IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Effect of sustainable materials on embodied energy, carbon footprint and cost for a proposed conventional apartment

To cite this article: Abhishek Manjunath and Nayana N Patil 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1166** 012037

Effect of sustainable materials on embodied energy, carbon footprint and cost for a proposed conventional apartment

Abhishek Manjunath[1], Nayana N Patil[1*]

[1] Department of Civil Engineering, Ramaiah University of Applied sciences, Bengaluru, Karnataka, India
[1]*abhimaan13@gmail.com*
**nayanapatil.ce.et@msruas.ac.in*

Abstract. The construction industry accounts for an incredible 36% of worldwide energy usage, and 40% of CO_2 emissions. Therefore, it is required to reduce the impact of construction on the environment. In this study, a few green materials have been selected along with few green techniques and are applied to the apartment and a comparison is provided. An ongoing project consisting of 18 typical floors and basement is selected for the study. Estimation of quantities are done according to the drawings and major materials such as blocks, internal paints, flooring and concrete are replaced with proposed sustainable materials. Embodied energy and carbon footprint analysis is performed for the building components such as blocks, tiles, paints, concrete and plastering. Alternate materials like compressed stabilized earth blocks, clay plaster, wallpaper, terrazzo tiles and blended cement concrete are chosen as replacements for the conventional materials. A comparison is provided with conventional materials with respect to the chosen sustainable materials. The results show 73% reduction in embodied energy and 52% reduction in carbon footprint of the structure. Also, reduction in cost by 30%. Hence, reducing the impact on the environment and making the structure sustainable.

Keywords: Sustainable materials, embodied energy, carbon footprint, compressed stabilized earth blocks, cost analysis

1. Introduction

The construction industry necessitates the extraction of large quantities of materials, which consumes energy resources and releases harmful pollutant emissions into the biosphere. Each material must be extracted, processed, and transported to its final destination. The energy used in these activities is necessary for human growth, but it also jeopardises the biosphere's quality and long-term viability due to unwanted or "second" order impacts. (Hammond, 2008) On a local, regional, or national scale, many of these side effects of energy production and consumption result in resource uncertainty and potential environmental risks. Energy and pollutant emissions like carbon dioxide (CO2) can be considered "embodied" in materials. Thus, embodied energy can be observed as the quantity of energy required to process, and supply to the construction site, the material under consideration. In order to determine the magnitude of this embodied energy, a methodology is required that sums the energy inputs over the major part of the material supply chain or life-cycle. (Imperatives, 1987) In the present context, the emission of energy related pollutants (like CO_2), which is a concern in the context of global warming and climate change, may be viewed over their lifecycle. This gives rise to the notion of 'embodied carbon'. The aim of the present study was to develop an open-access, reliable database of both embodied energy and carbon for (principally) Indian construction materials.

Table 1. Example for difference between green concept and sustainable concept.

Factor	Green concept	Sustainable concept
Clay Plastering	Clay is a naturally abundant Material.	The embodied energy is considerably low.
Wallpapers	Green product, eco-friendly and durable	But not sustainable because it is harvested in an environmental irresponsible way (by depleting the forest) and even expensive

Table 1 shows the difference between green concept and sustainable concept which implies they are similar but not the same.

Materials manufacturing consume maximum energy and large emission of carbon dioxide. This leads to global warming and depletion of non-renewable resources. Therefore, utilization of natural and renewable energy sources in the construction industry to minimize the drastic effect on the environment by the buildings. By comparative study, awareness and motivation about the advantages and benefits of green construction can be achieved.

2. Methodology and Materials

2.1 Methodology.

The main aim of conducting this study is to compare the benefits of alternate sustainable materials in the proposed residential complex, for that the following objectives are considered and followed.

Table 2. Methodology adopted for the study

Objectives	Methodology
Choosing Structure for the analysis	An on-going project consisting of a basement, stilt floor and 18 upper floors
Choosing materials with high impact on environment	Quantifying the materials needed for construction and choosing the major materials such as concrete, blocks, flooring tiles, paints and plaster
Embodied energy, carbon footprint and cost analysis	Embodied energy, cost and carbon footprint of the quantified materials are calculated. This is performed by data collection by referring journals and articles
Comparison between conventional and proposed materials	The results obtained by the analysis is then compared with actual construction parameters

Table 2 shows the methodology applied for the research conducted on conventional and sustainable approach for the selected structure

2.2 Selection of apartment.

The residential apartment chosen for the comparative study is located in Akshayanagar, Bangalore. An 18 storied residential building with a stilt floor and a basement. It has a built - up area of

1000sqm. Each floor has 4 numbers of 3BHK and 2 numbers of 2 BHK apartments. The site has been designed to have 25% garden area included in super built up area.

Table 3. Details of the selected apartment

Salient Features of the Project	
Project Name	Hiranandani Club Meadows
Project type	Commercial Project
Client	House of Hiranandani
Type of Contract	Item rate contract
Project Location	Akshayanagar, Near Hulimavu Lake, Hulimavu, Bannerghatta, Bangalore - 560068
Project Start Date	February 2019
Project Finish Date	July 2021
Project Specifications	The entire project consists of 5 towers and a clubhouse Lake Verandah, Hill Crest, Club Meadows, Queen’s Gate and Evita & Torino
Evita & Torino	1 Basement + Ground + 18 Upper Floors

The information is collected from the site office of Hiranandani Club House Meadows. *(Source: House of Hiranandani Clubhouse Meadows office)*

IOP Conf. Series: Materials Science and Engineering 1166 (2021) 012037 doi:10.1088/1757-899X/1166/1/012037

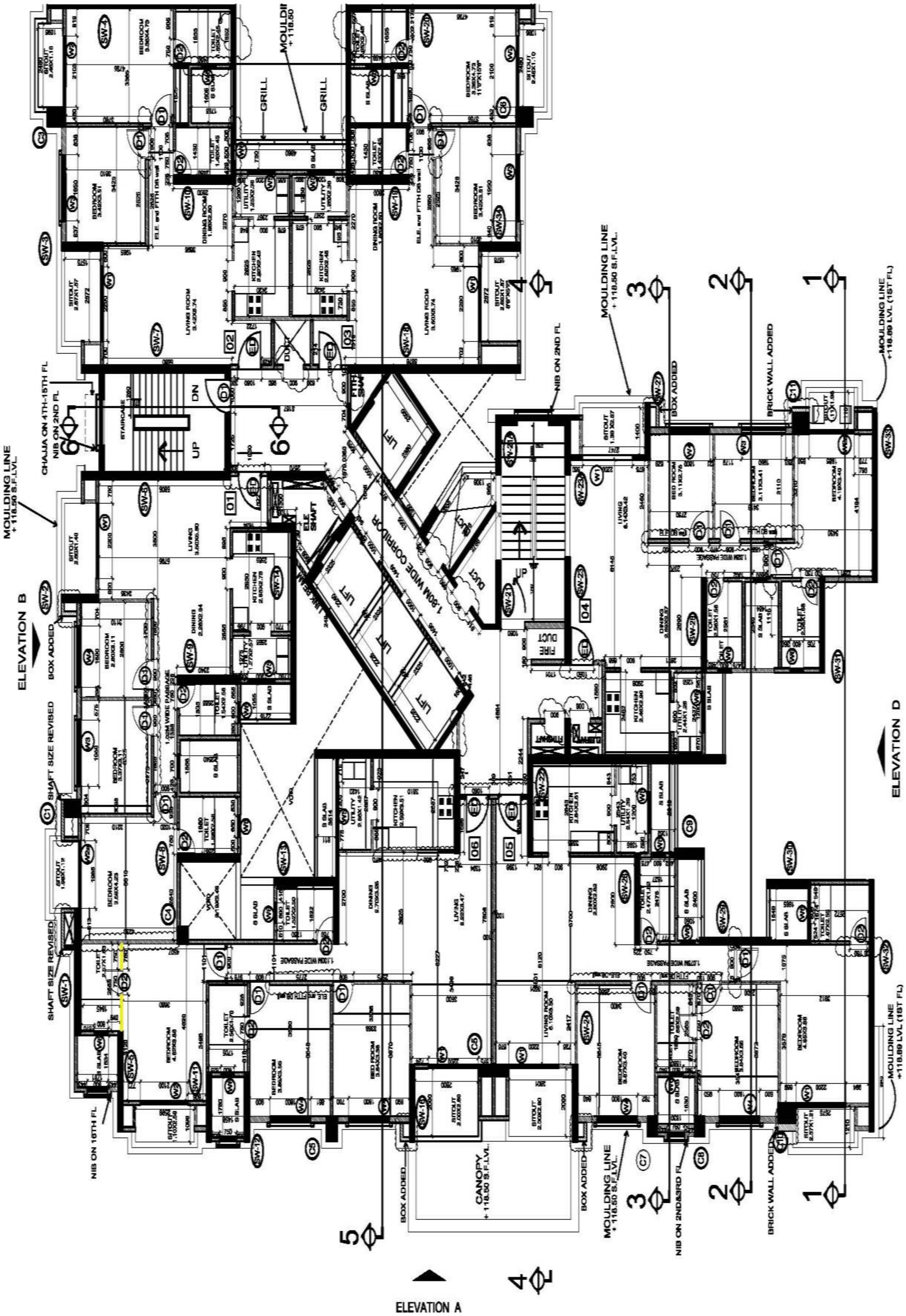

Figure 1. Typical Floor plan
(Source: House of Hiranandani Clubhouse Meadows office)

2.3 Materials used.
Once the values of embodied energy and carbon footing for early versions of the database had been selected, it was possible to apply the data in practical situations. The embodied energy and carbon footing of typical dwellings were analysed by first determining the quantities of material consumed during construction. The selection of material for replacement are based on certain criteria such as embodied energy, local availability, recycle content, functional life period, material cost, maintenance cost, construction waste management, minimum time consumption and toxicity/safety. In this study, materials such as clay, terrazzo tiles, blended cement concrete, wallpapers, compressed stabilized earth blocks (CSEB) and low E glass are considered as the alternatives for the conventional materials. Adopting the selected materials on the chosen structure from the quantity estimation obtained for this building and results are obtained. (Jin lee kim, 2014) (Sustainable construction managementat project level: a modified environmental management system structure, 2008)

2.3.1 Building block. An alternate for concrete blocks are compressed stabilized earth blocks (CSEB) which is low in embodied energy and made of earthly natural materials. This helps in reduction of carbon dioxide and embodied energy. The block is made of mix of fairly dry inorganic subsoil, non-expansive clay and aggregate along with a binder such as cement (Imperatives, 1987).

Table 4. Building blocks comparison between conventional and green building

Item Description	Size inch	Quantity	Unit	Embodied energy per unit	Embodied Energy (MJ/Unit)	Carbon Footprint per Kg	Carbon Footprint (CO2e)Kg	Cost per unit	Cost (Rs.)
Conventional building Block work	4	223109	Per piece	0.81	180718.29	0.06	267730.8	39	8701251
	6	61244		0.96	58794.24	0.07	115751.2	48	2939712
Compressed stabilized earth block	4	223109		0.41	91474.69	0.022	39267.18	26	5800834
	6	61244		0.49	30009.56	0.026	19108.13	33	2021052

(Riza, 2010), Embodied energy and carbon footprint values are taken from the cited paper.

2.3.2 Clay plastering is an old method of finishing surfaces which is proven to be sustainable. The benefits include cooler interior temperature, low embodied energy and naturally occurring material. Clay plaster is a mixture of clay and sand that makes a beautiful, environmentally friendly alternative to conventional plaster and paint. It is natural, non-toxic, durable and beautiful. Unlike most paint, it does not contain VOC's. (Natural Stabilized Earth Panels versus Conventional Façade Systems. Economic and Environmental Impact Assessment, 2018). Table 5 shows the comparison of Plastering material quantity, embodied energy and carbon footprint.

Table 5. Plastering material quantity, embodied energy and carbon footprint comparison

Item Description	Quantity	Unit	Embodied energy per unit	Embodied Energy (MJ/Unit)	Carbon Footprint per KG	Carbon Footprint (CO2e)	Cost per unit	Cost (Rs.)
Cement Plastering	3220	Sqm	94.5	304290	0.18	13910.4	161	518420
Clay Plastering	3220	Sqm	28	90160	0.047	2572.78	96	309120

(Natural Stabilized Earth Panels versus Conventional Façade Systems. Economic and Environmental Impact Assessment, 2018)

2.3.3 Blended cement concrete. The concrete made with 24% fly ash replacement and 36% replacement with GGBS showed highest reduction of 44% in embodied energy and 24% in cost. This can save up costs as well as reduce the impact on environment. comprising OPC that has been partly substituted by supplementary cementitious materials, are used as binders for concrete. Commonly used substitutes include fly ash, a fine waste residue that is collected from the emissions liberated by coal burning power stations, and ground granulated blast furnace slag(GGBS), a waste by-product from steelmaking. According to Flower and Sanjayan use of blended cements results in reduction of CO2 emissions by 13–22%. (An Economic and Embodied Energy Comparison of Geo-polymer, Blended cement and Traditional Concretes, 2014). Table 6 gives the Comparison of concreting materials used in conventional and sustainable construction.

Table 6. Comparison of concreting materials

Item Description	Quantity	Unit	Embodied energy per unit	Embodied Energy (MJ/Unit)	Carbon Footprint per KG	Carbon Footprint (CO2e)	Cost per unit	Cost (Rs.)
Concrete	6603	Cum	3890	25685670	0.25	4333219	5830	38495490
Blended cement concrete 24% fly ash and 36% GGBS	6603	Cum	982	6484146	0.14	2244492	2845	18785535

(An Economic and Embodied Energy Comparison of Geo-polymer, Blended cement and Traditional Concretes, 2014)

2.3.4 Flooring material Terrazzo is a composite material either poured in place or precast or hydraulically pressed as tiles. Terrazzo is used for floor and wall decorative finishes. It consists of marble, quartz, granite, glass or other suitable chips; sprinkled or unsprinkled, and poured with a binder that is cementitious, chemical or a combination of both. Terrazzo is cured, ground and polished to a smooth surface or otherwise finished to produce a uniformly textured surface. When comparing terrazzo to four other flooring types, it was observed, on the one hand, that porcelain stoneware and stoneware presented 65% greater embodied energy values, while in contrast, the values for granite and linoleum were less than 79% and 92%, respectively. Table 7 gives the comparison of flooring materials used in the study.

Table 7. Comparison of flooring material

Item Description	Quantity	Unit	Embodied energy per unit	Embodied Energy (MJ/Unit)	Carbon Footprint per KG	Carbon Footprint (CO2e)	Cost per unit	Cost (Rs.)
Ceramic Tile Flooring	11609	sqm	157	1822613	0.613	227722	611	7093099
Terrazzo Tile Flooring	11609	sqm	74	859066	0.51	82888.26	1076	12491284

(Materials, 2017) (Deshmukh, 2014)

IOP Conf. Series: Materials Science and Engineering 1166 (2021) 012037 doi:10.1088/1757-899X/1166/1/012037

2.3.5 Wallpapers are made of renewable resource such as bamboo and wood. Therefore, having less embodied energy and impact on the environment than paints. Wallpapers are durable, long lasting, and cleanable to meet the needs of different lifestyles and applications, holding up to the wear and tear of children or conditions in high traffic areas. According to a lifecycle analysis, it was established that wallcoverings now can last five times longer than paint under typical usage conditions. Table 8 gives comparison of internal finishing comparison. (Materials, 2017)

Table 8. Comparison of Internal Finishing comparison

Item Description	Quantity	Unit	Embodied energy per unit	Embodied Energy (MJ/Unit)	Carbon Footprint per KG	Carbon Footprint (CO2e)	Cost per unit	Cost (Rs.)
Emulsion Paints (2 coats)	31840	Sqm	39.24	1249401.6	2.54	40437	398	12672320
Wallpapers	15920	Sqm	15	238800	1.87	6847.192	605	9631600

3. Results and Discussion

Selection and adoption of sustainable materials to the selected structure is performed according to standard procedures and rates. It is found that locally available sustainable materials can solve the problem of costs as well as the harmful impact on the environment. The following shows the results of the analysis for the selected structure in aspect of cost, embodied energy and carbon footprint.

3.1 Complete embodied energy and carbon footprint of conventional building

Embodied energy calculation of whole building is calculated by considering energy embodied in MJ of each work at each stage as shown in Table 9. For this, considering embodied energy of each material is necessary. Embodied energy calculation of conventional building at each stage by considering embodied energy of each materials of entire work. Table 10 gives the summary of carbon footprint for the building.

Table 9. Summary of Embodied energy

Summary of embodied energy in MJ		
Description	Conventional Materials	Sustainable Materials
Building Blocks	239512.53	121484.25
Plastering	304290	90160
Concrete	25685670	6484146
Flooring	1822613	859066
Internal Finishing	1249401.6	238800

Table 9 represents the embodied energy in MJ for the conventional materials as well as the selected alternate materials. These values are for the entire structure consisting of basement, stilt floor and 18 typical floors. It can be observed that the embodied energy of sustainable materials are less when compared to conventional materials for the same quantity.

IOP Conf. Series: Materials Science and Engineering 1166 (2021) 012037 doi:10.1088/1757-899X/1166/1/012037

Table 10. Summary of carbon footprint

Summary of carbon footprint in CO_2(eq)		
Description	Conventional Materials	Sustainable Materials
Building Blocks	383481.96	58375.312
Plastering	13910.4	2572.78
Concrete	13910.4	2572.78
Flooring	227722.144	82888.26
Internal Finishing	40436.8	6847.192

Table 10 represents the carbon footprint in CO_2(eq) for the conventional materials as well as the selected alternate materials. These values are for the entire structure. It can be observed that the carbon footprint of sustainable materials are less when compared to conventional materials for the same quantity.

Table 11. Summary of Costs

Summary of costs in INR.		
Description	Conventional Cost	Sustainable Cost
Building Blocks	11640963	7821886
Plastering	518420	309120
Concrete	38495490	18785535
Flooring	7093099	12491284
Internal Finishing	12672320	9631600

Table 11 represents the cost in INR for the conventional materials as well as the selected alternate materials. These values are for the entire structure. It can be observed that the cost of selected sustainable materials are less except for terrazzo tile flooring. But the cost is less when compared entirely with the conventional mode.

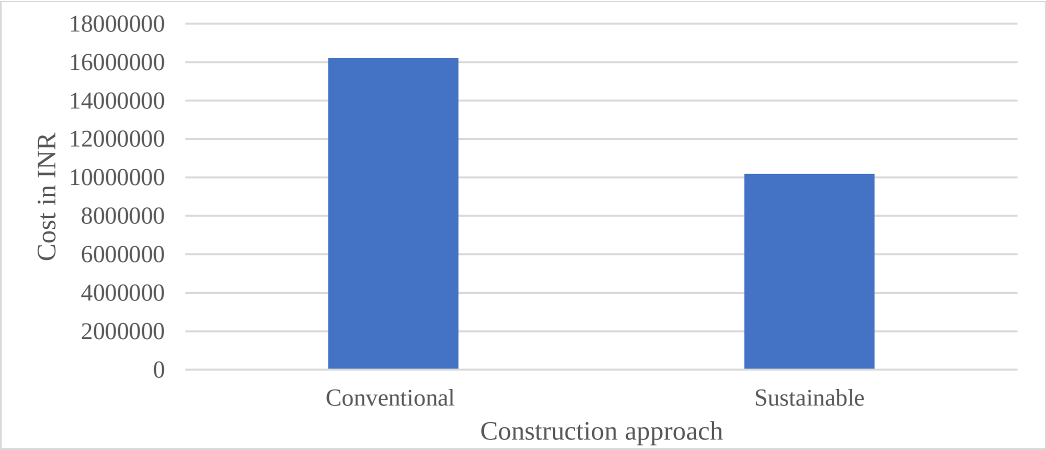

Figure 2. Cost comparison of overall cost for different building approaches

Figure 2 represents the cost comparison between conventional and sustainable concepts showing that sustainable concept is cheaper when compared to conventional.

The embodied energy and carbon footprint comparison for different materials are shown in the Figure 3 and Figure 4.

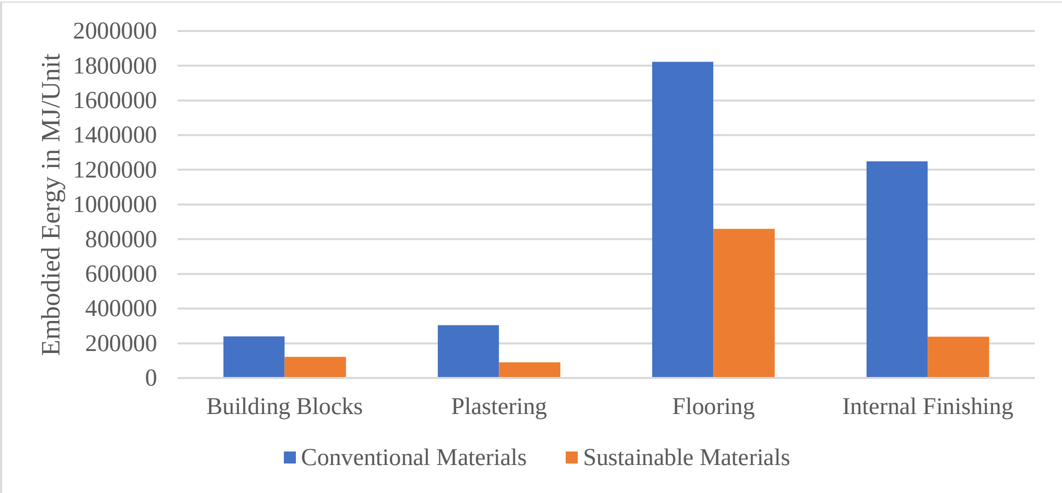

Figure 3. Comparison of embodied energy

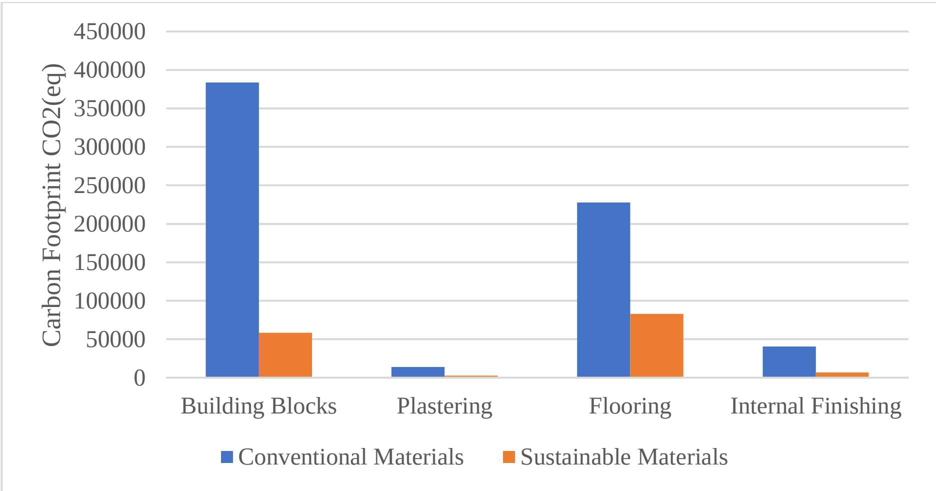

Figure 4. Comparison of carbon footprint

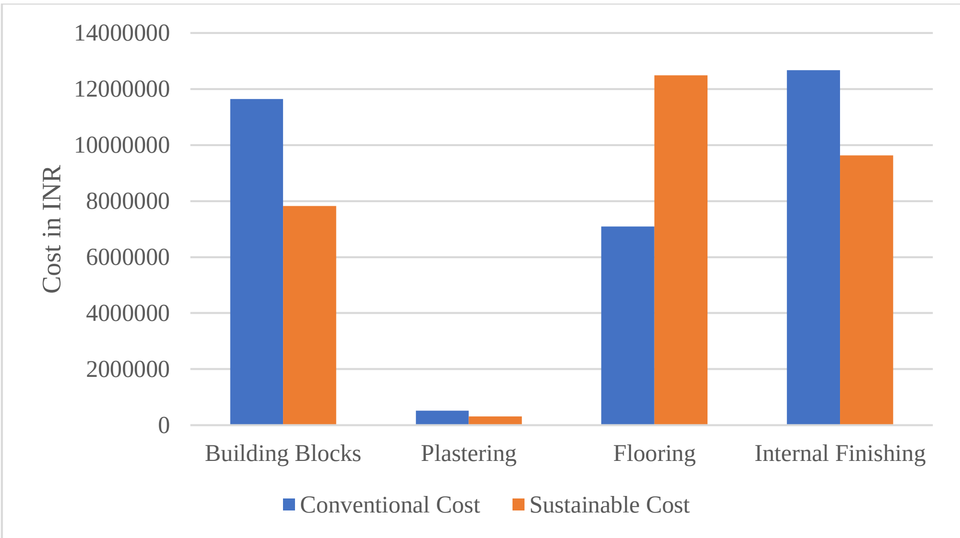

Figure 5. Comparison of Costs

4. Conclusion.

1. The CSEB blocks costs 32% cheaper than concrete blocks. Also the embodied energy and carbon footprint are 49% and 84% reduced when compared to conventional materials.
2. The Blended cement concrete costs 51% less than current market rate of M40 grade concrete. It also exhibits 74% reduction in embodied energy and 48% reduction in carbon emission.
3. Terrazzo tile flooring is 43% costlier than conventional tiles but the embodied energy and carbon footprint of the flooring are drastically less, 52% and 63% respectively.
4. Internal painting is replaced with wallpapers which resulted in cost reduction by 24% and reduction in embodied energy and carbon emission of 80% and 83% respectively.
5. By using clay plaster, the cost is reduced by 40% whereas the embodied energy and carbon emission are reduced by 70% and 81% respectively.
6. The material cost with respect to the selected materials is reduced by 30%.
7. The Embodied energy of the structure is reduced by 73% by adopting the chosen sustainable materials.
8. The Carbon emission of the structure is reduced by 52**%** by adopting the chosen sustainable materials.

5. References

[1] Manjunatha L R, Sandhya anvekar 2014 *An Economic and Embodied Energy Comparison of Geo-polymer, Blended cement and Traditional Concretes*. Researchgate, Journal of Civil Engineering Technology and Research
[2] Rohit Deshmukh, Ashok More. 2014. *Low energy green materials by embodied energy analysis.* International journal of civil and structural engineering research
[3] G. P. Hammond, C. I. Jones. 2008. *Embodied energy and carbon in construction materials*. Institution of civil engineers - energy
[4] *India Construction Materials Database of Embodied Energy and Global Warming Potential METHODOLOGY REPORT 2017*
[5] Jin Lee Kim, Martin Greene, Sunkuk Kim. 2014. *Cost comparative analysis of a new green building code for residential project development.* Journal of construction engineering and management.
[6] Carmen Galán-Marín, Alejandro Martínez-Rocamora, Jaime Solís-Guzmán, Carlos Rivera-Gómez. 2018 *Natural Stabilized Earth Panels versus Conventional Façade Systems. Economic and Environmental Impact Assessment.* Sustainability Journal MDPI.
[7] Venkatarama Reddy. 2009. *Sustainable materials for low carbon buildings.* International journal of low carbon technologies.
[8] Fetra Venny Riza, Ismail Abdul Rahman, Ahmad Mujahid Ahmad Zaidi. 2010. *A brief review of compressed stabilized earth brick.* International conference on science and social research.
[9] Bardhan S. 2011. *Embodied energy analysis of multi storied residential buildings in urban India.* WIT transactions on ecology and the environment
[10] Imperatives. 1987. *Report of the World Commission on Environment and Development: Our common future*. Development and International Cooperation
[11] Urban Persson, Anne Landin, Stefan Olander, 2008. *Sustainable construction management at project level: a modified environmental management system structure*. World sustainable building conference