinctive approach and choice of a definite database for the results. Different building structure types influence the results of carbon emissions. Past investigations have covered different building types, including villas, estates, skyscraper homes, office buildings and high-rise buildings. However,

there is a lack of research on residential apartment buildings with LCA ISO standard 14,040 specifications.

2.2. LCA Databases

Researchers show the utilization of various LCA software impact the outcomes owing to various strategies carried out in the software regardless of whether the information database utilized is something very similar, and LCA techniques are exact and comparable [16]. Significant outcomes are inferable from software–database combinations. The LCA tools decision has influenced the results of the assessment. There is non-consistency in the results of the two tools while evaluating the principal materials which contribute a high measure of fossil fuel by-products. The principal hotspot for its distinction is that the databases are inbuilt in the two tools [17]. The consistency and uniformity of LCA data sets must be improved in the area of the structure. The investigation was led by a few researchers, and an enormous number of analysts have discovered that strategy has some major fundamental gaps in its aftereffects regarding the same items which lead to results that have varieties in the LCA attributable to software–database blends [15].

Existing literature specifies the LCA for numerous products by incorporating with databases GaBi, ecoinvent and the environmental footprint database [14,15]. The findings are based on the significance of item frameworks with different databases for significant choices, as suggested [15]. The researchers found that it is almost difficult to assemble planning for every one of the cycles, so to lessen the cut-off error, they discovered a framework limit drawn by relying upon several databases [18]. From the published papers, it is found that there is a huge contrast in LCA results from numerous variations in the databases utilized. Various segments and cycles are associated with the life cycle databases, so the outcomes are unpredictable and inaccurate.

The study was conducted by several scholars where a large number of researchers found out that the methodology has some fundamental gaps in the results for the same products, which led to results which have variations in the life cycle assessments owing to software–database combinations. Some scholars thought about the data set system; nature of data factors influenced the examination result, and this is because of the distinction in data set received software, various components, information sources, areas and contrasts in scope. The life cycle databases massively affect the computation of carbon emissions. In developing countries, there are moderately finished life cycle databases, but for developing countries like India, LCA databases are available only for a few materials, which is inadequate to perform LCA. Moreover, most existing datasets do not consider the qualities of region, manufacturing and assembling strategy into account. Therefore, there is need for comparison of regionally available similar databases to access the LCA results.

2.3. LCA of Construction Materials

An assessment done for the three-bedroom semi-detached house in Scotland for 10 diverse construction materials was investigated and regular primary materials exhaustively utilized were taken in this study [19]. Carbon emissions are compared with respect to six concrete mixes during production and placement phases made in Portland cement, governing on impacts produced from global warming potential [20]. The office building in Finland invested on environmental life-cycle assessment over 50 years of service life [21]. The results of the study show most of the carbon emissions impact is associated with building material manufacturing like steel, concrete and paints and electricity use [21].

2.4. BIM-LCA Integration

Several researchers have used BIM to perform LCA of buildings. The information exchange through Bill of Materials (BoM) or schedule of materials sheet in BIM-LCA integration is the most common way to interpret combination between BIM and LCA tools. The BoM is exported from BIM 3D model data that contain material information and quantities. The information is inputted to LCA manually or automatically. The most

adopted approach is that the data imported into the LCA tool is inputted manually; this technique is very tedious and contains lots of mistakes. The plug-in LCA software with 3D model is the second most adopted approach [22]. Thus, it is essential to implement the automated method.

Faster results are obtained from BIM integrated LCA plug-in tools, but they make use of generic data which is one of their limitations. The BIM—LCA integration can be partitioned into two types: the first is the data extraction from the BIM model directly such as quantities and materials and collaborating with the accessible life cycle databases to obtain the LCA of the building structure. The second is the computation of LCA when BIM objects are embedded with environmental properties [23]. The first method is the most compatible method and can be used in this study.

2.5. Research Gap

All the above literature contributed to errors due to multiple computations of several materials producing confusion in implementation of carbon coefficients. Topographically, the above literature on LCA of structures has added Korea, the United States, China, Sweden, Finland and Scotland carbon emissions databases and government to the nearby local climatic conditions. These studies are related to tropical desert environments, sub-frigid environments, regions with blistering summers and cool winters. In any case, research on warm and humid climate in India has not been further developed. In spite of a few investigations about the ecological effect of structures, it is hard to track down data about the LCA of residential buildings in India. Existing literature focuses on the LCA of buildings on the GHG emissions and energy consumption of residential buildings, large-scale buildings, hospital building and office building located in the developed countries and for the respective climatic conditions. It was found that in India there is a lack of investigation on LCA of residential buildings due to non-availability of a life cycle database and less adoption of BIM in projects.

Existing literature considers all building materials; thus, the computation of results become very complicated. Therefore, in this study the distinction of life cycle databases is explained considering few construction materials for the better computation and understanding of databases and corresponding Carbon Emissions Coefficient (CEC) used. In India, commonly used Reinforced Cement Concrete (RCC) structure is a conventional construction building method unlike those of other countries like China, UK, Sweden and Australia. In Europe, the utilization of BIM in construction projects is seen in around 33% of cases [24]. Among emerging economies around the world, India is falling behind in BIM-LCA adoption and is confronting comparable difficulties, including absence of experienced experts and significant expense. Hence, this study emphasis on BIM-LCA integration using One Click LCA in build with two databases.

From the research gaps mentioned, this study focuses on the following aspects:

1. Evaluation of carbon emissions with four main contributing construction materials.
2. Evaluation of carbon emissions at every stage of the building life cycle with different databases using soft tools interconnected with BIM and with manual calculations.
3. Comparing the results of BIM-LCA and manual computations for conventional RCC residential buildings constructed in warm and humid climatic condition of India with a different lifecycle inventory database.

3. Methodologies

3.1. System Boundaries and Functional Unit

The unit processes are mostly dictated by the system boundaries which are to be included in the LCA. Defining system boundaries is partly based on a subjective choice, made during the scope phase when the boundaries were initially set. The output and input processes are specified outside the boundaries [25]. The functional unit has two key considerations; they are mainly the size and structure of the building, floor area

and geographical data. The boundaries considered in the present study are as shown in Figure 2.

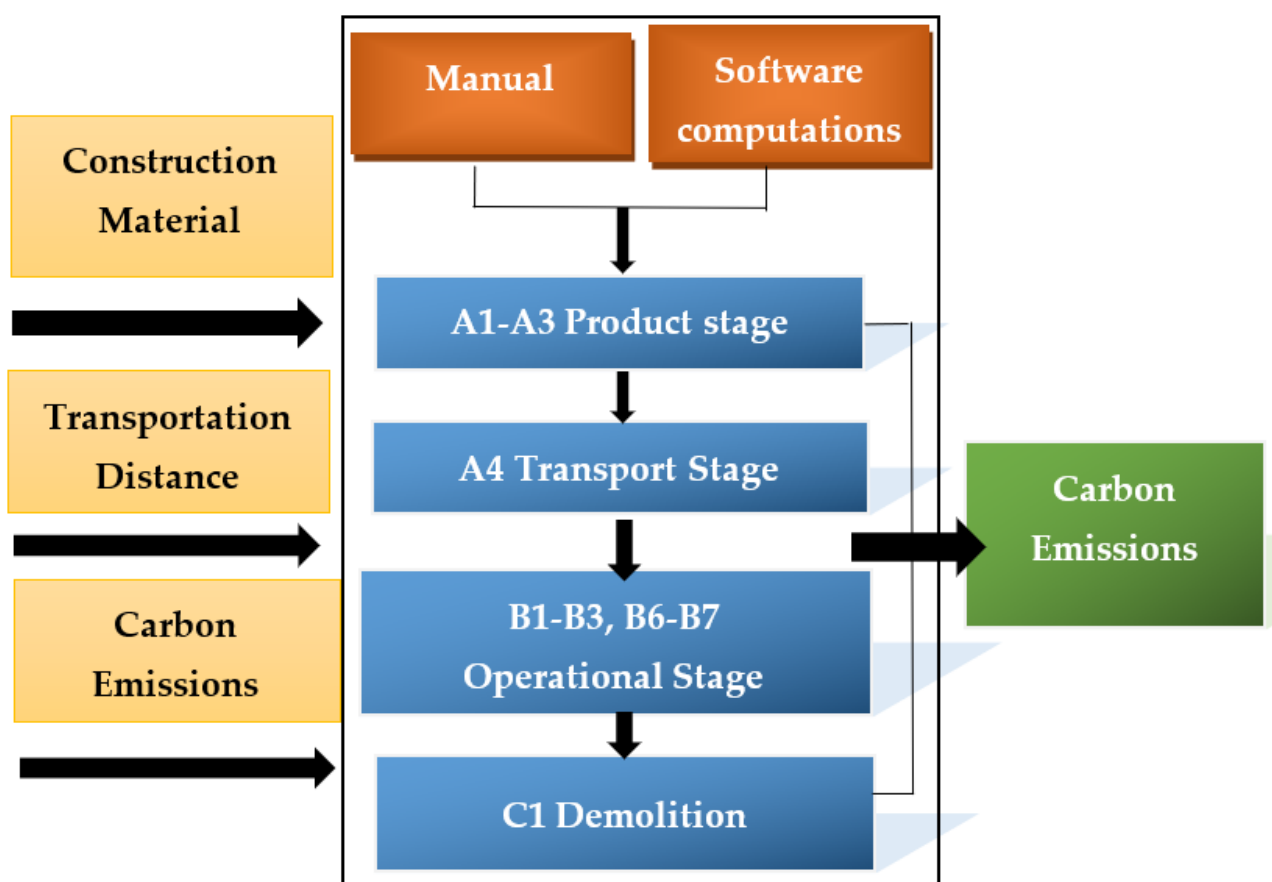


Figure 2. System boundaries of unit processes.

In the previous studies, a tally was used for LCA computations. A manual material mapping process was carried out using Tally EPD database; no automated material mapping process was performed. Due to errors and lack of quality of data in Tally, this study adopted One Click LCA which enables the process of automated material mapping.

The environmental impacts of the different building materials of life cycle phases of building stages are determined with three databases blends. To begin with, manual calculations are carried out by utilizing Inventory of Carbon and Energy (ICE) database and software computation carried out using One Click LCA, considering GaBi and ecoinvent databases [26–28]. One Click LCA is trailed by EPDs given the ISO 14040 and EN 15804 standards [29]. The present study investigates the carbon footprint of structures with four phases of the LCA. For the current study, building life cycle stages are considered as shown in Figure 2 within system boundaries. Particularly, it incorporates the construction stage (including material production, material transportation and construction on site), transportation stages (fuel consumption, number of vehicles and quantity of materials transported), the operational stage (including HVAC, lighting, water supplying and equipment use) and the demolition stage (destruction and renovation).

For an alternate extent of LCA, different life cycle stages are either compulsory or optional. In product level, EPDs modules A1 to A3 are obligatory under EN 15804 [30], while any remaining stages are optional. In any case, various accreditations and estimation frameworks may restrict the modules determined.

The entire computation of LCA is determined with time effectiveness, with the strength and estimation of LCA. The chance of evolving inside One Click LCA relies upon the materials and the decrease of carbon emissions. Finally, the strategy for esti-

mation for each phase of the life cycle, the combination of material databases and the purposes behind the experiential difference in the outcomes are clarified. The methodology for the evaluation of LCA according to ISO 14040 using BIM is presented in the flowchart demonstrated in Figure 3.

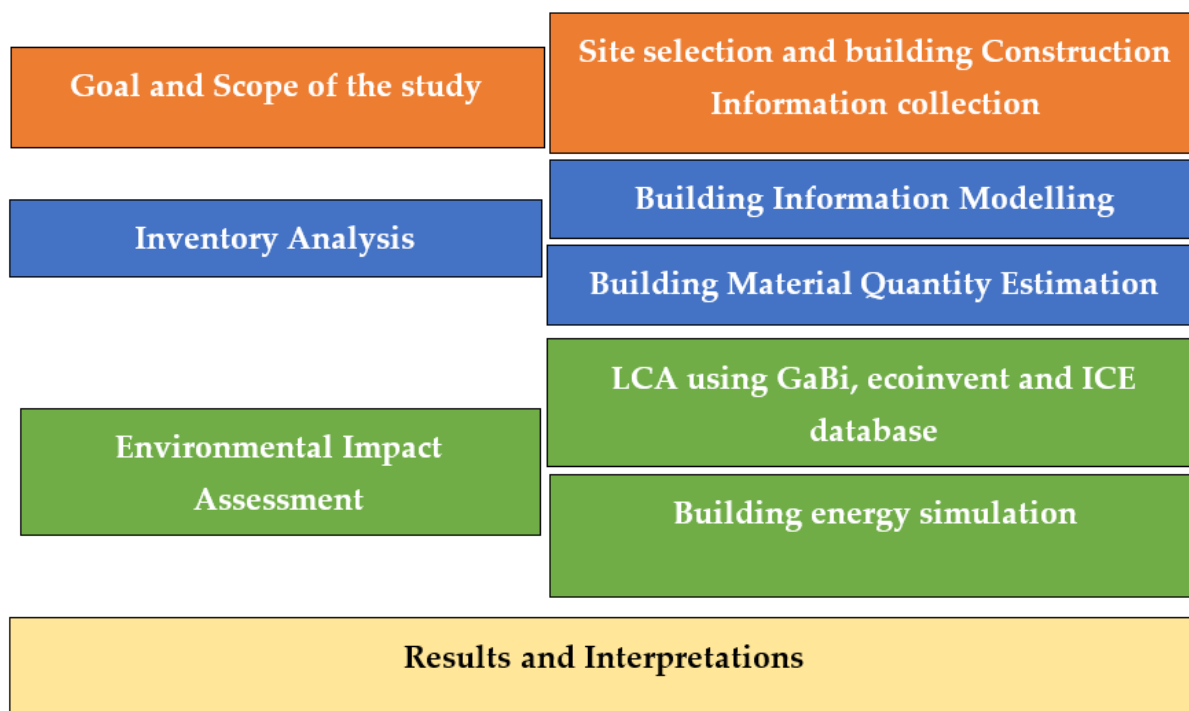


Figure 3. Flow chart of the methodology.

3.2. Building Information Modelling

A residential apartment building (G+2) project, a RCC structure located at Kakkanad, Ernakulam, Kerala, India, is taken for the contextual analysis for the venture appearing in Figure 4a. The 2D plans of the constructed RCC building are given in Figure 5. Ernakulam has warm and humid climatic conditions experiencing a maximum temperature of 38 °C in the summer and a minimum temperature of 20 °C during winter. The residential apartment building has a constructed area of 720 m². The building has a RCC flat roof of 125 mm thick and concrete masonry walls of 200 mm thickness. The burnt clay brick is also used for the parapet walls.



(a) Constructed building



(b) BIM of building

Figure 4. 3D View of residential building.

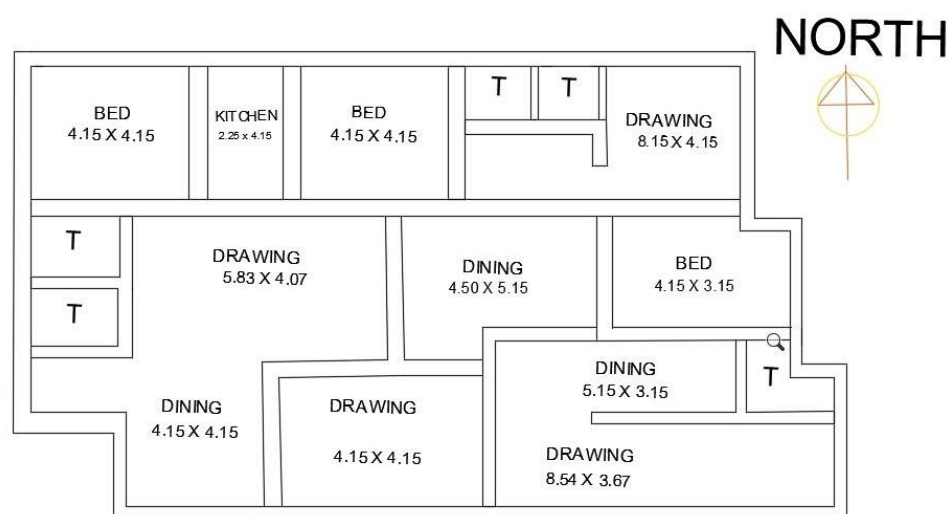


Figure 5. 2D plan of the existing first floor building. All dimensions are in m.

A 2D building plan is prepared in AutoCAD, shown in Figure 5, then exported to Autodesk Revit Architecture 2018, to make a 3D drawing and assign specifications. Autodesk Revit is Multi-disciplinary BIM software used to model inside the architectural and structural environment, realizing floor plans for building and houses. Enscape truly permits you to accomplish a beautiful presentation, rendering features with the snap of one button as demonstrated in the 3D view in Figure 4b.

3.3. Life-Cycle Database and Assessment of Building

The LCA is executed in steady stage to determine the carbon emissions effects. The selection of life cycle database is the important step involved in LCA. To perform the LCA through manually, the information's required are material amount at construction stages and machine electricity consumption, the number of hours and fuel consumption at transportation stages, and consumption of energy during operational stage is essential. The embodied energy and embodied carbon factors included in the ICE database are unique [26]. The GaBi database has by far the largest life cycle database data industry coverage worldwide [27]. The ecoinvent data set gives access to unit measures to support cradle to gate inventories covering diverse industrialized regions [28]. The ecoinvent contains worldwide industrialized data of life cycle inventory on stock information on energy supply, asset extraction, material inventory, synthetic substances, metals, agri-business and transport administrations.

3.4. Calculation of Life Cycle Assessment

The equations governing the total carbon emissions are given below:

$$U_{\text{tot}} = U_{\text{con}} + U_{\text{mt}} + U_{\text{ope}} + U_{\text{dem}} \quad (1)$$

where

- U_{tot} , represents total carbon emissions of all stages;
- U_{con} , represents carbon emissions at construction stage;
- U_{mt} , represents carbon emissions at transportation stage;
- U_{ope} , represents carbon emissions at operational stage;
- U_{dem} , represents carbon emissions at destruction stage.

3.4.1. Construction Stage

The construction stage carbon emissions contain quantity of materials multiplied by the carbon emissions coefficients. The CEC is obtained from the database chosen for corresponding materials.

$$U_{\text{con}} = \sum W_{\text{mp},i} \cdot S_{\text{mp},i} \quad (2)$$

where

W_{mp} represents quantity of material;
 S_{mp} represent CEC.

3.4.2. Transportation Stage

Equation (3) shows the calculation of transportation stage carbon emissions (U_{mt}):

$$U_{\text{mt}} = \sum S_{\text{mt}} \times \text{FC} \quad (3)$$

where

U_{mt} represents carbon emissions generated by material during transportation;
 S_{mt} represents the CEC of construction material hauling;
 FC represents consumption of fuel in liters.

3.4.3. Operational Stage

The only carbon emissions produced by electricity consumption are the essential measure to be calculated.

$$U_o = U_{\text{oa}} + U_{\text{ol}} + U_{\text{oe}} = (N_{\text{oa}} + N_{\text{ol}} + N_{\text{oe}}) \times S_{\text{ele}} \quad (4)$$

where

U_{oa} is the carbon emissions emitted by lighting fixtures;
 U_{ol} is the carbon emissions emitted by washing machine;
 U_{oe} is the carbon emissions emitted by other building equipment;
 N_{oa} is the quantity of electricity consumed by lighting fixtures;
 N_{ol} is washing machine electricity consumption;
 N_{oe} is other building equipment electricity consumption;
 S_{ele} is the CEC for electricity consumption.

3.4.4. Destruction Stage

The destruction stage is considered as 10% of the construction stage. Unavailability of data for demolition leads to assumptions. The type of equipment used for demolitions is tools such as concrete breaker and demolition hammer.

$$U_{\text{dem}} = U_{\text{con}} \times 10\% \quad (5)$$

3.5. LCA Through Manual Calculations

The carbon emissions are manually calculated by using the ICE database. Before performing manual computation, in the construction stage, the building material quantity is evaluated from Revit estimation software and presented in Table 1.

Table 1. Quantities of materials.

Building Material	Quantity (W_{mp}) (kg)
Cement	69,160.0
Concrete blocks	106,315.2
Ceramic tiles	10,308.2
Burnt clay brick	64,800.0

In the transportation stage, fossil fuels have high CEC, so it is mandatory to analyze CO₂ emitted for transportation of materials to site, which mainly depends on capacity of vehicles, vehicle type, mileage and number of trips for obtaining total carbon emissions. Difference in fuel consumption due to changes in terrain is not considered. The implemented shipping mode is the main road shipment. The Light Duty Vehicles (LDV) and Medium Duty Vehicles (MDV) are used for transportation of materials. The fuel efficiency of these vehicles is presented in Table 2. The carbon emission factor for diesel vehicles is considered as 2.6444 kg CO₂e/lit.

$$\text{Number of trips} = \text{Quantity of materials} / \text{Load carrying capacity} \quad (6)$$

Table 2. Fuel efficiency of vehicles.

Vehicles Used	Load Carrying Capacity (kg)	Fuel Efficiency (km/lit)
LDV (Ashok Leyland dost strong)	1250	8.58
MDV (Eicher Pro 2095XP)	8102	4.46

The distance for each material is calculated separately as shown in Table 3.

Table 3. Total distance travelled by the transportation vehicle with materials.

Building Material (Vehicle Used)	Quantity (W _{mp}) (kg)	Number of Trips	Distance Travelled for to and fro Trip from Factory for Single Trip (km)	Total Distance (km)
Cement (LDV)	69,160.0	55	26.7	1468.5
Concrete blocks (MDV)	106,315.2	13	25.0	325.0
Ceramic tiles (LDV)	10,308.2	8	20.5	164.0
Burnt clay brick (MDV)	64,800.0	8	23.6	188.8

The resultant fuel consumption in liters is calculated from total distance divided by fuel efficiency. The total distance is calculated by multiplying number of trips by the distance travelled for to and fro trip from factory to site given in Table 3. Table 4 shows fuel consumption for the material transportation. Therefore, total fuel consumption (Diesel) is 323.09 lit.

Table 4. Fuel consumption for the material transportation.

Building Material (Vehicle Used)	Total Distance (km)	Fuel Efficiency (km/lit)	Fuel Consumption (lit)
Cement (LDV)	1468.5	8.58	171.15
Concrete blocks (MDV)	325.0	3.59	90.50
Ceramic tiles (LDV)	164.0	8.58	19.11
Burnt clay brick (MDV)	188.8	4.46	42.33

For operational stage, electricity is the major component used. The service life span of the building is assumed as 80 years. The CEC for electricity is 0.95 kg CO₂e/kWh [31]. The location of the case study is in Ernakulam, Kerala, where the summer season is moderately hot and winter reasonably cold. Electricity is the single powerful resource throughout the operation and maintenance stages [31]. There are 9 apartments in the building, and the electricity consumption of different floors is collected separately from electricity bills for 2 months. The commonly used equipment is a refrigerator in most of the houses in Kerala with full time working hour than any other equipment. Table 5 provides the details of the electricity consumption collected from the electricity bills.

Table 5. Electricity consumption.

Electricity Consumption for Two Months (kWh)													
Floors	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total
Ground floor	440		567		548		446		317		421		2739
First floor	320		521		518		298		136		354		2147
Second floor	360		522		505		276		326		365		2354

Therefore, total yearly electricity consumption is 7240 kWh.

3.6. LCA Using Software

The computation of two types of databases GaBi and ecoinvent was assigned to the 3-D BIM model using plug-in software One Click LCA. For Revit families and components, One Click LCA precedes the material mapping process automatically. Based on its EPD database in addition to the BIM software data extraction, it also mapped the defined Revit components to the suitable materials [32]. It is concluded that Revit component data is extracted by One Click LCA, and objects are recognized and mapped to the materials based on the component definitions in the Revit model [32]. The CEC adopted in the One Click tool for major building materials are presented in Table 6. The transport of material goods is considered by road medium. The CEC for vehicle is considered as 0.40 kg CO₂e/ton km. The CEC for electricity grid is considered as 1.03 kg CO₂e/kWh.

Table 6. CEC in kg CO₂e/kg for GaBi and ecoinvent database.

Materials	GaBi	Ecoinvent
Cement	0.85	0.94
Concrete blocks	0.0611	0.0686
Ceramic tiles	0.46	0.27
Burnt clay bricks	0.19	0.19

4. Results of Carbon Emissions

4.1. LCA Results for Manual Computations

4.1.1. Construction Stage

The CEC is multiplied by the comparing material quantity to get the construction stage carbon footprint. The outcomes obtained for the determined individual materials are classified in Table 7.

Table 7. Carbon emissions of construction stage.

Materials	Quantity (W _{mp})(kg)	CEC (S _{mp}) (kg CO ₂ e/kg)	Carbon Emissions (U _{con}) (kg CO ₂ e)
Cement	69,160.0	0.95	65,702.0
Concrete blocks	106,315.2	0.088	9355.7
Ceramic tiles	10,308.2	0.78	8040.4
Burnt clay bricks	64,800.0	0.24	15,552.0

Total carbon emissions at construction stage (U_{con}) = 98.65 tCO₂e.

4.1.2. Transportation Stage

The vehicle utilized for shipping materials is substantial trucks. The separation from the materials development manufacturing plant to the structure site is noted.

Carbon emissions generated by material during transportation:

$$U_{mt} = 323.09 \times 2.6444 = 854.37 \text{ kgCO}_2\text{e} = 0.854 \text{ tCO}_2 \text{ e}$$

4.1.3. Operational Stage

Electricity consumption per year is obtained as 7240 kWh.
From Equation (4),

$$U_{op} = 7240 \times 0.95 \times 80 = 550.24 \text{ tCO}_2\text{e}$$

4.1.4. Destruction Stage

The carbon emissions at destruction stage (U_d) = $98.65 \times 0.10 = 9.865 \text{ tCO}_2\text{e}$.

4.1.5. Total Carbon Emissions

Therefore, $U_{mp} + U_{mt} + U_{op} + U_d = 659.6 \text{ tCO}_2\text{e}$.

The carbon emissions per m^2 of building area = $0.916 \text{ tCO}_2\text{e}/\text{m}^2$.

4.2. Life Cycle Assessment Results for Software Tools

After inputting all the necessary details into the software, the following results are obtained and presented in Table 8. To calculate the operation energy consumption, Green Building Studio is used, and electric consumption value is obtained as 17,443 kWh. The value of energy consumption obtained in Green Building Studio appears to be 58% higher than the original energy consumption values obtained from the actual electricity bills issued by state electricity board.

Table 8. Carbon emissions contribution at different life cycle stages.

Life Cycle Stages	Result Category	Carbon Emissions (kgCO ₂ e)	
		GaBi	Ecoinvent
Materialization stage	Construction materials	92,698.9	170,207.9
Transportation stage	Transportation to site	59,639.7	59,429.5
Operational stage	Energy use	1,441,762.7	1,441,762.7
Demolition stage	Deconstruction	4305.9	3171.3
Total carbon emissions in kgCO₂e		1,598,407.2	1,674,571.4
Carbonemissions in tCO₂e		1598.4	1674.6

The results show existing building accounts for 14.95%, 0.13%, 83.42% and 1.50% of total carbon emissions of 659609.2 tCO₂e for construction, transportation, operational and demolition stages, respectively, in manual computations using ICE database. Similarly, the percentage contribution of the other two databases is also calculated as shown in Table 9. Figure 6 shows the carbon emissions at all the stages for GaBi database.

Table 9. Percentage contribution of carbon emissions in different databases.

Life Cycle Stage	ICE	GaBi	Ecoinvent
Construction stage	14.95	5.80	10.16
Transportation stage	0.13	3.73	3.55
Operational stage	83.42	90.20	86.10
Demolition stage	1.50	0.27	0.19
Total	100	100	100

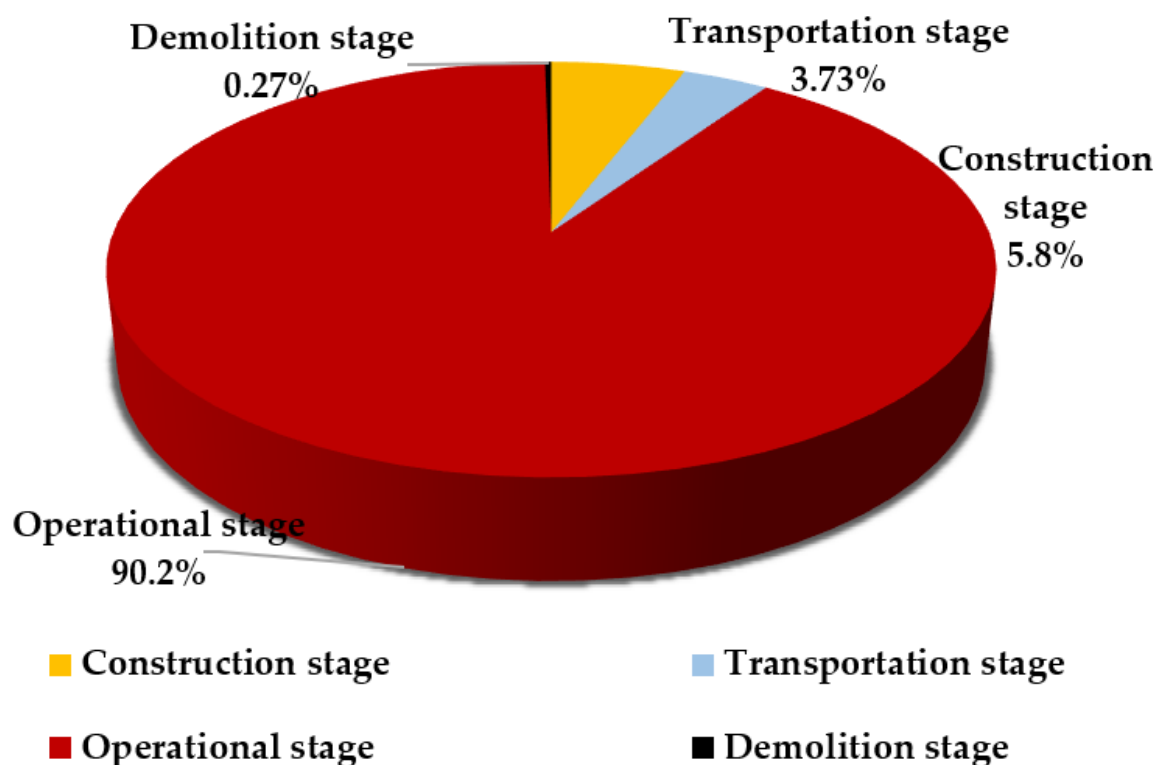


Figure 6. Percentage contribution of life cycle stages in GaBi database.

Being a RCC structure, cement contributes about 66.6%, concrete masonry blocks about 9.4%, ceramic tiles and bricks contribute about 8.1%, and 15.7% of total carbon emissions of construction stage accounts for about 98.65 tCO₂e in ICE database. In ecoinvent database from cradle to gate impacts, most contributing material is cement about 89 tCO₂e, around 52.5%, concrete blocks around 4.3%, bricks 39.4% and ceramic tiles 3.8%. Similarly, in GaBi database, cement contributes around 64 tCO₂e about 69.3%, concrete blocks 8.4%, bricks 15.9% and ceramic tiles 6.4%, respectively. In addition, it is evident from Figure 7 that cement is the highest contributor of carbon emissions in all databases.

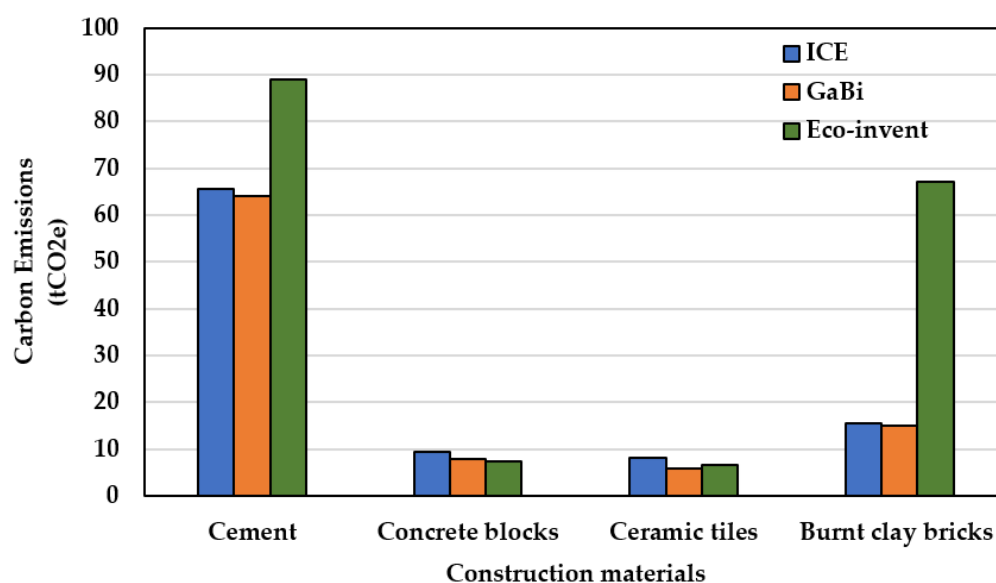


Figure 7. Carbon emissions of construction materials for various databases.

GaBi database is taken as the reference database, and relative differences in the outcomes to the other databases are calculated using Equation (7) and presented in Table 10.

Table 10. Relative difference in findings of carbon emissions.

Life Cycle Database	Carbon Emissions (CE) (tCO ₂ e/m ²)	Relative Difference
GaBi	2.20	0
ICE	0.916	−58.3
Ecoinvent	2.30	+4.5

Relative difference in

$$\% = ((CE_x - CE_{ref}) / CE_{ref}) \times 100 \quad (7)$$

CE_{ref} is the CE by GaBi database.

CE_x is the CE by ecoinvent/ICE database.

A value judgment is not inferred from the decision of the relative reference data set taken.

This technique can demonstrate index of comparison of a positive or negative distinction between the reference databases. The result of relative difference of −58.3% is nearly half of the result given by the reference database. The result of LCA with ecoinvent database is a similar result to the reference database.

The current examination covers large differences between the analyzed software database combinations and manual calculations, while the outcomes for software databases GaBi and ecoinvent are comparable. It is observable that the outcomes for ICE database are small and lower than GaBi and ecoinvent. Results for the GaBi database in One Click LCA, incidentally, are similar to ecoinvent database. The explanation is that ICE data set and ecoinvent database depend on information from different suppliers and geographic locations. The manual method has given appropriate, more precise and accurate LCA assessment results for each and every material inspected in the project, unlike BIM enabled LCA. The CEC also affects the estimation results. Because of the absence of coefficients of carbon emission comparable to coefficients in certain materials in India, this study adopted databases from different nations and compared them. In any case, the scientific research on different coefficients of carbon dioxide data sets should be investigated to tackle this issue.

Since the point of the investigation was to test the consistency of the two chosen methods and 3 databases, this study did not present a full investigation of the inconsistencies. There are two sources; first is distinctions in the three datasets of the LCA data for similar materials, secondly differences in the best manageable material area accessible in the data sets in similarity with the real material utilized in the structure. The main source is the software used for different purposes probably won't have produced the very same output regardless of whether the data sets were equivalent or not. In few of the points there is a moderate difference in between databases are discovered and various information components have differences in originates. Buildings are complex products quite possibly the main issues of LCA of structures. The dissimilar background information comparability of LCA results which involve multiple data for the evaluation. The assessment result represents equivalent patterns regarding the databases are confirmed in this investigation and comparable percentage variations between the three data sets are revealed by the outcomes.

5. Conclusions

This study recommends a life cycle assessment method through computation of carbon emissions collaborating manual LCA theory and BIM-LCA technique. The BIM tools are utilized for 3D model creation and calculations are estimated utilizing the ICE, GaBi, and ecoinvent database to ascertain building carbon emissions. The case study shows a residential apartment building in southern part of India with warm and humid

climate contributes around total carbon emissions of $0.916 \text{ tCO}_2\text{e}/\text{m}^2$ which is the realistic value and software database combinations give $2.2 \text{ tCO}_2\text{e}/\text{m}^2$, and $2.3 \text{ tCO}_2\text{e}/\text{m}^2$ for GaBi and ecoinvent database, respectively. The most carbon producing construction material in construction stage is cement. According to the GaBi and ecoinvent database above computation results shows the bigger segment of buildings carbon emissions are created during the operational stage have higher total carbon emissions accounts for about 83.4%, 90.2%, 86.1% which is the realistic result of ICE database used for Indian climatic conditions. The second biggest being the construction stage represents about 14.95%, 5.8%, 10.16%.

The result of the investigation has given an understanding of framework analysis for optimizing carbon emissions. The difference in results is due to the methods used for computation of stages. Software databases method is less time consuming than manual method but the databases automatically assigned by the software which cause errors and improper assigning of databases programmed. As a result, manual computation is done for proper understanding of differences caused by the BIM-LCA enabled method. It is accordingly inferred that the BIM-based LCA should develop better execution of results for optimizing carbon emissions and future use. The contribution of this research is attributed to the knowledge body regarding green construction and sustainable development. It assists with accomplishing the greenhouse gas emissions optimization over the entire life cycle of a structure. This optimization is relevant for contractors, homebuyers, and governments who are repeatedly searching for approaches to accomplish a low-carbon economy.

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