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Retraction

Retracted: Environmental Impact and Carbon Footprint Assessment of Sustainable Buildings: An Experimental Investigation

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] N. D. K. R. Chukka, A. Arivumangai, S. Kumar et al., "Environmental Impact and Carbon Footprint Assessment of Sustainable Buildings: An Experimental Investigation," *Adsorption Science & Technology*, vol. 2022, Article ID 8130180, 8 pages, 2022.

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Research Article

Environmental Impact and Carbon Footprint Assessment of Sustainable Buildings: An Experimental Investigation

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Carbon emission has been considerably higher in India in the last few decades. The greenhouse gases increased to an imaginary volume, a major contributor to global warming. Chennai is one of India's large cosmopolitan cities, contributing more Gross Domestic Product (G.D.P.) and carbon to the atmosphere. The infrastructure sector is always a booming sector in and around Chennai, which requires more construction materials. In turn, the construction of new buildings expands the city with a large area of urban and suburban Chennai, where I.T. division, automobile division, and industrial estates are available. Hence, this study deals with the carbon emission of a residential building constructed with conventional materials in and around Chennai. So, one can estimate the emission of carbon by the conventional building, which leads to global warming and climate change.

1. Introduction

The main reason for climate change and global warming is the increase in carbon emissions [1]. The entire world contributes to the carbon emission of greenhouse gases, which causes a rise in the earth's temperature after the boom of the automobile sector and I.T. sector [2]. The economy and G.D.P. increased, which led the construction industry to grow; as a result, the manufacturing of materials used in construction increased drastically by volume [3]. In recent years, the green building concept and usage of recycled materials have increased slowly. But these alternate materials have to be utilized in full-fledged practice [4]. The construction industry in the infrastructure sector does not contribute to the direct emissions. Still, they consume many different products that have to be manufactured and assembled to erect a building [5]. So, the construction industry has a major role in contributing to indirect CO_2 pollution [6]. The dependent variables identified are the amount of paper, glass, metal, organic, and plastic waste and the corresponding footprint values. The independent variables are season, location concerning Central Business District (CBD)/Major

Transportation Node (M.T.N.), population density (Popln density), household size (H.H. size), household income (H.H. income), waste disposal, housing unit, and ownership. The independent variables consist of different types/classes. The construction industry in India releases 22% of the emission of CO_2; 80% of the materials are like cement, steel, bricks [7] and polyvinylchloride which are used in tonnes of tonnes, which makes the quantity of CO_2 emission comparatively higher volume than other few materials [8]. From 1989 onwards, the consumption of material utilization is being increased 2.4% annually; in recent years, this peaked to 3.7% as well, before COVID-19 lockdown in India.

In the recent climate change summit 2021, India assured to reduce its CO_2 emission before 2070. But few countries have started their net-zero emission techniques [9]. There is a need to find and use low carbon footprint materials in buildings [10]. The total carbon emission in buildings is classified into embedded carbon and operational carbon emissions [11]. This embedded carbon emission is represented as emission by the material used in construction; operational emissions are produced by the activities of a human consuming the electricity by using home appliances [12]. The metal, organic, and plastic waste generation in the base year showed that the waste generation in locations near CBD/MTN is more when compared to generation in locations away from CBD/MTN. It can be attributed to the overconsumption of the people living in the CBD areas and the dependency on readymade goods and fast foods. The parity check showed no compatibility in the case of these wastes [13]. The paper waste generation in the years 2011 and 2013 showed similar variations. In these years, the generation of paper waste showed that the generation is more in locations near CBD/MTN when compared to the generation in locations away from CBD/MTN. The parity check also shows no compatibility between the waste generations in the two locations [14]. In embedded carbon, the role of emission is huge and should be controlled before the construction of the building, because if once used, the materials in the building may not be easy to replace with low carbon materials [15]. But the operational emission can be controlled daily [16], with newer products and best energy-saving practices [17]. This research study deals with the carbon emission of a residential building constructed with conventional materials available in and around Chennai.

1.1. Life Cycle Assessment of Materials. Life cycle assessment (L.C.A.) is the best tool for accessing the environmental impacts along the life cycle of construction materials. There are many software tools available to find the CO_2 emissions [18]. In India, the researchers assessed the carbon emission of embodied materials as 748.759 kg of CO_2 equivalent [19] and the electricity consumption around 4266.150 kg of CO_2 equivalent [20]. So, suppose one wants to reduce the carbon emission overall. In that case, it is necessary to use sustainable or less carbon-emitting materials as embodied materials [21]. The power consumption over the operational activities will be reduced by emitting less carbon during the building's life [22].

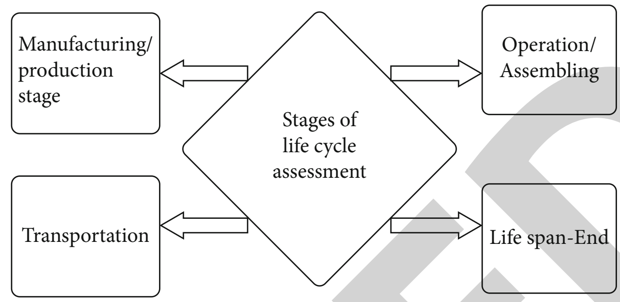

Figure 1: Stages of life cycle assessment.

2. Methodology

The material life cycle assessment has many stages, as shown in Figure 1.

2.1. Building Information. Recently, a residential building was constructed in Chennai with conventional materials. The building has two floors; each floor has 90 m^2 with paved setback area and wall fencing for 1.6 m height [23]. It has a hall (3 × 6 m), master bedroom (3 × 4 m), bedroom (3 × 3 m), pooja room (3 × 2 m), kitchen (3 × 4 m), and toilet bathroom (2 × 2.5 m). Chennai has a warm and humid climate with a maximum temperature of 42°C in summer and 22°C in winter as the lowest temperature [24].

Life cycle assessments of materials and activities are calculated manually [25]. Calculating the total carbon emission of a building has four important stages: material production, material transportation, construction on site, and vehicle emission. Material production has the emission for production of materials, transportation has the emission of vehicle emission (fuel emission), and operational stage has lighting, water pumps, and travelling of workers (own vehicle or large vehicle, minivan, etc.) [26]. Hence, to find the life cycle assessment of materials, it is derived from the existing data concerning the production emission and emission from the transportation of vehicles. Starting from the excavation for foundation, done by excavation machine, materials transported from various resource places through vehicles and transportation availed by workers to travel considerable distances to the sites are the key contributors of carbon emission through their activities and carbon emission of materials [27].

So, calculation of the life cycle assessment of materials can be governed by an equation as follows:

$$C_{tot} = C_{con} + C_{mt} + C_{ope} + C_{work}. \quad (1)$$

C_{tot} represents total carbon emissions of all stages.

C_{con} represents carbon emissions at the construction stage.

C_{mt} represents carbon emissions at the transportation stage.

C_{ope} represents carbon emissions at the operational stage.

C_{work} represents carbon emissions of vehicles used by workers for travelling to the site.

Table 1: Common materials used and emissions in residential buildings.

S. no.	Materials used in this sample building	Unit	Emission factor (kg of CO_2/unit)
1	Cement	kg	0.95
2	Stainless steel bars	kg	5.457
3	Clay bricks	kg	0.327
4	Glass windows	kg	1.735
5	Power	kWh	0.7898
6	Copper pipes	kg	3.02
7	Plastic pipes	m	0.40
8	Electric wires	kg	2.84
9	Lighting fixtures	Set	35.65
10	Tiles (floor and wall)	m^2	18.33
11	Plywood	kg	0.61
12	Plaster board	Sheet	11.35
13	Ceramic (wall care putty)	kg	0.78
14	Welding rod	kg	20.5
15	Timber plates	m^3	383
16	Gravel	kg	0.00241
17	Alcohol	kg	0.828
18	Water	Litre	0.42
19	Concrete	m^3	480
20	Electricity	kWh	0.30-1.2

The average carbon footprint of each material used in construction buildings is listed in Table 1.

2.2. Construction Stage. This emission stage is calculated by multiplying the materials with carbon emission coefficients. The manufacturing sector produces a carbon footprint of each material consumed by buildings [28]. If these materials are extensively used, then the carbon footprint increases, so most essential materials with proper quantity estimation and wastage management are essential. In most residential works, civil engineers are avoided by stockholders and they take advices from masons, where the masons are not aware of the sustainability principles and waste the material; in some cases, masons order and consume more material and get a commission for rates from material suppliers [29].

The quantity of materials utilized for this residential building is mentioned below in Table 2. These quantities include the wastages and damages. It is the real-time consumption of materials.

Carbon emission at construction stage is calculated by

$$C_{\mathrm{con}} = C_{\mathrm{pu}} \times V_{\mathrm{mat}}, \tag{2}$$

where V_{mat} represents quantity of material and C_{pu} represents carbon emission coefficient.

The carbon emission of materials at the construction/production stage is estimated concerning the values from Table 3. Few values are converted from one measurement unit to another for calculation purposes.

Table 2: Materials with the quantity used in residential building.

Sl. no.	Materials	Quantity	Measurements in units
1	Burnt clay bricks	16400	Numbers
2	Cement	18813	kg
3	Steel bars	6476	kg
4	Timber wood	47	m^3
5	Glass	173.5	kg
6	Aluminium	27	kg
7	Vitrified tiles	478	m^2
8	Lighting fixtures	34	Numbers
9	PVC pipes	132	kg
10	Electrical wires	172	kg
11	Electrical switches	52	Numbers
12	Plumbing fittings	42	Numbers
13	Gravels fillers	65	m^3
14	Concrete	71.5	m^3

The variation of the footprint values of these wastes concerning seasons showed similar variations with that of the quantity of waste generation as explained above. The parity check of organic footprint values and plastic footprint values showed a similar trend as organic waste generation and plastic generation, respectively. The high quantity of waste generation in the festival season can be attributed to the purchase of new commodities and the reliance on packed food items in the festival season.

Hence, the total carbon emission in construction/manufacturing stage (C_{con}) is 125,692 kg of CO_2.

2.3. Material Transportation Stage. The material transportation stage is very important, which is a major contributor to carbon emission by vehicle emission [30]. If the transporting distance is long, the emission will be higher. In this case study, the transporting distance is around 40 km from the site where there are no other options to reduce this distance as the building is located inside the city premises [31]. Many materials are ordered in bulk with large suppliers to reduce the material cost like filler gravel soil (basement fillers), coarse aggregate, fine aggregate, steel, cement, and bricks which are the important materials transported a long distance from sources about 40 km.

The transportation stage carbon emissions are

$$C_{\mathrm{mt}} = C_{\mathrm{fuel}} \times V_{\mathrm{fuel}}, \tag{3}$$

where C_{mt} represents carbon emissions generated by material during transportation, C_{fuel} represents the coefficient of carbon emission of construction material hauling, and V_{fuel} represents the consumption of fuel in litres.

In Table 4, burnt brick, which was manufactured near the site with a distance of 9 km away from the construction site, was transported by a medium-duty vehicle in 6 trips. Cement was supplied by a supplier from a distance of 1 km from the site by mini truck vehicle in 8 trips. Materials steel, timber, glass, and aluminium were supplied by another

Table 3: Materials and carbon emission in the construction stage.

Sl. no.	Materials	Quantity	Measurements in units	Emission of CO_2 in kg
1	Burnt clay bricks	16400	Numbers	13,407.00
2	Cement	18813	kg	17872.00
3	Steel bars	6476	kg	32742.00
4	Timber wood	47	m^3	18000.00
5	Glass	43.5	kg	76.10
6	Aluminium	27	kg	36.00
7	Vitrified tiles	478	m^2	8761.50
8	Lighting fixtures	34	Numbers	606.50
9	PVC pipes	132	kg	15.04
10	Electrical wires	172	kg	489.00
11	Electrical switches	52	Numbers	24.60
12	Plumbing fittings	42	Numbers	12.00
13	Concrete	71.5	m^3	34320.00

Table 4: Transportation distance of the vehicle.

Sl. no.	Materials	Distance for transportation (to and fro)	No. of trips	Total distance travelled in km
1	Burnt clay bricks	18	6	108.00
2	Cement	2	8	16.00
3	Steel bars	0.3	5	1.50
4	Timber wood	0.3	5	1.50
5	Glass	0.3	5	1.50
6	Aluminium	0.3	5	1.50
7	Vitrified tiles	2	1	2.00
8	Lighting fixtures	0.6	5	3.00
9	PVC pipes	0.6	5	3.00
10	Electrical wires	0.6	5	3.00
11	Electrical witches	0.6	5	3.00
12	Plumbing fittings	0.6	5	3.00
13	Soil gravel fillers	40	7	280.00
14	Concrete	40	3	120.00

supplier from 300 m of distance, transported in four to five trips by a small truck; vitrified tiles were supplied by 2 km away supplier in a single trip by a truck vehicle; lighting fixtures, P.V.C. pipes, electrical switches, and plumbing fittings were supplied by a single supplier and transported by small vehicle in 4-5 trips with a distance of 600 m; soil gravel was tripped for seven times, and concrete was prepared in the site as per the requirement of the building element, so the coarse aggregate had two trips of 19 m^3 volume truck; the fine aggregate was supplied by 19 m^3 truck in one trip from 40 km away from the site.

2.3.1. Calculation for Vehicle Emission. Vehicle emission depends on the fuel type and efficiency of the vehicle. The vehicles used here are the diesel engine and light-duty vehicles (L.D.V.), medium-duty vehicles (MDV), and heavy-duty vehicles (HDV). Transportation distance and carbon emission are listed in Table 5. The mileage of light-duty vehicles is 15 kmpl, that of medium-duty vehicles is 4.5 kmpl, and that of heavy-duty is 3.5 kmpl. Carbon emission of diesel vehicles is 2.65 kg/litre of fuel [32].

Hence, the total CO_2 emission by the transportation of materials (C_{mt}) is 394 kg of CO_2 from the equation.

2.4. Operational Stage. This is the stage where all the materials are assembled to erect the building, like bricks with mortar, concrete, steel, and other fixtures. For assembling or erecting, the components of buildings need tools and devices which can be operated manually or mechanically [33]. Nowadays, manual working methods are reduced to construct the walls and plaster in residential buildings; mostly electrically operated machines mix mortar concrete, and water is lifted from the ground using pumps. The case study building is near a lake, so groundwater is available for utilization. In other places of Chennai, they have to purchase the water and transport to their site every day. Lights provide brightness inside the rooms where sunlight is insufficient to give proper brightness as the surrounding area was already constructed with 3-4 floors of residential apartments. Equipment like drills are used to put holes, cutters for cutting gutters in walls, and vibrators used to compact concrete [34].

The electricity consumed by electrical devices is represented as C_{op}.

$$C_{op} = C_{emi} \times TP_{cons} = C_{oa} + C_{wp} = \left(Q_{oa} + Q_{wp}\right) \times P_{cons}, \quad (4)$$

where C_{oa} is the carbon emissions emitted by lighting fixtures, C_{emi} is the carbon emission per unit of power (kWh), TP_{cons} is the total power consumption of all devices, C_{oa} is the carbon emissions emitted by drilling/cutting machines, C_{wp} is the carbon emissions emitted by water pump, Q_{oa} is the quantity of electricity consumed by lighting fixtures, Q_{wp} is the quantity of electricity consumed by water pump, and P_{cons} is the coefficient of carbon emission for electricity consumption.

As one could not get the exact power utilization of individual devices, the overall consumption is from the Tamil Nādu Electricity Board Electric meter. The total power consumption from starting to the end of the construction was calculated as 840.5 kWh as in Table 6.

Table 5: Transportation distance and carbon emission.

Sl. no.	Materials	Type of vehicle	Mileage	Consumption of fuel in litres	Emission of CO_2
1	Burnt clay bricks	HDV	3.5	31.0	82.150
2	Cement	MDV	5.5	3.0	8.000
3	Steel bars	MDV	5.5	0.3	0.800
4	Timber wood	LDV	15	0.1	0.265
5	Glass	LDV	15	0.1	0.265
6	Aluminium	LDV	15	0.1	0.265
7	Vitrified tiles	LDV	15	0.13	0.345
8	Lighting fixtures	LDV	15	0.2	0.530
9	PVC pipes	LDV	15	0.2	0.530
10	Electrical wires	LDV	15	0.2	0.530
11	Electrical switches	LDV	15	0.2	0.530
12	Plumbing fittings	LDV	15	0.2	0.530
13	Soil gravel fillers	HDV	3.5	80	208.000
14	Concrete	HDV	3.5	34.5	91.500

Table 6: Calculation of emission by electricity consumption.

Sl. no.	Materials	Consumption	CO_2 emission	Total emission by electricity utilization
1	Electricity	840.5 kWh	1 kg/ 1 kWh	840.5 kg

Chennai is powered by Ennore Thermal Power Station which is run by coal, so carbon emission by the coal thermal power station will be around 1 kg of CO_2 for 1 kWh of electricity.

For paper waste in 2010, the row housing units (RHU) generated more waste followed by houses in individual plots (H.I.P.), low-rise buildings (L.R.B.), and high-rise buildings (H.R.B.). The parity check of the paper generation trend showed that the H.I.P. showed parity with RHU; L.R.B. showed parity with H.I.P. and RHU; and the H.R.B. showed parity with L.R.B. The metal waste generation (2010) is more for L.R.B., followed by RHU, H.I.P., and H.R.B. The parity checks showed that H.I.P. shows parity with RHU; RHU show similarity with L.R.B.; and H.R.B. show parity with H.I.P. in the case of metal waste generation. The amount of organic waste tends to get generated more in H.R.B., followed by samples in RHU, L.R.B., and H.I.P. Parity checks show that the waste generation trend of H.I.P. shows parity with L.R.B. and H.R.B.; RHU with H.R.B.; L.R.B. with H.R.B. and RHU. The paper footprint is more for H.I.P., followed by L.R.B., RHU, and H.R.B. The parity check shows that the RHU show parity with H.I.P. and L.R.B. L.R.B. show parity with H.I.P. The metal footprint values and organic and plastic footprint values show the same trend of glass footprint. The parity check of organic footprint shows that the footprint values of RHU show parity with L.R.B.; H.R.B. show parity with H.I.P. The plastic footprint is more for H.I.P., followed by L.R.B., RHU, and H.R.B. The parity check of plastic footprint shows that the RHU show parity with H.I.P. and H.R.B.; L.R.B. show parity with H.I.P.; and H.R.B. shows parity with all the other three housing units.

2.5. Carbon Emission by the Vehicle Used by Labourers. There is a large carbon emission emitted by workers by using the vehicle for travelling from their places to site [35]. Labourers travel at least 5 to 40 km (both ways) each day in Chennai, and it depends upon the site and residing place. But individual residential building construction may have the local labourers around the site. In this case study, the labourers travel 7-8 km per day from their house to the site. Also, they use their vehicle as the site is situated interior from the main road for common transport accessibility [36]. Most construction workers use their vehicles to comfort them, even in fluctuating working time. The vehicles used by them are mostly 100 cc to 150 cc four-stroke bikes with the fuel efficiency of 55 kmpl to 35 kmpl, which in this case, the average fuel efficiency is 47 kmpl. The motor of the vehicles is BSIII standard vehicles. They had five vehicles, and some shared the same vehicle most of the time. The construction work took 90 days to complete all the works.

$$C_{\text{work}} = C_{\text{fuel}} \times V_{\text{fuel}}. \quad (5)$$

$V_{\text{fuel}} = (\text{total working days} \times \text{no.of vehicles each day} \times \text{distance travelled every day (to and fro)})/\text{mileage (average in city)}$.

C_{work} represents carbon emissions of vehicle (fuel) for travelling to the site.

C_{fuel} is the carbon emission per litre of fuel (petrol).

V_{fuel} is the volume of fuel used by the workers for travelling to the site.

Total distance covered in the working days is 90 days × 7.5 km × 5 vehicles = 3375 km.

So, the total fuel consumption (C_{work}) is 3375 km/47 kmpl = 71.08 l petrol.

$C_{\text{work}} = 2.3\ \text{kg/lit} \times 71.08\ \text{l} = 164\ \text{kg of } CO_2$.

The analysis over the years was done by curtailing the sample size to the minimum sample size in all the years. For this, the samples are selected at random. The pooled analysis has been done in a split plot manner. Since the samples are restricted to a minimum sample size, the means in the ANOVA for the years and that for pooled analysis will be different.

3. Results and Discussion

In this study, the residential building emits the quantity of carbon equivalent to the sum of manufacturing, transportation, construction, and personal vehicle emissions.

So, the total CO_2 emission is

$$\begin{aligned} C_{tot} &= C_{con} + C_{mt} + C_{ope} + C_{work} \\ &= 125{,}692\,\text{kg} + 394\,\text{kg} + 840.5\,\text{kg} + 164\,\text{kg} \\ &= 127{,}090.5\,\text{kg}\,CO_2. \end{aligned} \tag{6}$$

It is well known that building construction is a huge contributor to embodied energy and carbon emission production [37]. The understanding of this study implies the contribution of carbon to the environment in its entire life cycle of materials used in residential buildings. This building is a "sleeping volcano" of carbon; when its life span ends, all these embodied carbons will be released to the environment and the future generation will have to deal with it. The manufacturing of each material has exploitation of earth soil, surface and groundwater, and air, which was not created by humans and cannot be created by humans in the future. For example, if all hills and mountains are considered, those mountains and hills cannot be created for manufacturing sand. At the life end, these materials may end up in landfills or recycling which again exploits the land and environment. There are no effective large-scale recycling methods and procedures to deal with this issue in India.

The most important thing about microplastics here in the construction sector is the plastic pipes and other plastic items used, which produces many microplastic leftover in the site itself. This is a major issue that is unnotified and neglected [38]. Hence, like this, the carbon footprint of every material increases. The transportation of materials from one place to another place having a long distance makes a huge carbon emission by burning fossil fuels in vehicles. This fuel emission of carbon is very high in volume, which directly increases greenhouse gases and global warming. It also exploits the surroundings of resource areas like an oil rig, ocean, and vegetation land, which any modern techniques can recover.

Transportation distance must be reduced to the maximum accessible point shortest distance so that one can avoid fossil fuel carbon emission. Workers and labourers also travel for a long distance which consumes fuel for transporting them from their place to site which can also be considerably controlled. To reduce carbon emissions, a systematic strategy is needed to develop new methods of manufacturing assembling/construction and transportation. During this construction, the quantity of the material was properly calculated and purchased, but in real time, the quantity exceeded the calculation because of the supplier's supply errors. So, the utilization of materials was cumulated at the end of the construction. This type of residential house construction plays a major role in wasting materials in real time. To control this wastage and control the carbon emission, alternate materials are to be used; many consumers are unaware of the alternate materials. Sometimes, it is hard to find suppliers near the construction site. In Chennai, small individual residential houses and small residential apartments are very popular. If the awareness and material availability are easier, the usage of sustainable materials may increase and the carbon emission can be reduced.

Prefabrication materials can play a major role in reducing the scaffolding timbers and shell shutter in construction sites; it can prevent or reduce materials' wastages of shifting individual material to the site [39]. This prefab can lower the CO_2 emission in buildings than conventional concrete in situ. The timbers used for doors and windows are important in deforestation. Using alternate materials like plywood, pressed wood, veneers, and plaster of Paris can reduce the carbon footprint; these materials can be recycled again and again. While doing the plan approval process, the required building code and sustainability guidelines should be instructed to the consumers, along with the sources of sustainability material suppliers, which may increase the awareness and utilization of recycled materials.

Training should be given to masons, consumers, and fresh engineers about the carbon emission, life cycle assessment, green building concept, sustainability, and standards of code by the government authorities.

4. Conclusions

Studies on embodied carbon and carbon emission of construction materials in India are intensively taking place. The Indian infrastructure sector is associated with carbon emission, which is to be immensely optimized to control the carbon emission. The study has exposed a few materials widely used in the construction sector that are the major contributors of carbon footprint to the environment. These materials' utilization should be controlled and lots of changes in the manufacturing process. Cement, sand, coarse aggregate, fine aggregate, steel, timber, and bricks should be used in reduced quantity and avoided in unwanted places. These materials contribute 98% of carbon in total emission in the construction sector. Also, they contribute environmental pollutants in production places.

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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