Assessment and Reduction of Embodied Carbon in buildings

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Abstract - *The problem of increasing carbon emissions and subsequently caused global warming potential cannot be tackled without reducing the embodied carbon emission of buildings. The paper presented modulates a framework for estimation of embodied carbon in buildings and assess the efficiency of possible reduction strategies. The study was limited to 3 stages of analysis, namely material production stage, transportation stage and construction stage. The carbon estimation was carried out with the help of Building information model (BIM). The embodied carbon emission of the building was found to be 1233.23 tonnes, which is 583.66 $KgCO_2e/m^2$. Material production stage was found to be the major contributor, corresponding to 90 percentage of the total embodied carbon emission produced. In material production stage, cement manufacture was identified as the key emission source. During analysis of transportation stage, the aggregate transport was computed to be the highest contributor of carbon emissions. Construction stage analysis comprised of determining the emissions caused by electricity and fuel consumption. Various embodied carbon reduction strategies were identified and their possible reduction capabilities computed. By adopting the reduction strategies discussed, an overall reduction of 13 percentage can be achieved, bringing down the embodied carbon emission of the building to 510 $KgCO_2e/m^2$. Therefore, a building law ensuring the reduction of embodied carbon in buildings should be made mandatory.*

Key Words: Embodied carbon Emission, BIM, estimation, Reduction strategy.

1. INTRODUCTION

Of the many environmental impacts of development, the one with the highest profile currently is Global Warming Potential (GWP). Global warming is the consequence of long term build-up of Greenhouse gases (CO_2, CH_4, N_2O, etc.) in the higher layer of atmosphere due to intensive environmentally harmful human activities [1]. The Tyndall Centre has suggested that a 70% reduction in CO2 emissions will be required by 2030 to prevent temperature rising by more than 1°C [2]. Apart from global warming, the increasing presence of Greenhouse gas emissions (GHG), results in ocean acidification, smog pollution, ozone depletion as well as changes to plant growth and nutrition levels.

The building sector which comprises of buildings, building materials, components etc. are responsible for 30% of anthropogenic GHG emissions and 40% of global energy consumption [3]. While buildings provide the essential infrastructure for civilization and need for shelter, they also create an ecological threat in terms of resource consumption and depletion. Therefore to address the issue of global warming, it is essential to reduce carbon emissions from buildings.

The GHG emissions of a building are generated directly and indirectly throughout the building's life cycle stages, namely the material production stage, transportation stage, construction stage, operation stage, repairing stage and disposal stage. In the building life cycle Embodied Carbon (EC) is the carbon dioxide equivalent (CO_2e) or GHG emissions associated with the non-operational phase of the project. It does not include the carbon emissions associated with the operational phase (heating, lighting or cooling) in the completed building [4].

As we build increasingly energy efficient buildings that use minimal energy to run and rely increasingly on locally-generated low carbon power sources, the proportion of the building's lifecycle carbon that comes from the embodied carbon becomes more significant. As per the reports of Architect 2030, about 80 million m^2 of new and rebuilt buildings will be constructed in urban areas worldwide by 2030 and during this period approximately 26% of new building stock's emissions will be from its operational energy while nearly three quarters will be from its embodied energy [5] (Fig. 1.3.1).

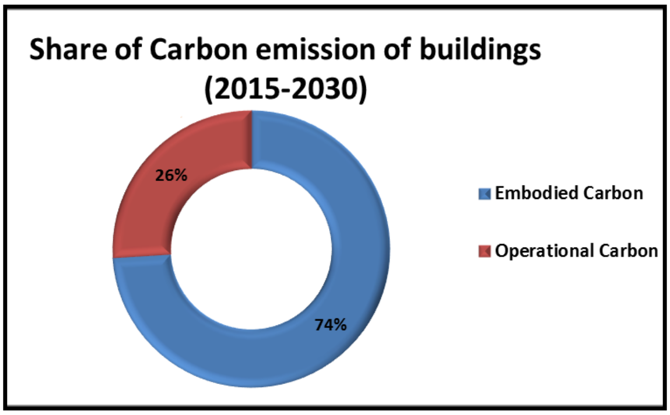

Fig -1: Proposed carbon share of buildings

Therefore it is evident that the problem of increasing carbon emission cannot be tackled without giving prior importance to the embodied carbon emission.

In contrast to operational carbon emissions for new buildings, which are regulated through Building Regulations, embodied carbon is currently not regulated. The negligence shown towards Embodied Carbon regulation of buildings would result in a scenario where the whole of building emission would be caused in the non-operational stage of the building.

In India, the concept of embodied carbon and its implementation in building construction has not yet evolved fully. Motivation for doing this project is to integrate the concept of Building Information Model (BIM) for formulating a method for estimation of embodied carbon of the building and evaluating the efficiency of various embodied carbon reduction strategies.

2. LITERATURE SURVEY

Researchers and practitioners have recognized the importance of developing early design strategies for reducing the buildings' embodied carbon emission. Numerous researchers have shown that the earlier decisions that are made in the design process and the fewer the changes to these decisions at later stages, the greater is the potential for reducing the building's environmental impact.

Using BIM as a Life Cycle Assessment (LCA) model tool for evaluating energy consumption and carbon dioxide emissions of a building in an early design phase of a building was evaluated [6]. It was found that the implementation of BIM both in new and existing buildings induced profound changes of processes and information flows, providing improved data management [7,8].

Various methods and frameworks to calculate the whole life embodied carbon of buildings where analysed [9]. Multiple data sources were used to analyse the barriers for effective measurement and reduction of embodied CO_2e in practice [10].

Different strategies to mitigate and reduce Embodied Carbon in the built environment were reviewed. It was seen that no single mitigation strategy alone seems able to tackle the problem. Rather, a pluralistic approach was necessary. The use of materials with lower EC, better design, an increased reuse of EC-intensive materials, and stronger policy drivers were emerged as key elements for a quicker transition to a low carbon built environment[11,12].

3. METHODOLOGY

3.1 Project scope

A Life Cycle Assessment (LCA) framework is selected to assess the energy consumption and CO_2 emission of the building. An important distinction to be made when analysing the data on impacts of an entire building, is the boundaries of the LCA used to produce the data. In simple terms, the more stages of the lifecycle that are included in the life cycle assessment, the more of the carbon emissions associated with the product or building that are brought into the analysis. For this project, the LCA analysis for carbon estimation chosen was Cradle-to-completed construction [11].

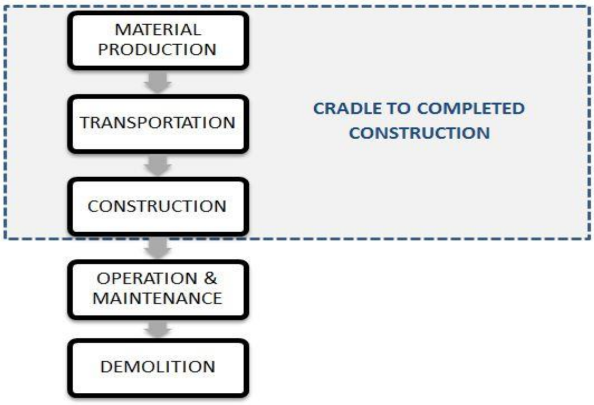

Fig -2: Scope for Cradle to Completed construction approach

Cradle to completed construction stage analysis covers the carbon emitted for:

- Manufacture of materials
- Delivery of materials to the site
- Construction activities occurring at site

3.2 Material Take-off

With recent technological developments in 3-D modelling, the way projects are being designed, estimated, and delivered is becoming more efficient. Building Information Modelling (BIM) software has allowed the industry to begin to move toward BIM-based Quantity Take-Off (QTO).Autodesk Revit and Vico Take Off Manager are a few programs which allow the industry to shift toward BIM-based QTO and estimates. AutoCAD Revit was used for creating the BIM model. The model includes floor slab, columns, exterior walls, interior partitions, building envelope, doors, windows, glass, concrete, roofs, ceilings, footages etc.

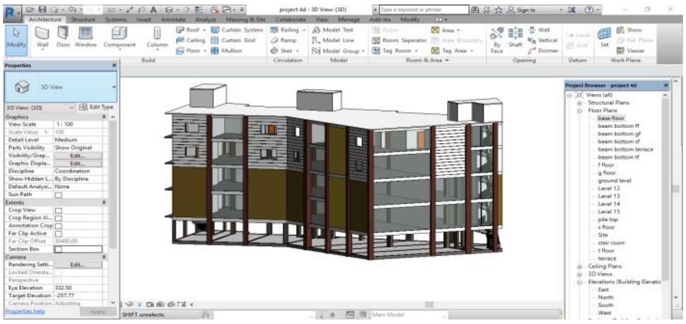

Fig -4: BIM model of the building

Material take-off is obtained from the previously created BIM model with the aid of 'PriMus-IFC V.7' software and Bill of Quantities. Both AutoCAD Revit and PriMus shares IFC platform, enabling data exchange within.

The equivalent CO_2 emissions of the structure's building materials (concrete and reinforcement steel) represent a dominant proportion of the building's total equivalent CO_2 emissions. Structural building material corresponds to around three fourth of total equivalent CO_2 emissions. Since concrete is used in a very large quantity in any construction, it is responsible for a large share of the gross embodied CO_2 emission. The CO_2 equivalent emissions of buildings envelope materials represent a lower proportion of the building's total CO_2 equivalent emissions, about the one fourth of the total CO_2 emissions from the building [10].

In this project, the concrete and reinforcement used for construction of substructure, superstructure and envelope materials (non-load bearing solid block work and its cement plaster) of the building was considered for calculation of embodied carbon.

Table -1: Material Take-off of different building components

Building Components	Material Name	Quantity (in Tonnes)
Sub Structure	Cement	111.04
	Fine Aggregate	194.33
	Coarse Aggregate	388.66
	Reinforcement	31
Super Structure	Cement	543.47
	Fine Aggregate	987.68
	Coarse Aggregate	1614.31
	Reinforcement	157.54
Envelope Material	Cement	52.44
	Fine Aggregate	161.5
	Coarse Aggregate	31.63
	Solid block (1:3:5)	452.3

3.3 Determination of embodied carbon coefficient

Embodied carbon emission of a building is calculated by multiplying the quantity of all materials needed for the building's lifetime by the carbon coefficient (expressed in kg CO_2e per kg of material) for each material. Therefore the embodied carbon coefficient of the materials and components is one of the key data requirements to assess embodied CO_2e of buildings.

However, the embodied carbon data and databases exhibit inaccuracies and variation because of the inconsistent methodologies, non-standard methodologies used and insufficient data provided by manufacturers for research (Table-2). Due to which, there is a lack of a comprehensive overview of a simplified, applicable embodied CO_2e assessment approach for wide use in the construction industry.

Table -2: Variations in embodied carbon coefficient in ICE and Hong Kong material database

Material Name	Embodied Carbon Coefficient ($KgCO_2e/Kg$)	
	Inventory of Carbon & Energy (ICE)	Materials database for Hong Kong
Ordinary Portland Cement	0.950	0.906
Steel Rebar (39%Recycled)	1.86	1.900
Plywood	1.1	1.932
Stone	0.079	0.113

There are a range of publications where the average emission coefficients have been compiled into one database, the Inventory of Carbon and Energy (ICE) being the prominent among them. It is a database produced by the University of Bath and provides average values for materials taken from a range of studies and assessments. These factors usually refer to cradle-to-gate emissions [12].

In India, the concept of embodied carbon is still in its adolescent stage. An authentic database of Indian context, consisting of carbon emission coefficients of locally produced and available materials is still not available. Therefore, in this project the carbon emission coefficients were chosen from the ICE database, Piti methodology, Handbook of low carbon concrete, Auroville Earth Institute.

3.4 Assessment of Embodied carbon value

Based on the Cradle to Completed construction approach chosen, CO_2 emissions of a building can be calculated as given in equation:

$$C_{EM} = C_M + C_T + C_C \qquad (1)$$

Where,
C_{EM} = Embodied CO_2 emissions ($kgCO_2e$)
C_M, C_T, C_C = Equivalent CO_2 emissions at material production, transportation and construction stages ($kgCO_2e$).

Material Production stage

The equivalent CO_2 emission caused at material production stage can be termed as cradle to gate embodied carbon of materials. It ideally accounts for three types of carbon emissions:

- Emissions due to the release of carbon compounds in the raw material and its extraction
- Carbon emissions caused during the material manufacturing and processing operations
- Emissions due to a depreciation in the embodied carbon value of the machinery used to process materials

The emission due the carbon compounds in raw materials and its extraction can be estimated through evaluating the composition of the material used, whereas the one caused due to manufacturing of raw materials requires a detailed evaluation of the processes involved in manufacturing and processing of materials into their final form, before leaving the gate of the manufacturer's site. The third type of embodied carbon, caused by the depreciation of machinery used, is often neglected.

However, the embodied carbon coefficients of materials vary by a great deal depending on the manufacturing processes used, the technology used and the properties of the raw material sources available to the manufacturer, transport available etc.

Equivalent CO_2 emissions at material production stage, C_M can be calculated as:

$$C_M = \sum_{i=1}^{n} m_i \times f_{i,n}$$

Where,

n = total number of material types
m_i = quantity of material type i (Tonnes)
$f_{i,n}$ = carbon emission coefficient of type i material (TCO_2e/T)

The different materials involved in the material production stage are cement, fine aggregates, coarse aggregates, steel reinforcement bar and solid concrete block. The value for embodied carbon coefficients are obtained from numerous databases and sources.

Therefore, C_M, the equivalent embodied CO_2 emission of the building generated at the material production stage was calculated to be equal to 1112.02 tonnes

Table -3: Embodied carbon emission in Material production stage

Building Components	Material Name	m_i, Quantity (in Tonnes)	$f_{i,n}$, Embodied CO_2 coefficient (TCO_2e/T)	Embodied CO_2e at material production stage (in Tonnes)
Sub Structure	Cement	111.04	0.67	74.4
	Fine Aggregate	194.33	0.115	22.35
	Coarse Aggregate	388.66	0.0459	17.84
	Reinforcement	31	1.86	57.66
Super Structure	Cement	543.47	0.67	364.12
	Fine Aggregate	987.68	0.115	113.58
	Coarse Aggregate	1614.31	0.0459	74.1
	Reinforcement	157.54	1.86	293.02
Envelope Material	Cement	52.44	0.67	35.13
	Fine Aggregate	161.5	0.115	18.57
	Coarse Aggregate	31.63	0.0459	1.45
	Solid block (1:3:5)	452.3	0.088	39.8
C_M, Total embodied Carbon at Material production stage (in Tonnes)				1112.02

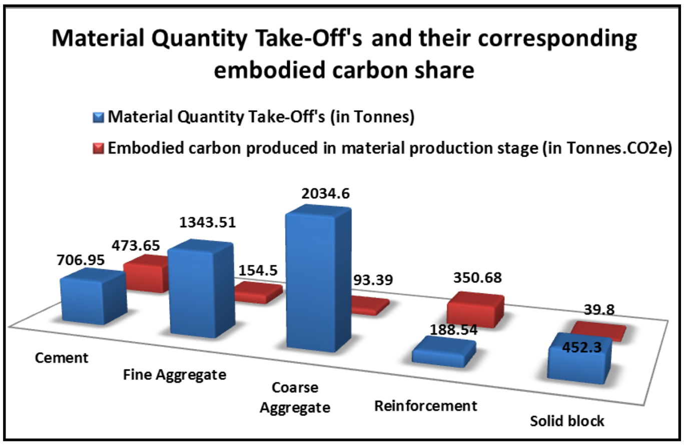

Fig -3: Embodied carbon distribution along the materials in Material production stage

Cement was found to be the major contributing material for the Embodied carbon of a building. 706.95 tonnes of cement used in the building resulted in a carbon dioxide equivalent emission of 473.65 tonnes.

Transportation stage

The equivalent CO_2 emission at transportation stage is the result of movement of products from the place of its manufacture to the site of construction. Emissions caused by the various transportation modes involved are computed in this stage.

The equivalent CO_2 emissions during the transportation stage depend upon factors such as:

- Distance from the manufacturing site to construction site
- Mode of transportation of materials
- Efficiency of transporting vehicle

Once the emission factors for different type of vehicles are determined or deduced from emission inventories, the carbon emissions due to transportation of building materials or equipment can be calculated using the following equation,

$$C_T = \sum_{i=1}^{n}[(m_i/T) \times d_i \times T \times f_{t,i}]$$

Where,

T =capacity of transportation vehicle (Tonnage)
d_i = two-way distance between material supply point to construction site (km)
$f_{t,i}$= carbon emission factor for material transported over unit distance (kgCO2/km).

The distance considered is two way distance (distance from the manufacturing plant to construction site and back to manufacturing plant), assuming that the transporting vehicle is going back with empty load.

There is no conclusive database for embodied carbon emission of vehicles, mainly due to factors such as:

- Varying vehicle emission
- Difference in vehicle makes
- Present condition of vehicle etc.

Table -4: Carbon emission coefficients for various modes of transport (source: http://fluglaerm.de/hamburg/klima.htm)

Mode of Transport	Equivalent Carbon emission per Tonne Km ($Kg.CO_2e$/T Km)
Truck (14 Wheel)	.110
Truck (10 Wheel)	.090
Freight train	.035
Sea Freight	.020

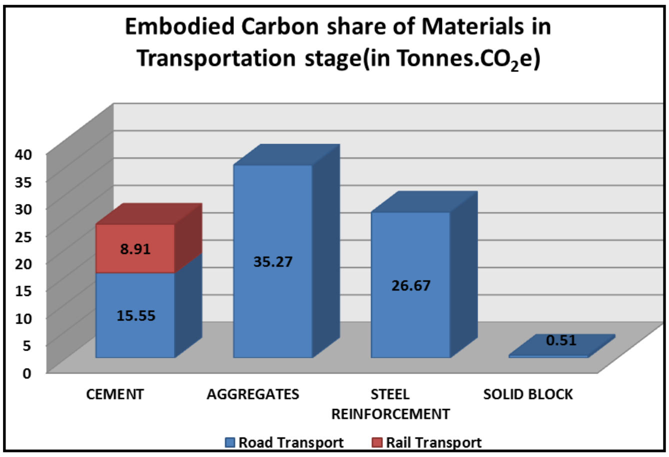

Fig -4: Embodied carbon distribution along the materials in Transportation stage

Therefore, the embodied carbon of the building generated at the Transportation stage was computed to be 86.91 tonnes.

Construction stage

Stipulated time for the completion of the project is 12 months. The possible sources of CO_2 emission occurring during this time frame were identified. The major sources of CO_2 emission at construction stage were found to be:

- Electricity consumption
- Fuel Consumption
- Operation of machines

CO_2 emission at construction stage, C_c is due to the operation of construction machinery and equipment during on-site construction activities, which is given as:

$$C_C = \sum_{i=1}^{j} (Q_{c,i} \times f_{c,i})$$

where,

j = total number of construction activities
$Q_{c,i}$ = quantity of construction activity i
$f_{c,i}$ = carbon emission factor for fuel/electricity used for the construction activity i (kgCO2/l or kgCO2/kwh).

Construction sites are a major consumer of electricity. The total electricity requirement is met from KSEB [Kerala State Electricity Board]. Carbon emission in the production stage and Transmission & Distribution (T&D) stage is considered for the estimation. The electricity consumption for one month was found to be 1080 Kwh. Assuming constant electricity usage during construction period and considering a 20% electricity loss during transport and distribution stage, the total electricity consumed was found to be 15.55 MWh.

The embodied carbon coefficient for electricity (Southern grid) is 0.75 Tonnes.CO_2e/MWh as per Central Electricity Authority [17].

Therefore, the total carbon emission due to electricity consumption = 15.55 x 0.75 = 11.66 Tonnes

Petro-chemical fuels are used for the operation of machinery in construction sites. However, the quantities of fuel consumed vary in daily basis, depending on the running time of machines and frequency of its use.

The average monthly fuel consumption was calculated. It was found that 730 litres of petrol and diesel were used monthly. It was found that majority of the fuel was used for operation of concrete plant and pump, which would be completed in six months' time.

Therefore, the quantity of fuel consumed during the construction phase = 730 x 6
= 4380 Litres

Assuming the fuel consumption to be reduced by half during the remaining six months, the fuel consumed during the non-structural phase of building =730 x 0.5 x 6
=2190 Litres

Therefore, the total fuel consumption = 6570 litres

The carbon emission caused by refining process of gasoline, for manufacture of petroleum is .3434 KgCO_2e/ litre of fuel [18].

Therefore, the total equivalent carbon emission due to fuel consumption = 6570 x .3434
= 22.56 Tonnes

The machinery present in construction site, when operating causes carbon emission. The extent of emission depends on the type of machine used, frequency of the use of machine, operating mechanism etc. The major machineries were identified to be concrete pump, mixing plant, diesel generator, concrete vibrators etc.

However the necessary database required for finding out the emission was not available. Therefore emissions from machine operations were neglected.

Therefore, the total embodied carbon emission during construction stage= 11.66 + 22.56 = 34.22 tonnes

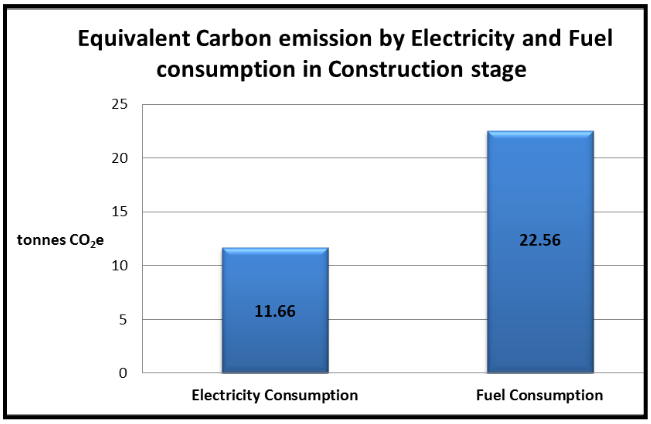

Fig -5: Embodied carbon distribution along the materials in Construction stage

Total Embodied Carbon of the building

The total embodied carbon of the building considering the material production phase, transportation phase and construction phase =1112.02 + 86.99 + 34. 22
=1233.23 tonnes

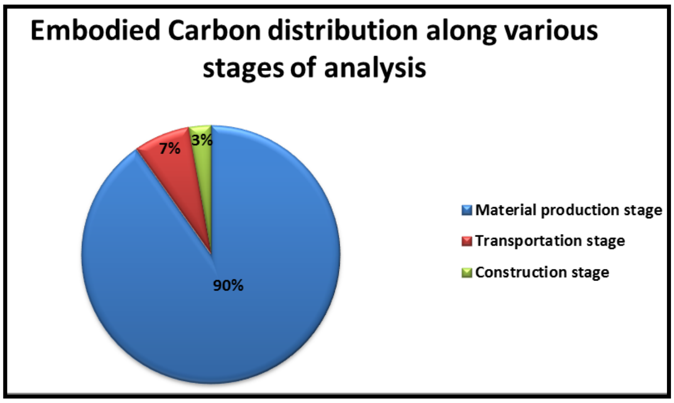

Fig -6: Embodied carbon distribution along the various stages of building life-cycle

Therefore, while reviewing the various stages of building life cycle it was found that the Material production stage is the major contributor of carbon emissions.

The embodied carbon emission of the building produced within the scope of the project was found to be 583.66 Kg/m^2.

3.5 Embodied Carbon Reduction Strategy

For reducing the embodied carbon of a building, an efficient reduction strategy needs to be formulated during the design phase of the building, where the carbon reduction ability is the highest and the design and choices of materials can be influenced [4].

The reduction strategies adopted should be done keeping in mind of the following aspects:

- Build nothing –the root cause of the requirement or need of the building is questioned; exploration of alternative approaches for achieving the desired outcome.
- Build less – maximising the use of existing assets and optimising the asset operation, thereby urging the management to reduce the extent of new construction required.
- Build clever – designing the use of low carbon materials, streamlining the delivery processes, hence minimising the resource consumption.
- Build efficiently – embracing new construction technologies, thereby eliminate the waste.

Detailed study on reduction strategies were carried out and its efficiency in carbon mitigation discussed. The reduction strategies adopted are:

Cement Substitution

Cement is a major constituent in concrete and is responsible for 43% of carbon emission in material production stage for the project. The carbon emission coefficient of cement is relatively high, which reduces with the substitution of cementations material.

The cement used in the project was Portland Pozzolana Cement (PPC). The fly ash constitution of cement was identified to be 28% from the work test certificate issued from the manufacturing plant. The embodied carbon coefficient of the PPC with 28% fly ash composition was calculated from the ICE database to be 0.67 KgCO$_2$e/Kg.

The possible substitute for Portland Pozzolana Cement (PPC) is Portland Slag Cement (PSC). The Portland Slag cement with 50% slag composition was chosen as the alternative. The embodied carbon coefficient for PSC was interpolated from the ICE database was found to be 0.52 KgCO$_2$e/Kg.

The substitution of cement can only be made if the strength and adjacent properties of the alternate cement is comparable. A comparative check was carried out and the results found satisfactory.

The compressive strength, fineness, setting time and soundness properties of the cements were analysed. On comparing the compressive strengths, it was seen that PPC had higher 7 day strength. However, by 28 days the strength attained by both PPC (57 MPa) and PSC (59 MPa) were almost the same. Fineness was found to be lower for PSC than PPC. Setting times for PSC is lower by 30-50 minutes. Soundness was found to be identical for PPC and PSC.

Therefore, it is possible to substitute the Portland Pozzolana Cement (PPC) with Portland Slag Cement (PSC) for use in construction.

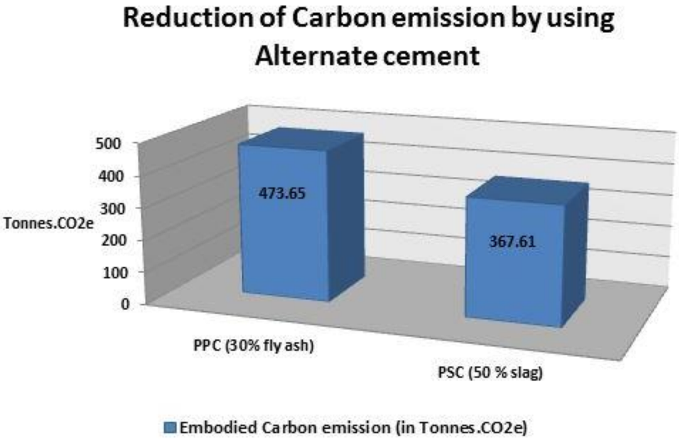

Fig -6: Reduction attained by using alternate cement

Hence, a carbon emission reduction of 106.04 tonnes was attained by altering the Portland Pozzolana Cement with Portland Slag Cement. The carbon emission due to cement at manufacture stage alone was reduced by 22.38%.

Use of Glass Fiber Reinforced Gypsum walls

Concrete solid blocks are commonly used building envelope materials for construction. The possibility of reducing the carbon emission caused by solid block masonry using an alternative material, namely Glass Fiber Reinforced Gypsum (GFRG) wall panel is explored.

GFRG wall is a new composite wall product made of gypsum plaster reinforced with glass fiber. The glass fibers are randomly distributed inside the panel skin and ribs in the manufacturing process. Panels are hollow and manufactured in 124 mm thick by 12 metre length and 3 metre width.

Fig -6: Construction carried out using GFRG wall panels

On observing the Strength characteristics of GFRG panels, the axial load capacity was found to be 160 KN/m and Compressive strength to be 7.178 KN/mm^2, which was well within the limits of load bearing wall.

To avoid the risk for the breakage of panels or for the development of every third cavity of the walls of the building should be filled with M20 concrete and reinforced at minimum. The remaining empty cavities should be filled with quarry dust mixed with 5% cement and water. Wherever electrical pipelines or conduits had to be provided, the cavity was left empty for this purpose, and subsequently filled [20].

By avoiding concrete solid blocks for construction, carbon emission of 39.8 tonnes is reduced.

Now assessing the carbon emission caused due to GFRG wall panels.

Total area of GFRG wall panels required = 1507.65 m^2

The embodied carbon emission coefficient of GFRG panels at material production stage was found to be 1.991 KgCO$_2$e/m^2 [14].

The total volume of concrete required for in-filling is 43.47 m^3. Assuming a density of 2400 Kg/m^3 for concrete, the weight of concrete used is 1,04,321 Kg.

Assume a minimum reinforcement usage of 30 Kg/m^3 for GFRG wall construction. Therefore, the total weight of reinforcement used is 1304.1 Kg.

Hence, calculating the embodied carbon emission caused by GFRG wall panels.

Material Name	Quantity used	Embodied CO$_2$ coefficient	Embodied CO$_2$e at material production stage (in Tonnes CO$_2$e)
GFRG wall panel	1507.65 m^2	1.991Kg CO$_2$e/m^2	3.001
M20 Concrete	1,04,321 Kg	0.155 KgCO$_2$e/Kg	16.17
Reinforcement	1304.1 Kg	1.86 KgCO$_2$e/Kg	2.425
Total embodied carbon emitted by using GFRG wall panels (in Tonnes.CO$_2$e)			21.596

Table -5: Computation of Carbon emissions by GFRG wall panels

The reduction in carbon emission attained by substitution of Concrete solid block with GFRG wall panels at manufacture stage is 45.7%.

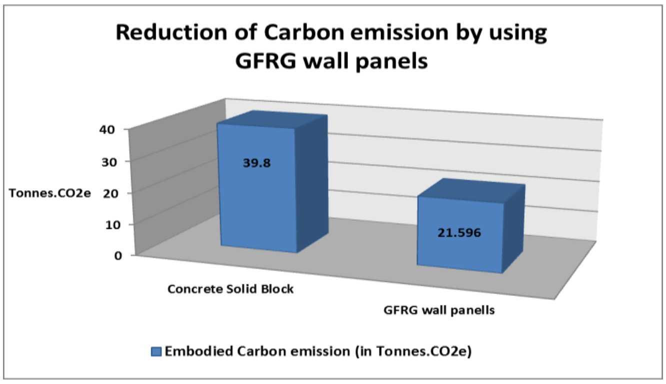

Fig -6: Reduction attained by using GFRG wall panels

Use of Locally sourced materials

Prior to the construction of building, a detailed study on availability of materials for construction should be carried out, with preference given to locally available materials. However, it should be ensured that the locally sourced materials follow the required specifications and quality standards.

For the project, the aggregate transport was found to be the major contributor of Embodied carbon in transportation stage with 35.27 tonnes of carbon emission (see Fig. 5.9). Therefore, the possibility of reducing the embodied carbon from aggregate transport was checked.

It was found that the aggregates for construction where brought from a quarry and crusher unit located at Kanjirappilly, Kerala situated 58 Km's away from the construction site. On detailed analysis of the area, a quarry was found at Charalkkunnu, Ranni situated at a distance of 18 Km's from the construction site. The fine and coarse aggregates from the nearby quarry were found to be following the required specifications and quality standards.

Therefore by using locally available aggregates 24.32 tonnes of embodied carbon was reduced.

Grid-Connected Solar Photo-voltaic system

The use of grid connected solar Photo-voltaic System was recommended to reduce the electricity consumption. These Grid Connected Photo-Voltaic systems have solar panels that provide some or even most of their power needs during the day time, while still being connected to the local electrical grid network during the night time. The main advantage of a grid connected PV system is its simplicity, relatively low operating and maintenance costs as well as reduced electricity bills.

A 5kW Grid-Connected Solar Photo-voltaic system comprising of 20 solar panels, solar inverter etc. can be used in site. The whole unit can be mounted on top of site offices, cement stores etc. thereby avoiding wastage in space.

The average output generation of the proposed solar unit is 20 units per day. Therefore, they are capable of producing 600 units per month and 7200 units per year.

The embodied carbon coefficient of electricity produced from solar panel is 50 gCO_2e/KWh, which is 0.05 $Tonnes.CO_2e/MWh$ [21].

Total electricity requirement for 12 months= 12,960 units
Electricity produced by solar unit = 7200 units

Therefore, 5760 units have to be taken from electricity grid. Considering transmission loss the total current consumption is computed to be 6912 units.

Calculating the total current consumption,

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Calculating the embodied carbon emission,

Table -6: Embodied Carbon emission after placing solar unit

Current source	Current consumed (in MWh)	Embodied carbon coefficient ($T.CO_2e/MWh$)	$Eq.CO_2$ at Transportation stage (in Tonnes)
Current Grid	6.912	0.75	5.184
Solar Photo-voltaic system	7.2	0.05	0.36
Carbon emission by using 5kW Grid-Connected Solar Photo-voltaic system (in $Tonnes.CO_2e$)			5.544

Therefore, 6.166 tonnes of savings in carbon emission was achieved by using 5kW Grid-Connected Solar Photo-voltaic system

Total carbon emission savings

Regulating the embodied carbon emission of buildings is gaining importance, with increasing share of embodied carbon in life cycle analysis of building. The savings on embodied carbon attained by adopting embodied carbon reduction strategies was computed.

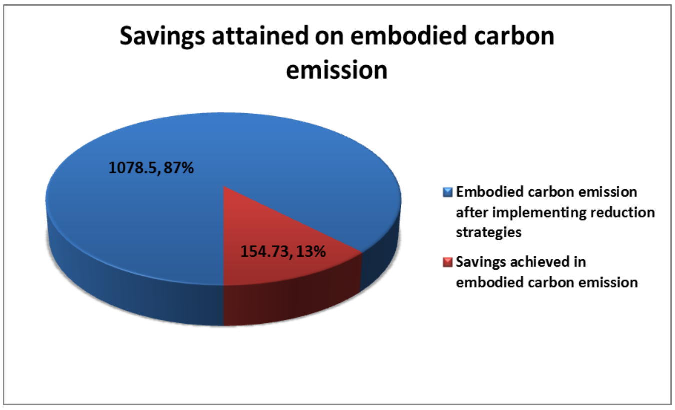

Fig -7: Total savings achieved on embodied carbon emissions

Therefore, a reduction of 154.73 tonnes, which is 13% of the initial embodied carbon emission, was attained by implementing reduction strategies.

3.6 Cost incurred for reduction strategies

Reducing the embodied carbon of buildings can make a valuable contribution for reducing the global greenhouse gas emissions. The developer and the contractors associated with the project should be ascertained that the reduction in embodied carbon of the building can be achieved in a cost neutral manner, starting with simple and cost effective reduction measures. A cost-effective reduction plan for embodied carbon would be highly effective.

The cost incurred to alter the building for reduction of embodied carbon is studied. A market study was carried out to determine if the cost for the reduction strategy proposed would over shoot the present budget.

On comparing the cement prices, the cost of PPC used was found to be Rs.360/bag, while the PSC was available at Rs.315/bag. The rate for constructing solid concrete block masonry is around 2000/m^2, while the GFRG panel costs around 1500/m^2.

The rates of aggregate bought from a quarry 58 Km's away, was found to be same to that of aggregates available at nearby source to the site. Also, savings can be achieved in transportation expenses.

The initial investment made for solar panel is high. However with a service life of 25 years, the returns from electricity savings make use of solar panels quite economical.

Therefore, it is evident that the embodied carbon reduction strategies can be implemented with no additional cash expense, rather it can bring in cash savings.

4. CONCLUSION

The building sector is responsible for 30% of total greenhouse gas emissions occurring throughout the world. Due to the increased efficiency in building techniques and equipments used in the operational stage, the building's lifecycle carbon that comes from the embodied carbon stage is becoming more significant. Therefore, proper means to reduce the embodied carbon of the building should be identified.

This paper formulated an integrated framework for the assessment of embodied carbon footprint of a building and adopted various strategies to reduce the amount of embodied carbon in building.

Building Information Model (BIM) was used to obtain the material take off of building. BIM provides for integrated preplanning, design and project delivery of buildings, and is used by the architecture, engineering and construction (AEC) sector.

Embodied carbon coefficients for various materials and activities were determined in reference to various databases. However, missing information and the absence of a database of Indian reference was noted. The emissions caused at the embodied carbon stage of the building were computed. Material production stage was found to be the largest contributor of embodied carbon emission and cement the major contributing material.

A few of possible embodied carbon reduction strategies were discussed and it was found to have a combined reduction of 13% on initial embodied carbon emission. On conducting an economic analysis, it was seen that the reduction strategies could be carried out with no additional cash input.

Presently, no regulation is been set on embodied carbon emission of a building. As a framework for computation of embodied carbon emission was formulated and the potential on possible embodied carbon reduction identified, the need for embodied carbon regulation in buildings should be carried out extensively. The regulation of embodied carbon should be made a mandatory clause in the building law.

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