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# SUSTAINABILITY DEVELOPMENT INDEX (SDI) FOR TALLER BUILDINGS

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## Abstract

The metropolitan area requires multistory buildings. Building materials are plentiful. A building must always have energy. is a term for high-rise buildings that use a lot of energy. The figure of merit measures tall buildings' embodied energy (FoM). The FOM parameter ZC takes into account the material's elasticity, density, unit cost, and cost per unit area. Using the FoM equation and other energy indicators, such as embodied energy, CO2e, and transport energy, dimensionless interaction values are produced. $I_1$ to $I_3$ Embedded energy and global warming; embodied energy and building materials FoM can be used to measure the environmental impact of building materials throughout planning and construction by computing the Sustainability Development Index (SDI). This study creates a sustainable development-based material sustainability index.

**Keywords**: EE, tall buildings, ecologicalimpact, FoM, GHG emissions, SDI, building materials

## 1. Introduction

According to the 2011 Indian census, 31.5% of India's 1.21 billion inhabitants reside in urban areas, and this percentage will approach 50% by 2030. Between 2015 and 2030, urbanisation is anticipated to grow at 2.1%, roughly double China's average. JLL's Economic Survey 2015-16 of India shows a 20 million-home shortfall in India. The survey finds that 95% of the urban housing shortage in the country is caused by the EWS and LIG. Migration from rural to urban areas will increase land costs and reduce the availability of large areas for construction According to migration studies in India, urbanisation is limited to a few high-rise cities in India. High rises can fit on small lots. High-rise construction must maximise land, energy, and natural resources. With new design construction technology and growing real estate demand, high-rise structures offer superior living conditions at accessible prices. Many countries outside of this investigation are also building supertall and megatall skyscrapers.

Towering structures' energy usage and footprint differ from low-rise structures'. These challenges must be addressed with structural loads and systems while conservation and sustainability are prioritised. According to a 1987 WCED study, developing a sustainable environment entails considering both present and future generations' needs. This can be done by managing existing natural resources, using low-energy materials, using energy-efficient building methods and technologies, and implementing eco-friendly design ideas. These measures help all four building lifecycle stages. Building automation can save energy during a building's operation. Sustainable development must meet four goals simultaneously, according to Tall Buildings and Sustainability **(Pank, &Girardet, 2002),** and learn that progress entails fulfilling everyone's needs. Renewable energy, economic growth and environmental protection

### 1.1 Tall Structures

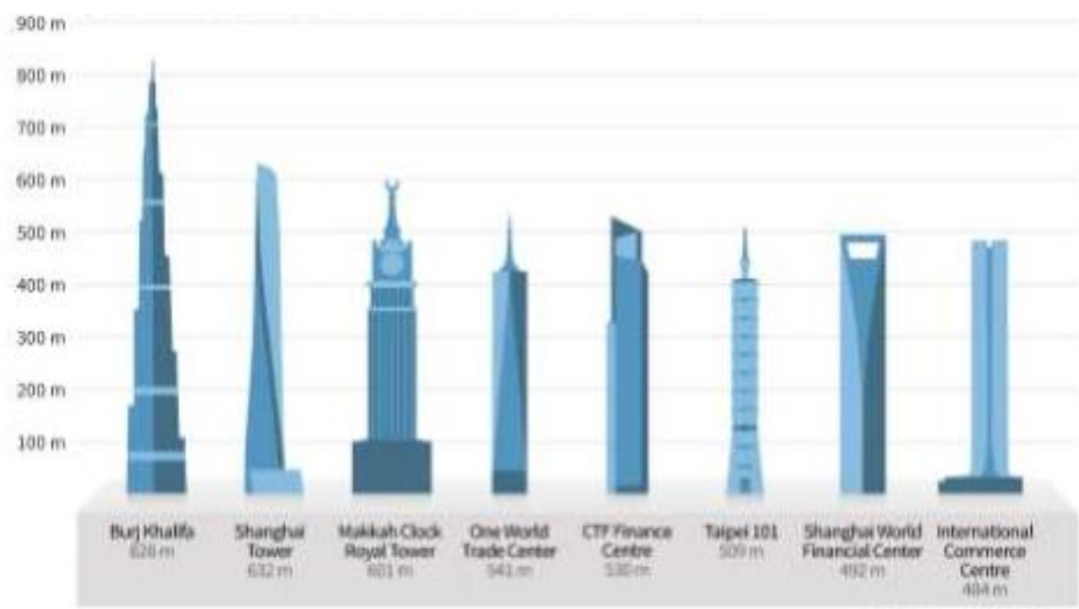


Figure 1: Height comparisons of the world's highest structures (emporis.com)

"Tall buildings" aren't uniformly defined. According to the Council on Tall Buildings and Urban Habitat (CTBUH), a building's "tallness" is determined by its height, proportion, and technology. A tall building has 14 floors or is at least 50 metres tall, although this is not enough. Supertall constructions are over 300 metres, and megatall structures are over 600 metres. Skyscrapers are over 100 metres tall, while high-rise buildings are 35–100 metres. Modern attempts to categorise skyscrapers by fire safety criteria are sensible. High-rise buildings are those with more than 10 floors, because fire vehicles can't reach them. The 2015 edition of India's National Structure Code (NBC) defines height limitations based on the width of the road in front of the structure, its floor space to total area ratio, and local fire department regulations. In this study, we focus on buildings over 100 m tall **(Knoke 2006)**

Table 1- Tall buildings height criterion

| CATEGORY | HEIGHT | UNIT | CRITERIA |
|---|---|---|---|
| Mega Tall | $> 600$ | meters | CTBUH |
| Super Tall | $300 - 599$ | meters | CTBUH |
| Skyscraper | $> 100$ | meters | Emporis |
| High-Rise | $35 - 100$ | meters | Emporis |

**1.2 Indian scenario**

According to the Council on Tall Buildings and Urban Habitat, India registered 130 13-to-60-story buildings in 2016. (CTBUH). Only 2 of these 130 constructions are over 250 metres, 32% are between 150 and 250 metres, 49% are between 100 and 150 metres, and 20% are between 60 and 100 metres. Most are in Mumbai. According to the CTBUH list, practically all buildings use concrete. In this essay, we assume comparable trends exist in India and that structures under 150 metres employ concrete as their principal structural element according to **(Heinonen et al,2016)**most research has concentrated on energy usage during a building's operational-maintenance phase, leading to energy-efficient techniques to reduce GHG emissions.**(Saynajoki et al.2012)**Construction emissions arise in a shorter time period and are more destructive than operation pollutants**(Hong et al 2015)** use a case study of Chinese structures to show that the construction industry contributes significantly to GHG emissions and global warming. The construction industry consumes 40% of global energy and emits 25% of global $CO_2$. Between 1999 and 2004, global $CO_2$ emissions from building construction rose 2.7% annually. Due to the complexity of the building phase (material extraction, processing, manufacture, transportation, and implementation), assessing energy impact on the natural environment is difficult. An integrated evaluation tool is needed to measure sustainability levels during the design stage. We may recommend more sustainable materials based on this study to reduce carbon emissions **(Ignacio et al 2011)**. According to their examination of 60 buildings in 9 nations, frame materials account for roughly half of a building's embodied energy. To reduce a building's overall embodied energy, use low-embodied-energy, high-recyclability materials. Recycled steel and aluminum can cut embodied energy in half **(Reddy and Jagadish,2003)**

**Role of embodied energy (EE)**

Cradle-to-cradle analysis considers the full life cycle of a structure, from its inception to its eventual demise. The total amount of energy expended over a structure's entire life cycle is the sum of its embodied, transport, operational, and destruction components. Embodied energy includes both direct and indirect forms of energy. "Direct energy" refers to the energy required in the construction itself, as well as in the installation of temporary structures like formwork, the prefabrication of components, their assembly on-site, their movement around the site, and the administration of the site. Direct energies do not include the initial and total embodied energies. Embodied energy is the sum of all energy inputs and outputs during the production process. Renovation and maintenance need "recurrent energy." Demolition plus debris disposal equals total demolition energy.

This presentation analyses how to quantify high-rise structures' energy implications using the 'Figure of Merit' (FoM). The FoM parameter represented as ZC takes into account the modulus of elasticity and density of building materials, two key engineering characteristics.

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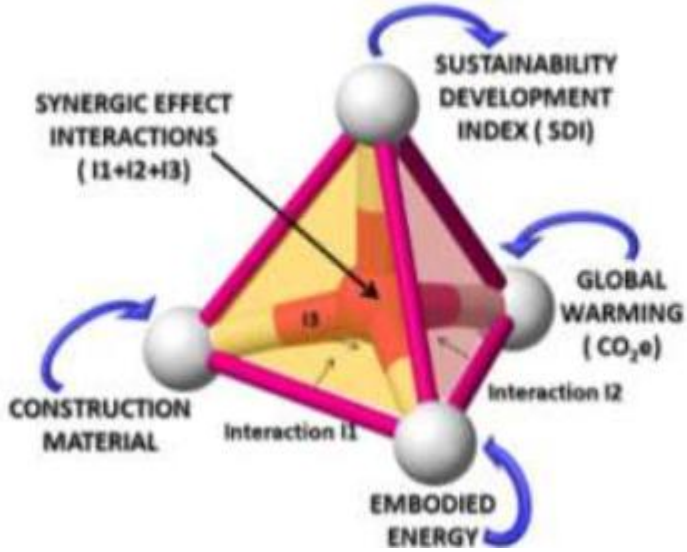


Figure1.2: SDI 3d Model (Tetrahedron Model)

This research aims to provide a FoM-based Sustainability Development Index to evaluate a construction or infrastructure project's sustainability. Sustainability percentage is used to express SDI.

$$Z_C = \frac{E}{\rho} \times C_m \times \frac{1}{C_a} \ldots\ldots\ldots\ldots\ldots\ 1$$

Where;

$E =$ Modulus of Elasticity in $Kg/m2$

$\rho =$ Density of material in $Kg/m3$

$C_m =$ Cost of material in INR $/m3$

$C_a =$ Cost of construction per square meter in INR

The standard data table range for E, the current unit cost of building materials, and the cost of construction per square foot were plugged into the aforementioned Equation 1 to arrive at FoM values for some of the most essential construction materials used in Indian contexts. Information is available in Table 1.2.

**Interaction equations**

While determining Interaction Values, four function formats were considered namely, normal, square root, cube root and fourth root. Magnitudes of interaction values were found to be too large or too low under normal, cube root and fourth root computations. Hence, three interaction equations (I1, I2 and I3) are represented as square root functions as 1.2, 1.3 and 1.4.

$$I_1 = \sqrt{\phantom{x}}(Z_C \times E_C \times TE_C) \ldots \ldots \ldots .1.2$$
$$I_2 = \sqrt{(Z_C \times EC_C \times TE_C \times \mu)} \ldots \ldots ..1.3$$
$$I_3 = \sqrt{\phantom{x}}(Z_C \times E_C \times EC_C \times TE_C) \ldots \ldots 1.4$$

Where; $I_1, I_2, I_3$ are Non-dimensional Interaction Values, $EE_C =$ Embodied Energy Co.

**Methodology**

The goal of creating $Z_C$, for different building materials is to evaluate their viability from a sustainable supply chain standpoint and fully integrate it alongside other environment like carbon intensity (EE), factors that are associated (EC), rising temperatures, engineering era, GHG, and mass transit energy, as well as create contact formulas. By means of an exclusive index called ASP-SDI presented in percentages, interactive equilibria (IE) created using FoM as a tool allow us to evaluate the exist in any phase in architecture and building development. A rigorous architecture job evaluation follows the logical analysis of sustainably levels during the preuse era, which will in turn results in friendly systems engineering. Only the calculation of FoM is covered in this Chapter since the development of the Figure of Performance solution is discussed in.

**FoM Computation**

Using Equation 1 study technique, the calculated and exhibited Start figuring of Merit (FoM) for certain fundamental concrete structures and assemblies under the Metal, Tiles, and Hybrid resource divisions is shown. The spread of Anti - anti from common data sets, the current unit cost of building materials, and the construction expense each unit region in Indian metro cities are all taken into consideration while computing the FoM numbers. According to data gathered from developers and builders of current buildings in Delhi, India, it is projected that the construction cost per unit volume of a finished making would be in the range of INR 20000-50000 (US $ 335-850) every sq foot.

Table 1.2 Figure of Merit (ZC) Values of Construction Materials

| Material | Density Kg/m3 | E (MOE) GPA | | Cm x 103 Cost / m3 | Ca x 103 Constn.Cost / m2 | | Zc x 106 x 10-6 FoM | | MEAN Z |
|---|---|---|---|---|---|---|---|---|---|
| | | Low | High | | Low | High | Low | High | |
| **Metals** | | | | | | | | | |
| Low Car-bon steel | 7800 | 200.0 | 215.0 | 312.00 | 20.0 | 50.0 | 16.31 | 43.83 | 30.07 |
| Structural Steel | 7800 | 200.0 | 215.0 | 468.00 | 20.0 | 50.0 | 24.46 | 65.75 | 45.11 |
| Aluminium | 2700 | 68.0 | 82.0 | 567.00 | 20.0 | 50.0 | 29.11 | 87.77 | 58.44 |
| Brass | 8500 | 110.0 | 120.0 | 2975.00 | 20.0 | 50.0 | 78.49 | 214.07 | 146.28 |
| Stainless steel(304 grade) | 8000 | 189.0 | 210.0 | 1800.00 | 20.0 | 50.0 | 86.70 | 240.83 | 163.76 |
| **Polymers** | | | | | | | | | |
| Polythelene(HDPE) | 960 0 | 6 0.9 | 215.0 | 115.20 | 20.0 | 50.0 | 0.15 | 0.53 | 0.34 |
| Polypropyline | 910 | 0.9 | 1.6 | 136.50 | 20.0 | 50.0 | 0.28 | 1.19 | 0.73 |
| PVC | 1580 | 2.1 | 4.1 | 252.80 | 20.0 | 50.0 | 0.70 | 3.38 | 2.04 |
| Polycarbonate | 1210 | 0.2 | 0.2 | 411.40 | 20.0 | 50.0 | 0.14 | 0.42 | 0.28 |
| Epoxy 20.0 50.0 | 1400 | 2.4 | 3.1 | 1120.00 | 20.0 | 50.0 | 3.83 | 12.56 | 8.20 |
| **Ceramics** | | | | | | | | | |
| CSEB | 1850 | 7.0 | 10.0 | 2.75 | 20.0 | 50.0 | 0.02 | 0.08 | 0.05 |
| Stone (Hard) | 2880 | 35.0 | 50.0 | 2.24 | 20.0 | 50.0 | 0.06 | 0.20 | 0.13 |
| Bricks in Clay 1st | 2080 | 10.0 | 50.0 | 6.00 | 20.0 | 50.0 | 0.06 | 0.74 | 0.40 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Qlty | | | | | | | | | |
| Cement tiles | 2200 | 10.0 | 50.0 | 41.60 | 20.0 | 50.0 | 0.39 | 4.82 | 2.60 |
| Concrete | 2400 | 15.0 | 25.0 | 5.00 | 20.0 | 50.0 | 0.06 | 0.27 | 0.16 |
| Solid Concrete Blocks 20.0 50.0 | 1800 | 15.0 | 25.0 | 3.12 | 20.0 | 50.0 | 0.05 | 0.22 | 0.14 |
| AAC Concrete Blocks | 760 | 15.0 | 25.0 | 4.17 | 20.0 | 50.0 | 0.17 | 0.70 | 0.43 |
| Cement Mortar wet | 1900 | 2.0 | 3.0 | 33.30 | 20.0 | 50.0 | 0.07 | 0.27 | 0.17 |
| Granite (Polished) | 2880 | 50.0 | 60.0 | 107.60 | 20.0 | 50.0 | 3.81 | 11.43 | 7.62 |
| Sand stone | 2200 | 25.0 | 40.0 | 25.00 | 20.0 | 50.0 | 0.58 | 2.32 | 1.45 |
| Marble | 2500 | 60.0 | 80.0 | 134.50 | 20.0 | 50.0 | 6.58 | 21.94 | 14.26 |
| Glass(Soda-lime) | 2500 | 68.0 | 72.0 | 134.50 | 20.0 | 50.0 | 7.46 | 19.74 | 13.60 |
| Ceramic Tiles Dry | 2000 | 350.0 | 400.0 | 64.56 | 20.0 | 50.0 | 23.03 | 65.81 | 44.42 |
| **Hybrids** | | | | | | | | | |
| Gypsum Plaster Boards | 800 | 1.5 | 3.5 | 157.00 | 20.0 | 50.0 | 0.60 | 3.50 | 2.05 |
| MDF | 500 | 2.0 | 4.0 | 62.50 | 20.0 | 50.0 | 0.51 | 2.55 | 1.53 |
| Teakwood or equivalent | 550 | 8.4 | 10.3 | 106.00 | 20.0 | 50.0 | 3.30 | 10.12 | 6.71 |
| Plywood | 700 | 6.9 | 13.0 | 104.00 | 20.0 | 50.0 | 2.09 | 9.84 | 5.97 |
| Hard Wood | 940 | 20.6 | 25.2 | 55.00 | 20.0 | 50.0 | 2.46 | 7.52 | 4.99 |

Table 1.2, tabulates range values of material density, modulus of elasticity, cost of construction per unit area, cost of material as available in the market per unit volume. Substituting these values in FoM equation 1, we obtain range of values for Figure of Merit. Thus, from Table 1.2 and from FoM perspective, metals have high $Z_C$ values as compared to materials under ceramic and hybrid categories. Among metals, low carbon steel exhibits lowest FoM value and hence most suitable as construction material. Materials like compressed stabilized earth blocks show zero mean FoM value implying negligible magnitude.

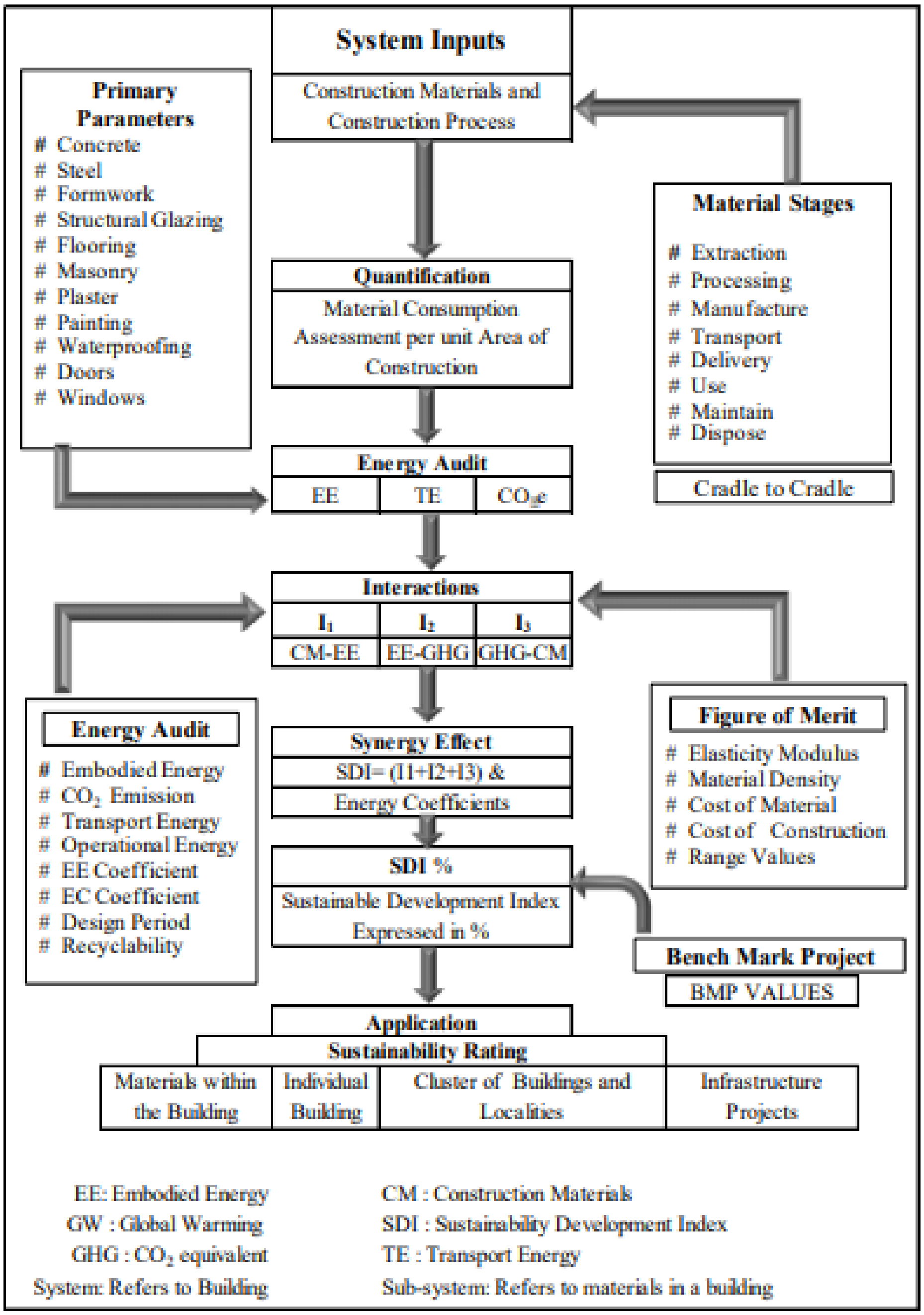


**Figure 1.3:** ASP-SDI Model

Figure 1.3 explains different stages involved in the computation of three interaction equations leading to ASP-Sustainability Development Index..

**Results**

Urbanization and industrialization have created increased structures necessary in metropolitan settings. Therefore, a multi-story structure is used as the Evocative Project to demonstrate the usefulness of the ASP-SDI concept (IP). A thorough investigation was done on a home construction project that had already been finished in Mysore, India. Karnataka is 920 metres above mean sea level and has a warm, humid climate including a current temperature range of 14 to 39 degrees mercury. According to the 2016 Indian estimate, it contains an approximate population of 11.5 market is projected to approach 200 million by 2025. It is located at latitudes 12.97°Longitudes 77.56°E. The key IP characteristics are shown in Table 1.3.

**Table 1.3:** Salient Features of Illustrative Project (IP)

| FEATURES | SPECIFICATIONS |
|---|---|
| Type of Project | Residential Apartment |
| Area of Construction | 25076 $m^2$ (super built-up area) |
| Number of Floors | 18 |
| Floor height | 3.0 m (Average) |
| Structure Type | RCC Frame |
| External Walls | Solid Concrete Blocks (400x400x200) mm |
| Internal Walls | Solid Concrete Blocks (400x150x200) mm |
| Doors | Wooden Frames with Flush door shutters |
| Windows | UPVC windows with plain single glass shutters |
| Water Proofing | Roof, Exposed balconies, treated with Membrane type and protective laye of screed or tiles. |
| Flooring | Toilet water proofing as above + crystalline method for RCC slab. Flooring Combination of Natural stones, Vitrified and Glazed tiles of varying size |
| Formwork | Conventional type with steel floor plates, adjustable props and spans, wood for primary and secondary supporting joists, ply for beam sides |

The Emotionally evocative Projects (IP) was developed as an element rate contract, the project was completed also with assistance of various entities. The project sits in a bustling neighbourhood with convenient entry to a markets, a mrt station, schools and universities, and entertainment centres, making it a real representation of such urban environment. The platform gives its buyers the chance to move in immediately. The discourse of SDI is only applicable to processes involving civil infrastructure. Statistics have now been adjusted per square metre of ultra region for comparability purposes. The processes for calculating the SDI are as under. Embodied energy and Embodied carbon evaluated for IP are based on actual bill of quantities and stipulated specifications.

**Step 1:** Computation of FoM Computation of Figure of Merit (FoM) is described in section

**Step 2:** Calculating Involved Energie (EE) According to the actual amount of work completed based on the bills of quantities, IP's entire EE consumption per sqm is calculated. the variety of work categories in the BOQ are categorised into 10 major categories.

**Table 1.4:** Total EE and Carbon per Square me-
ter

| Primary Parameters | EE (MJ) | $kgCO_2e$ |
|---|---|---|
| Concrete works | 2724.74 | 285.99 |
| Steel works | 1120.33 | 93.44 |
| Block masonry | 181.09 | 19.69 |
| Plastering | 148.95 | 10.87 |
| Doors | 36.31 | 4.04 |
| UPVC Windows | 179.29 | 9.75 |
| Flooring | 157.40 | 10.65 |
| Painting | 39.24 | 3.59 |
| Formwork conventional | 595.40 | 47.92 |
| Water Proofing | 2.98 | 0.83 |
| Total $/m^2$ | 5185.73 | 486.77 |

Using material density and an inventory-based EE rate, EE for sq foot is calculated. As an estimate, the actual number of transverse reinforcement utilised in the IP as stated in the BOQ is 986000 kg. Material should weigh about 39.32 kg/m2 according to the total length of 25076 sqm. We calculate the EE for steel inside this IP as 849.33 MJ by adding up the average amount of such best range EE index from steel (21.60 MJ/kg) as well as steel a sqm. These calculations provide a 271 MJ EE values per sq.m for stainless components. The total of these two figures, 849.33+271=1120.33 MJ, is shown for steel mill in Desk 4.2. As a result, the overall EE per sqm is in the range of 5185.73 MJ.

It may be deduced from Table ii and from the perspectives of EE and Eg that ordinary fixture, steel, and steel have a significant influence. Doors and walls, drainage, and painting have a small effect, but stone building, drywall, UPVC (UV resistant PVC) glazing, and parquet have a moderate effects. According to Figure 1.4, pavement, rebar, steel falsework respectively provide around 53%, 22%, and 11% of the total impact.

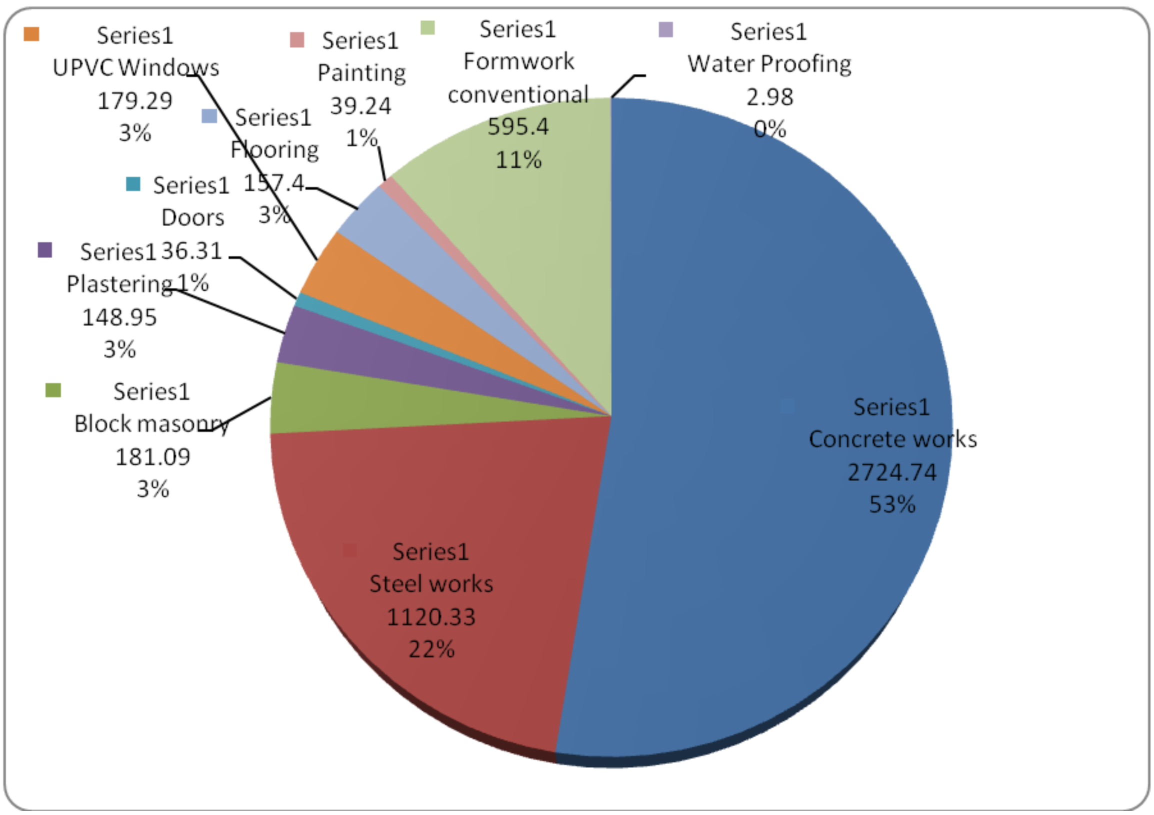


**Figure 1.4:** EE Distribution per Square meter

**Conclusion**

Most current approaches to evaluating materials' sustainability are criterion-based, overlooking vital technical aspects. Growing populations necessitate expanding infrastructure, which in turn requires a lot of resources. Prudent use of raw materials, decreased energy consumption throughout the life cycle of buildings through the application of scientifically reliable measures, and procedures are urgently needed. Only considering a building's embodied energy use is insufficient for making a determination on its overall sustainable performance. It is proposed to create a tool that takes into account energy factors, critical material qualities, and the lifespan of materials. All industry participants can benefit from the new ASP-SDI sustainability development index by making adjustments to their designs that will result in greener buildings with smaller carbon footprints. The process allows the designer to lessen the building's energy footprint before construction even begins. This can be accomplished through a variety of means, including the use of low-energy alternatives, the investigation of locally-accessible resources, the prevention of unnecessary waste, the acceptance of recyclable materials, the introduction of cutting-edge construction techniques, and the adoption of the right decisions. The current analysis concludes that more SDI% for a given individual parameter indicates a greater interaction value and, thus, less sustainability supplied by the given parameter. Its goal is to implement different materials and methods to lower the interaction value of a building's system..

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