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Assessment of Embodied Carbon Footprint of an Educational Building in Pakistan using Building Information Modelling (BIM)

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Abstract. The current study presents one of the few embodied carbon footprint assessments for an educational building in Pakistan. A four storey building with an area of 35,353 Sq. ft has been modeled in a 3D environment using Building Information Modeling (BIM). Life cycle assessment (LCA) methodology with “cradle to gate” boundary limitation has been adopted. A total of 922,000 Kg-CO_{2E} have been calculated with a contribution of 26.09 Kg-CO_{2E}/Sq. ft. Among the materials brick, steel, concrete, brick mortar and ceramic tile were the top contributors in the environment. Load with a collective contribution of 92.86% from these five materials. The study suggested that a proper adoption of green materials at the design stage would help to lower down these environmental concerns to promote sustainable developments.

Keywords: Greenhouse Gases(GHGs), Building Information Modeling (BIM), Life Cycle Assessment (LCA)

1 Introduction

Infrastructure of basic necessities is key element for human survival. To ensure the basic infrastructure, construction industry plays a prominent role. The efficiency and progress of this industry can relate with many other industries and their working. Construction industry revolutionizes the world providing vast opportunities in development of everyday needs. There is a general consensus that construction industry improves the Gross Domestic Product (GDP) and improves the living standards. However, improper functioning of construction industry would effectively contribute in impediments for growth as well in personal lives of a nation [1]. Construction industry consumes about 60% of the raw material which enters into the global economy and produces 65% of atmospheric carbon dioxide during transformation of raw material to construction material [2].

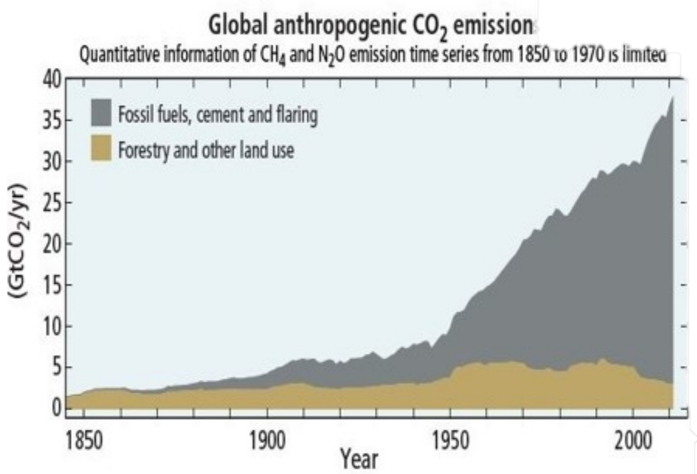

Fig. 1. Global CO_2 emissions over the years by IPCC 2014[3]

Pakistan is a developing country and the construction is required for rapid development of the nation, environmental parameters must be kept in mind to keep the standards of healthy living. Construction process mainly depend on natural resources which are depleting day by day and also a major cause of global warming [4]. According to research, the global temperature is changing and the Earth is getting hotter as a result of activities undertaken by humans. Ozone layer is depleting and that is because of the increase in human activities[5]. The construction industry plays a huge part in these activities. The global quest for development and increase in population growth has accelerated the construction activity. Greenhouse Gases (GHGs) are those gases which trap heat in the atmosphere. The use of these natural reserves and fuels releases Greenhouse Gases (GHGs). Carbon dioxide is a naturally occurring gas which is major component of such gases. A fair amount of carbon footprint, known as embodied carbon, is released during extraction to utilization of material in construction activities [6]. Embodied Carbon Footprint can be ascertained as the measure of the total amount of carbon dioxide emissions that is directly and indirectly caused by an activity. Evaluation of carbon footprint is a serious issue in construction business now because of the climate change and its after affects. Not only do they directly impact our current environment, but also indirectly affect the living standards and quality of life for our future generations. Therefore, the main focus in this evaluation is laid on embodied phase of carbon footprint emission (CO_{2E}). It largely depends upon the type of material, energy utilized in manufacturing, extraction, transportation, assembling of material and dismantling of material after useful life.

2 Literature Review

Intergovernmental Panel on Climate Change (IPCC) report 2014 reports that 40% utilization of materials globally is by construction industry and impact of over a half global CO_2 emanation was done by building sector, with an increasing at rate of 2.7%

per year [3].Among construction facilities, the building make the major chunk. The assessment of embodied carbon from educational buildings have been an interesting field for many researchers. The critical review of literature has highlighted that Building Information Modeling (BIM) is a new method being utilized to achieve such targets, table 1. Life-cycle assessment with boundary condition “from cradle to gate” is a technique to assess environmental impacts associated with the stages of a product's life cycle.

Table 1. Previous studies on carbon footprint assessment using BIM and LCA.

Author	Country	Findings
George, J., & Jacob, J. [7]	India (2018)	The building sector is responsible for 30% of total greenhouse gas emissions occurring throughout the world.
Yanga. X, Hu. M, Wu. J & Zhao. B[8]	China (2018)	The operation phase contributes 69% of the total GHG emission, building material production contributes to 24%.
Syngros, G., Balaras, A.C. & Koubogiannisa, D.G. [9]	Greece (2017)	Concrete causes more emission because of its quantity.
Peng, C. [10]	China (2016)	Emission is more in usage, lesser emissions in demolishing then construction.
Lu. C, Chen. J, Pan. C & Jeng, T.[11]	Taiwan (2015)	Reveals significant difference in the immediate carbon footprint computation
Shafiq et al. A.[12]	Malaysia (2015)	Introduced smart integrated low carbon infrastructure model
Biswas. W K [13]	Australia (2014)	Total embodied CO_2 emission is during usage stage.

3 Objective of Study

The main objective of current study is to assess the embodied carbon footprint potential of a conventionally constructed educational building by utilization of Building Information Modeling (BIM) and Life Cycle Assessment (LCA).

4 Case Study

The building is located in capital city of Pakistan. It is four (04) story framed structure with an approximate covered area of the building is 6,354 sq. ft for each floor. The external walls of the building are cladded with face bricks whereas internally, the floors are covered with porcelain tiles, it is sheathing with porcelain tiles till sill level, mostly wooden doors are used with some door with glass embedding. Fig. 2 shows the conventional educational building selected as case study.

Fig.2. Educational Building selected as case study

5 Methodology

The methodology adopted for current study is graphically represented in fig. 3. LCA with boundary limitation of “cradle to gate” has been adopted in the study. Building Information Modelling (BIM) is utilized to foresee 3D development in a virtual environment. Data pertinent as to the materials for this case are extracted from these 3D systematic models using Microsoft Excel to achieve life cycle inventory .

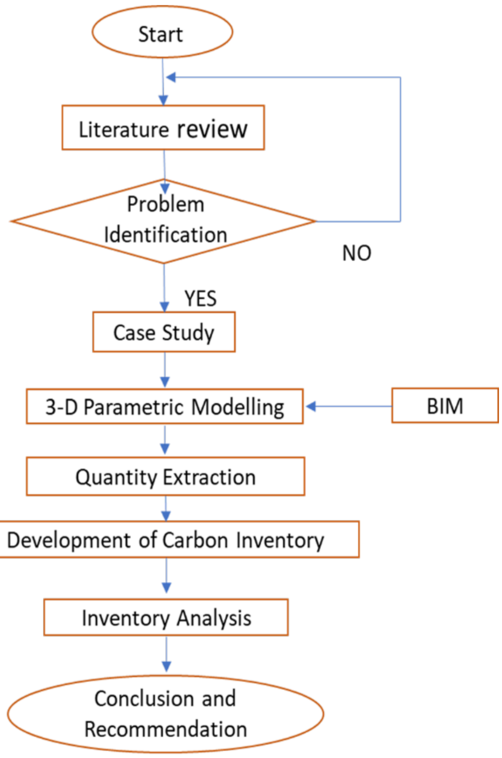

Fig.3. Methodology for current study

The Inventory Carbon and Energy (ICE) developed by Hammond & Jones [14] was adhered to assess the embodied carbon footprint. The Architectural and structural model is show in fig. 4.

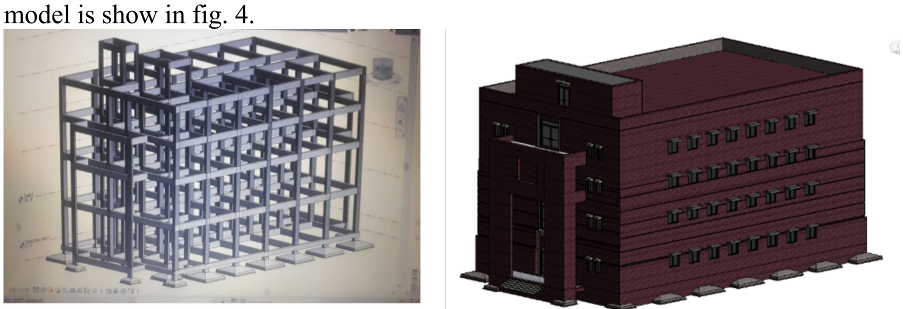

Fig.4. Virtual 3D model of case study

6 Results and Discussion

Based upon 3D modeling, the quantities of materials were extracted to develop life cycle inventory, table 2. This inventory was compared with the actual Bill of Quantities

(B.O.Q). However, minor variations were observed. Table 3 details the carbon footprint contribution from these construction materials:

Table 2. Quantity of material extracted from Revit (3-D model) of case study

S.No.	Description of Materials	Unit	Quantity
1	Aluminum	Kg	1755.96
2	Brick	Cft	26,623.18
3	Brick Mortar	Cft	3,550.33
4	Ceramic Tile	Cft	821.02
5	False Ceiling	Sft	23,558
6	Glass	Cft	96.82
7	Paint	Sft	29,213
8	Paint	Sft	27,654.36
9	Plain Cement Concrete (1:4:8)	Cft	4,353.77
10	Plaster	Cft	2,002.54
11	RCC Concrete (1:2:4)	Cft	24,305.42
12	Stain less Steel	Kg	388.33
13	Steel	Kg	120,000
14	Wood (Play wood)	Cft	46.08

Based upon the carbon inventory developed by Hammond and Jones[14], the extracted quantities were multiplied with the carbon equivalent factors to calculate the embodied carbon emission. A total of 922 tons of CO_{2E} has been emitted by the case study building. Fig. 4 shows the percentage contribution of material in the research.

Table 3. Carbon Footprint emission -KgCO_{2E}

S.No.	Description of Items	Carbon Conversion Factor Kg-CO_{2E}	Carbon Emissions (Kg-$C0_{2E}$)
1	Plain Cement Concrete (1:4:8)	0.1	21698.13
2	RCC Concrete (1:2:4)	0.107	129611.60
3	Stain less Steel	3.27	1269.86
4	Wood (Play wood)	0.55	502.360
5	Ceramic Tile	0.7	22768.90
6	Steel	2.77	332400
7	Paint	0.87	2361.16
8	Aluminum	9.16	16084.59
9	Glass	0.91	6237.21
10	Brick	0.24	347389.40
11	Paint	0.87	2235.18
12	Brick Mortar	0.13	24831.90
13	Plaster	0.13	14006.26
14	False Ceiling	0.47	1028.65

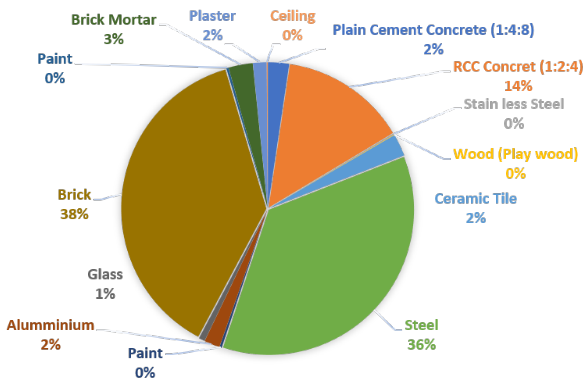

Fig.4. Percentage contribution of each of material .

Table 4. Material ranking which contributes more in carbon emissions.

S.No.	Description of Items	Carbon Content (Kg-$C0_{2E}$)	Ranking
1	Brick	37.66	Rank-1
2	Steel	36.03	Rank-2
3	RCC Concrete (1:2:4)	14.05	Rank-4
4	Brick Mortar	2.69	Rank-3
5	Ceramic Tile	2.46	Rank-5

In order to observe the contribution on individual basis, ranking was performed in table 4. According to results, brick (37.66%), steel (36.03%), reinforced concrete (14.05%), brick mortar (2.69%) and ceramic tile (2.46%) were the top five contributors in carbon emissions. The overall contributions from these materials was more than 90% of the total.

7 Conclusion

Embodied carbon footprint assessment of a conventional educational building has been performed. The 3D model was developed in BIM along with LCA methodology. It has been concluded that :

- Total emissions of almost 922,500 Kg-CO_{2E} was observed.
- Educational building selected as a case study with total area of 35,353 Sq. ft, the per unit area contribution is summed up to be 26.10 Kg-CO_{2E}/Sq. ft.
- The major contributing materials are brick (37.66%), steel (36.03%), concrete (14.05%), brick mortar (2.69%) and ceramic tile (2.46%).
- It is learnt that incorporation of Building Information Modeling (BIM) technology for further refinement of materials and their usage, further harm can be reduced and fruitful results for future construction can be obtained.

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