Implementation of sustainable materials in an existing residential building and comparison

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Abstract. Construction and construction related industries are chiefly responsible for depletion of natural resources and environmental problems, hence it is necessary to solve these issues using sustainable materials and techniques. In the study, a few alternative sustainable materials have been selected and have been implemented in an existing residential building. The effectiveness of sustainable materials in reducing the embodied energy and carbon footprint is enumerated in the selected conventional building constructed in 2014 and re-estimated as per the current SR Book of rates. The materials like building blocks, flooring material, paints, doors and windows and conventional slabs are replaced by their alternatives chosen through a detailed literature survey. To quantify usefulness of green materials in terms of cost and positive environmental impacts like reduced embodied energy and carbon footprint, a similar green residential building is proposed and to conduct comparative study for green versus conventional with all respective aspects. Materials used are brick prepared using mine waste, SHGC glass, filler slab, Bamboo doors and windows and low VOC paint materials. Overall construction cost is also 15.2% lesser than conventional as per the abstract between re-estimated conventional building and the sustainable green building. The overall carbon footprint and the embodied energy of sustainable green building is 39.3% lesser than the conventional one.

Key words: Sustainable, conventional, Green, Residential, Filler slab, Building block.

1. Introduction

The conventional buildings are one of the main factors causing depletion of natural resources, the major cause for environmental issues [1]. The construction industries are responsible for these environmental problems, hence it is necessary to be solved by finding new alternatives for replacing and implementing the green materials to achieve sustainable output [2]. Implementation of sustainable construction will certainly decrease the energy consumption and in turn reduce the carbon emissions. Another way to attain green construction is by utilizing different waste materials for manufacturing building materials [3]. The commonly used waste materials for manufacturing the building materials are fly ash, GGBS, IOT, lime, M-Sand, waste collected from demolished building, mine waste which are locally available [6]. Green and sustainable buildings are similar but in some perception they are little different, the answer is that although the terms can sometimes be used interchangeably, there are some key differences. [4] Green isn’t always sustainable but sustainable is always green. Materials manufacturing consume maximum energy and large emission of carbon dioxide. This leads to global warming and depletion of non-renewable resources [5]. Therefore utilization of natural and renewable energy sources in the construction industry to minimize the drastic effect on the environment by the buildings. By the comparative study embodied energy and carbon footprint can be minimised along with cost [6]. In the study cost, embodied energy and carbon footprint of the building is reduced.
2. Materials and methodology.

2.1. Methodology. The main aim of conducting the study is to find the usefulness of replaced alternative materials in an existing residential green building. The following objectives are considered and followed.

1. Selection of existing conventional residential building built in 2014 and re-calculation (quantity estimation and rate analysis) of the cost of construction as per the current market rates using SR Book 2018-19 of PWD, Karnataka.
2. All alternative materials and sustainable material are adapted to the proposed green building and again calculation of cost (quantity estimation and rate analysis) has been done as per the current market rates using SR Book 2018-19 of PWD, Karnataka.
3. Comparison of the cost, embodied energy and carbon footprint has done between the selected conventional building versus proposed green building.

2.2. Selection of residential building.

The conventional building chosen for the comparative study is located in Whitefield, Bangalore. The building is a 4 storied residential building with a stilt floor. It has a site area of 6000sqft, site area acquired by building is 2400sqft and built up area is about 7208sqft. The selected building details is as shown in below table 1.

| Table 1 Selected conventional building data |
|------------------------------------------------|
| **Project Name** | **Residential project** |
| Total Area of the Building | 2400 sqf, (240sqm) |
| Built up area | 7208sft (720.8sqm) |
| Levels | Ground floor + 4 upper floors |
| Typical Floors | 1 No of 3BHK in each floors |
| Total Flats | 4 number of flats |
| Project completed | 2013-14 |
| Located | White-field, Bangalore |

2.3. Materials used for replacement in the proposed structure.

From the quantity estimation obtained for this building, materials are the important component of the building; hence these materials are replaced with green material. All selected component of green building and with respect to existing residential building are shown in the table 2 below.

| Table 2: Materials used in residential building |
|------------------------------------------------|
| **Building component** | **Conventional Building material** | **Alternate Sustainable material** |
| Building block | Normal Clay Bricks | Un-stabilized Bricks of mine waste |
| Building window envelop | Ordinary Glass | SHGC glass |
| Building slab | Conventional slab | Filler slab |
| Flooring material | Marble and Granite | Kota stone (of marble & granite finish) |
| Paints | VOC paints | Low VOC paints |
| Wood | Burma/Teak wood | Bamboo |
2.3.1. Building block.
The building blocks are prepared using waste materials are a good alternative to normal brick to resolve the problems. This helps in reduction of carbon dioxide in many ways by using mine waste which is locally available in Belgaum and Bellary. [5] The bricks chosen for the study are prepared using red mud, IOT, GGBS and lime waste of proportion 45 to 60%, 15 to 30%, 10%, 3.75% and water 11.25%. And its quantity and cost detail is as shown in table 3 below.
Table 3 Comparison of building blocks between conventional and sustainable building

| Building block type | Dimension | Quantity (cum) | Rate per (cum) | Total cost |
|---------------------|-----------|----------------|----------------|------------|
| Conventional building block work | 150mm block work | 156.72 | 5802.7 | 909399 |
|                     | 100mm block work | 26.4 | 7482.9 | 197549 |
| Green building Block work | 150mm block work | 156.72 | 3570.96 | 559641 |
|                     | 100mm block work | 26.4 | 4147.9 | 109505 |

2.3.2. Solar heat gain coefficient (SHGC) window:

SHGC is the fraction of solar radiation admitted through the glass or the window in which it has been used. It is expressed as a number in between 0 and 1. If a window has a SHGC value of 0.5, it transmits 50% of the incident solar radiation through it. When air conditioning is generally not of concern, a higher SHGC in the range of 0.30 to 0.60 can be helpful, as during winter months, the solar heat gained can help warm the house. [6]

2.3.3. Filler slab:

It is a technique to replace the concrete in the tension zone. The filler material, thus, is not a structural part of the slab. By reducing the quantity and weight of material, the roof become less expensive, yet retains the strength of the conventional slab. The most popular filler material is the roofing tile. The structure requires less steel and cement and it is also a good heat insulator. It is adopted in the construction of green building in which 50mm of the concrete in the tension zone is replaced by terracotta tiles which again have a U-value half of that of concrete. In table 4 all the description of filler slab and conventional slab materials are mentioned. [4]

Table 4 Filler slab and conventional slab data

| Particular          | Description          |
|---------------------|----------------------|
| Floor dimension     | 6.3x6.8m             |
| Service load        | 2 KN/m²              |
| Concrete            | M-20                 |
| Steel               | Fe-415               |
| Conventional roof   | RCC                  |
| Tile                | Hollow clay tile     |
| Tile dimension      | 350x250x65mm         |
Table 5 Calculation of embodied energy of conventional slab and filler slab

| Particulars         | Quantities of Conventional Slab (Kg) | Embodied Energy for Materials (MJ/kg) | Embodied Energy for Conventional Slab (MJ) | Quantities of Filler Slab (Kg) | Embodied Energy for Filler Slab (MJ) |
|---------------------|--------------------------------------|--------------------------------------|-------------------------------------------|--------------------------------|----------------------------------|
| Cement              | 2556.60                              | 5.2                                  | 13294.34                                  | 2264.45                        | 11775                           |
| Fine Aggregate      | 3854.11                              | 0.10                                 | 404.68                                    | 1252.74                        | 131.53                          |
| Course Aggregate    | 7708.28                              | 0.08                                 | 639.78                                    | 2505.51                        | 207.95                          |
| Steel               | 129.88                               | 32                                   | 4156.25                                   | 117.14                         | 3748.57                         |
| Hollow Roof Tiles   | N/A                                  | 6                                    | N/A                                       | 20 Nos                         | 120 MJ                           |
| **Total embodied energy** |                                      |                                       | **18494.33 MJ**                           | **15983.07 MJ**                |

Table 5 shows the results are obtained from the calculation of embodied energy of conventional slab is 18494.33 MJ and filler slab is 15983.07MJ and 13.57% is decreased in filler slab with respect to conventional slab and where it has a difference of 2,511.2646MJ.

Table 6 Calculation of carbon footprint of conventional slab and filler slab

| Particulars         | Embodied Energy for Conventional Slab (MJ) | Carbon Emission | Carbon Footprint for Conventional Slab (CO₂Eq to Kg) | Embodied Energy for Filler Slab (MJ) | Carbon Footprint for Filler Slab (CO₂Eq to Kg) |
|---------------------|-------------------------------------------|-----------------|------------------------------------------------------|----------------------------------|------------------------------------------|
| Cement              | 13294.34                                  | 0.4048          | 2018.50                                              | 11775                           | 1757.97                                   |
| Fine Aggregate      | 404.68                                    | 0.0088          | 3.56                                                 | 131.53                          | 1.15                                      |
| Course Aggregate    | 639.78                                    | 0.0088          | 5.63                                                 | 207.95                          | 1.83                                      |
| Steel               | 4156.25                                   | 2.196           | 9127.13                                              | 3748.57                         | 8231.87                                   |
| Hollow Roof Tiles   | N/A                                       | 0.0056          | N/A                                                  | 72                              | 0.403                                     |
| **Total carbon footprint** | **11,154.84**                            |                 | **9,993.23**                                         |                                  |                                          |

Table 6 shows the results are obtained from the calculation of carbon footprint of conventional slab is 11,154.84 CO₂/Kg and filler slab is 9,993.23 CO₂/Kg and 10.41% is decreased in filler slab with respect to conventional slab and where it has a difference of 1,161.61 CO₂/Kg.
Table 7 Calculation of cost of conventional slab and filler slab

| Particulars       | Quantities                      | Rate per Unit | Cost (Rs)  | Quantities                      | Cost (Rs)  |
|-------------------|---------------------------------|---------------|------------|---------------------------------|------------|
| Cement            | 2556.60 Kg (50 bags)            | INR 340/bag   | 17000      | 2264.45 Kg (45 bags)            | 15300      |
| Fine Aggregate    | 3854.11 Kg (136.10 C.ft)        | INR 70/Cu.ft  | 8166       | 1252.74 Kg (44.240 Cu.ft)       | 2654.4     |
| Coarse Aggregate  | 7708.28 Kg (272.216 C.ft)       | INR 23/Cu.ft  | 6261       | 2505.51 Kg (88.48 Cu.ft)        | 2035.04    |
| Steel             | 129.88 Kg                       | INR 51.8/Kg   | 6727.94    | 117.14 Kg                       | 6068.01    |
| Hollow Roof Tiles | N/A                             | INR 20/Tile   | N/A        | 20 Nos                          | 240        |

Total Cost INR 38,154.94/- 26,297.45/-

Table 7 shows the results are obtained from the calculation of the total cost of conventional slab is INR 38,154.94/- and filler slab is INR 26,297.45/- and 32% of the total cost is decreased in filler slab with respect to conventional slab.

2.3.4. Flooring material.

Kota stone flooring (with Kota stone of marble finish and granite finish) In spite of its advantages over marble and granite, Kota stone is much cheaper than both. This combined with its longevity and other advantages makes Kota stone a truly incredible building material. And it also certified by GRIHA as green certification. Table 8 gives the estimation cost details of flooring materials.

Table 8 Flooring material cost of both the buildings

| Building type | Conventional Building | Sustainable building |
|---------------|-----------------------|----------------------|
| Total amount of marble and its alternative material (Kota stone MF) | 4,13,770.77/- | 2,49,734.20/- |
| Total amount of granite and its alternative material (Kota stone GF) | 1,24,683.3/- | 72,267/- |

Table 8 shows the results are obtained from the calculation of the total cost of conventional flooring is INR 538453.07/- and Kota flooring is INR 3,22,001.2/- and 41% of the total cost is decreased in Kota flooring with respect to conventional flooring.

2.3.5. Bamboo doors and window.

Bamboo replaces timber frames appropriate function, the mat shutters fixed to bamboo frame bamboo boards fixed to the frame which wall can be used as a door[7]. There are some inherent properties of bamboo that makes it a preferred material for longevity and sustainability. Bamboo frames are the sustainable way to reduce the usage of hardwood in interior. Highly compressed bamboo strands give these modern frames the look of a high grade dark wood grain. They are available in different colors and sizes and cost estimation is as shown in Table 9.
Table 9 Cost of green building bamboo doors and windows and conventional building Burma/teak wood doors and windows

| Doors and windows | Common Quantity | Price/piece (avg) | Amount | Price/piece (avg) | Amount |
|-------------------|-----------------|-------------------|--------|-------------------|--------|
| Bamboo doors      | 20              | 21000             | 420000 | Burma wood doors  | 35000  |
| Bamboo window     | 48              | 15000             | 720000 | Teak wood window  | 18000  |
| Total amount      |                 |                   | 11,40,000/-|                | 15,64,000/-|

Table 9 shows the results are obtained from the calculation of the total cost of conventional doors and windows is INR 15,64,000/- and green doors and windows is INR 11,40,000/- and 27% of the total cost is decreased in Kota flooring with respect to conventional.

2.3.6. Alternative paints

Low VOC paints are those that contain less VOC (Volatile Organic Compounds) or VOC Solvents than traditional coatings. The VOC solvents act to slow the initial drying by maintaining a “wet-edge” which gives a longer time to work with the product, so to overcome this application methods will also need to be altered to achieve the best finish[6]. High levels of VOC solvents contribute to the formation of pollution and reduce the indoor air quality. In order to minimize the level of VOCs released during construction and to take care of occupant health from regular paints this low VOC paints are used and its cost estimation is as shown in table 10.

Table 10 Cost of internal and external wall painting

| Conventional Building | Green Building |
|-----------------------|----------------|
| Internal painting INR.3,25,913.64/- | Internal painting INR.3,42,683.65/- |
| External painting INR.123435.08/- | External painting INR.446,14/- |
| Total cost. INR 4,49,348.7/- | Total cost. INR 7,88,829.65/- |

Table 10 shows the results are obtained from the calculation of the total cost of conventional paints is INR 4,49,348.7/- and green paints is INR 7,88,829.65/- and 44% of the total cost is increased in low VOC paints with respect to conventional paints.

3. Results and Discussion:

Selection and adoption of sustainable materials to the selected conventional residential building is re-calculated as per the current SR-Book (standard procedures and rates). It is found that locally available sustainable materials can solve the problem of embodied energy, carbon emission and costs where the harmful impact on the environment can be reduced. The following shows the results of the analysis for the conventional with respect to sustainable green building in aspect of cost, embodied energy and carbon footprint.
Figure (2) Cost comparisons between conventional and green building of selected materials

The cost between the conventional building and sustainable green building of selected materials is as shown in above Figure 2, where the graphs representations are based on the cost calculations of each selected material either conventional materials or green materials as shown in the tables of cost calculation of materials.

The cost calculation of the building blocks are as mentioned in the Table 3, where the calculation is done using the quantities (units are as per cubic meter) and overall cost of the building blocks of conventional and green buildings, where the Figure 2 shows the green building block work of 150mm block work is 39% lesser in price than conventional, similarly in 100mm block work 45% is lesser.

The cost calculation of the normal slab and filler slab is mentioned in the Table 7, where the calculation is done using the quantities (of cement, fine aggregate, coarse aggregate steel and hollow roof slab) and overall cost of the slab of conventional and green buildings, where the Figure 2 shows that green building filler slab is 32% lesser in price than conventional normal slab.

The cost calculation of the flooring material is as mentioned in the Table 8, where the calculation is done using the quantities (of cement, fine aggregate, coarse aggregate steel and hollow roof slab) and overall cost of the filler slab of conventional and green buildings, where the Figure 2 shows that green building filler slab is 40% lesser in price than conventional flooring.

The cost calculation of the doors and windows materials are as mentioned in the Table 8, where the calculation is done using the quantities (units in numbers) and overall cost of the doors and windows of conventional and green buildings, where the Figure 2 shows that green building bamboo doors and windows is 28% lesser in price than conventional Burma/teak wood.

The cost calculation of the wall paints is as mentioned in the Table 10, where the calculation is done using the quantities and overall cost of the normal paint of conventional and low VOC paints of green buildings, where the Figure 2 shows that green building low VOC paint is 22% greater in price than conventional normal paints.
Figure (3) Comparison of embodied energy and carbon footprint of conventional slab and filler slab

The embodied energy and carbon footprint comparison between conventional slab and fillers slab of both the conventional and sustainable green building are as mentioned in the Table 5 and 6, where the Figure 3 is the graph representation of embodied energy and carbon footprint comparison is as shown.

After the selection of necessary sustainable materials, estimating the quantities and its rate analysis are prepared and comparison graphs are represented and an abstract of green building is considered at every stage of work like excavation, PCC, plastering, RCC, flooring, painting and etc. In overall cost estimation comparison between Conventional building and Sustainable green building, and its difference is Rs.19,48,685/- that is 15.2% lesser cost after its complete estimation. In overall cost estimation comparison between Conventional building and Sustainable green building, and its difference is Rs.19,48,685/- that is 15.2% lesser cost after its complete estimation.

Figure (4) Total cost comparison between sustainable green building and conventional building.

Embodied energy calculation of complete building is calculated by considering the energy embodied in MJ of each work at each stage as shown in Table 11. For this considering embodied energy of each material is necessary. Embodied energy calculation of conventional building at each stage and every by considering embodied energy of each material of entire work.

Embodied energy and carbon foot print comparison between the sustainable green building and the conventional building. And the graph is as per the calculation.
Table 11 Embodied energy calculations

| Particulars                                      | Embodied energy of conventional building (in MJ/Unit) | Embodied energy of green building (in MJ/Unit) |
|-------------------------------------------------|------------------------------------------------------|---------------------------------------------|
| PCC                                             | 30642.26                                             | 29817.76                                   |
| RCC of slab, column, beam, footing, Cheju, lintels & stairs | 34626.98                                             | 33856.48                                   |
| Painting                                        | 107712.5                                             | 30445                                      |
| Block work                                      | 351605.8                                             | 219999.4                                   |
| Excavation                                      | 345375.8                                             | 213529.4                                   |
| Plastering                                      | 184600.1                                             | 184243.7                                   |
| **Total**                                       | **869963.34**                                        | **527648.04**                              |

Figure (5) Total embodied comparison between sustainable green building and conventional building.

The calculated embodied energy data of each item in MJ/unit of the conventional building and sustainable green building is shown in figure (9), where total embodied energy of conventional building is 869963.34 MJ/unit and sustainable green building is 527648.04 MJ/units, where the difference is 342315.3 MJ/units, sustainable green building is 40% lesser in consumption of embodied energy.
Table 12 Carbon footprint calculations

| Particulars      | Carbon footprint of Conventional building (CO₂/kg) | Carbon footprint of Sustainable building (CO₂/kg) |
|------------------|---------------------------------------------------|-------------------------------------------------|
| Reinforcement    | 387800.000                                        | 387800.000                                      |
| Steel            | 1053346.875                                       | 561122.94                                       |
| Concrete         | 267730.800                                        | 97032.496                                       |
| Blocks 4 inch    | 115751.160                                        | 36981.048                                       |
| Blocks 6 inch    | 56006.280                                         | 11724.526                                       |
| Plastering       | 72771.000                                         | 24644.730                                       |
| Flooring         | 316798.400                                        | 138599.30                                       |
| External Cement  | 455738.400                                        | 455738.400                                      |
| Plastering       | 14859.000                                         | 14859.000                                       |
| External Painting| 282.88                                            | 216.32                                           |

The calculated carbon footprint data of each item in CO₂/kg of the conventional building and sustainable green building is shown in Table 11.

Figure (6) Total carbon footprint comparison between sustainable green building and conventional building.

From the results presented in above graphs, it can be observed that the sustainable green building is holds good in every comparison than the conventional building. Where here in graph each and every particulars of construction stage has lesser carbon footprint due to the less carbon footprint of each selected alternative building material like kota stone, mine waste bricks, bamboo materials, low VOC paints etc.

4. Conclusion.

1. The building block from the mine waste is 35% to 45% less in price compared to conventional clay brick.
2. The filler slab tiles has reduced the 25% of concrete consumption in slab construction in every floors and also cost is reduced 32% lesser than conventional building slab.
3. In flooring, Kota stone marble and granite finish flooring cost is 40% lesser than conventional flooring and also looks similar.
4. The Bamboo doors and windows cost is 28% lesser than Burma/Teak wood and suits to say sustainably green.

5. Low VOC paint and another partial external elevation and wall painting is replaced by Green wall (vertical gardening) which cost is 22% greater than conventional building wall painting.

6. Overall construction cost is also 15.2% lesser than conventional as per the abstract between re-estimated conventional building and the sustainable green building.

7. The overall building carbon footprint and the embodied energy is 39.3% of sustainable green building is lesser than the conventional one.

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