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

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Abstract. The construction industry accounts for an incredible 36% of worldwide energy usage, and 40% of CO₂ 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 CO₂), 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)
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 management at 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).

| 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 | Sqm | 0.81 | 180718.29 | 0.06 | 267730.8 | 39 | 8701251 |
| | 6 | 6124 | Per piece | 0.96 | 58794.24 | 0.07 | 115751.2 | 48 | 2939712 |
| Compressed stabilized earth block | 4 | 223109 | Sqm | 0.41 | 91474.69 | 0.022 | 39267.18 | 26 | 5800834 |
| | 6 | 6124 | Per piece | 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.

| 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                   | 82888.2               | 1076         | 12491284   |

(Materials, 2017) (Deshmukh, 2014)
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)

| 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     |

### Table 8. Comparison of Internal Finishing comparison

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.

| 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.
Table 10. Summary of carbon footprint

| 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

| 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](image.png)

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.

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