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Literature Review

Environmental impact assessment of demolition of a building in India-A case study

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Abbreviations: FAR: Floor Area Ratio; EE: Embodied Energy; LCA: Life Cycle Analysis; LCE: Life Cycle Energy; GHGs: Green House Gases; GFC: Good for Construction; BUA: Built-up Area; RCC: Reinforced Cement Concrete; NBC: National Building Code of India; CPWD: Central Public Works Department; PAR: Plinth Area Rates; Malba: Debris/Rubbish from building demolition; EIA; Environmental Impact Assessment; EEm: Embodied Energy of Construction materials; EEc: Embodied energy in construction; EEt: Energy of transportation; DE: Energy in Demolition & Recycling; OE: Energy in operations of buildings; IEE: Initial Embodied Energy; REE: Recurring Embodied Energy

Abstract

Buildings are demolished, when they outlived their service life, become structurally/functionally unfit, or have been built illegally. In India, an RCC framed, 40-storied high-rise building, with a built-up area of about 75,000 sqm, built without relevant approvals along with lots of violations of building bye-laws, has been demolished. There is nothing new in this demolition process, but its effect on the environment is unavailable. A study has been conducted to understand the environmental impact of this demolition. Based on the main primary construction materials, the embodied energy of this demolished building has been computed as 7.07 GJ/sqm. The civil construction cost of the building was found to be about INR 200 Crores (USD 27 million, assuming a conversion rate of 1 USD 75 INR in the year 2022). Expected GHGs emissions corresponding to this embodied energy were estimated as 42.42 × 10^3 MT. Energy in the demolition of the building has been computed to be about 8.7 GJ/sqm. The situation, in which this building can be retrofitted and made compliant with local building bye-laws, has been analyzed for its environmental impact.

Introduction

Buildings consume about 30% - 40% of primary energy & 16% of potable water and generate about 40% of GHGs (Green House Gases) annually [1,2]. High-rise buildings have higher footprints of primary energy and construction costs [3-6]. Buildings are designed/constructed to last for 30 - 100 years as per construction practices, specifications, climate, and uses in various countries [6-10]. Buildings may be required to be demolished before the end of their service life. The reasons for demolition include structural, functional, availability of more FAR (Floor Area Ratio), better land use, or are ordered to be demolished by local statutory authorities due to issues like acquisition, illegal construction, court orders, or other reasons [8]. Energy in the demolition of buildings is generally insignificant if performed manually [7,11-16], but can be significantly higher if machines or explosives are used [2,7, 17-19]. There is a tremendous wastage of natural resources and energy in such pre-mature demolition cases. Demolition causes lots of environmental degradation, like impact on the ground (shock waves) in case of demolition by the blast, noise pollution, and spread of fine particles in the air. Due to impact-induced shaking of the ground, the risk to occupants & buildings in the vicinity may also be high. Hence, LCA (Life Cycle Analysis) of premature demolition of buildings needs to be done and then an appropriate decision can be taken as per LCA methodology as discussed by Kashif, et al. [20].

A study has been performed on a 40-storied, 100 meters high RCC-based building, which is to be demolished by putting explosives in it, for its environmental impact and effect of this demolition on nearby construction & population. Based on the available literature, a qualitative analysis has been done to map GHGs due to demolition and the situation in which this building is retrofitted in conformity with local building bye-laws, so that this retrofitted building can be retained with changed use with a reduction in its working population, less working time, etc., to study the advantage of this retrofitting over demolition.

Literature review

Buildings consume various types of natural resources extracted from the earth. The consumption of natural resources in building construction & maintenance is very high [7,9,19,21,22]. Major natural resources used in the construction of conventional Indian buildings are cement, steel, bricks/blocks, sand, coarse aggregates, etc., [3,4,6,7,14,17,22-29]. Embodied energy (EE) & construction costs of Indian conventional buildings are dependent on the specifications, architectural/engineering design, types of buildings, climate, geography, building uses, and quantities of various construction materials used in these buildings [3,6,7,25,27-38]. The embodied energy of various primary construction materials (EEm) has been quantified by many researchers based on Indian data & international data and presented in Table 1 and plotted in Figure 1.

From Table 1, it is seen that there are significant variations in embodied energy values (- 67% to + 453%) of a few construction materials (between Indian data and international data), which may be attributed to differences in their specifications, performances, technology involved and time zone considered. The present study considers the embodied energy values of construction materials from Indian sources.

Generally, construction materials, equipment and labor are transported using various types of motorized & non-motorized vehicles with known & unknown distances. Transportation energy varies very much depending on these factors and can be low to high [41,42]. Transportation energy (EEt) in the Indian construction system has been calculated by many researchers and has been presented in Table 2.

Burdhan, et al. [17] have calculated that EEt is 1.85% of EE of smaller buildings in India and EEt decreases in bigger buildings. William, et al. [44] have computed EEt as 0.7% of LCE (Life Cycle Energy). Barbara Rossi, et al. [12] have found EEt to be 2% of LCE. Adalberth, et al. [45] have found that energy in transport & construction of buildings is 1% of its total energy use. Dutil, et al. [5] have found that transportation of construction materials has no effect on the LCE of buildings. Pinky Devi, et al. quoted Kua & Wong, that energy required in onsite construction & transportation is 12% of embodied energy and 0.96% of LCE [31]. Hence, EEt is not very significant in the LCE of buildings.

In building construction, lots of energy is also used in construction equipment and various site activities (EEc), which have been quantified by many researchers like Pinky Devi, et al. [7] as 4% of LCE. Ramesh, et al. [13] have found that the construction & demolition energy of Indian houses is less than 1% of LCE. Praseeda, et al. [14] have calculated that energy in miscellaneous works is 1% of LCE. Since in India lots of manual labor is used in the construction & maintenance of conventional buildings, thus in LCE of Indian buildings, energy due to construction has been found to be insignificant

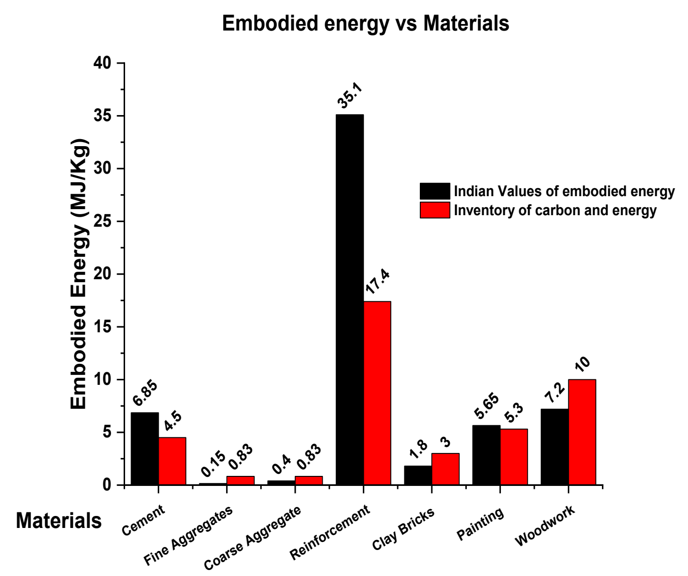

Figure 1: Embodied Energy of Prominent Construction Materials.

Table 1: Embodied Energy of some prominent Construction Materials [3,7,22,27,31,32,39,40].

S/N	Item	Indian Values of embodied energy (DA/BMPTC, 1995; [39] Reddy & Jagadish, 2003; [27] Shukla, et al. 2009, [22] Pinky Devi [7,31]	Inventory of carbon and energy (ICE) [40]	% Change in ICE values from Indian Values
		Embodied Energy (MJ/Kg)	Embodied Energy (MJ/Kg)	
1	Cement	5.9-7.8 (avg. 6.85)	4.5	-34%
2	Fine Sand/Aggregates	0.1-.2 (avg. 0.15)	0.83	+ 453%
3	Coarse Aggregates/Gravel	0.4	0.83	+ 107%
4	Reinforcement	28.2-42 (avg. 35.1)	17.4	-50%
5	Clay Bricks (weight of brick 2.6 Kg/ No's)	1.8	3	+66%
6	Painting (Lime)	5.65	5.3	-6%
7	Woodwork	7.2	10	+38%
8	Copper wire	110	36	-67%
9	PVC Conduit	104-108 (avg. 106)	67.5	-36%

[25,45-50]. Even, European Union has given less importance to embodied & construction energy in energy efficiency in European buildings [51]. Calculation of labor and machine output in high-rise construction in India has been done by Pinky Devi, et al. as 41% of its LCE [7]. Computation of manual energy by various researchers has been presented in Table 3.

However, since manual energy does not have any carbon footprints directly associated with it, this is generally not accounted for in the LCE/LCA of buildings.

Embodied Energy (EE) of the buildings has been calculated by adding embodied energy of construction materials used in construction (including spillages & wastages) along with the energy required in actual construction & transportation of these to construction sites along with all upstream & downstream processes as EE = EEm + EEt + EEc and presented in Table 4.

Further, there is energy consumption in various phases of service life of the buildings, which are also very important and are known as operational energy (OE), Demolition & Recycling energy (DE), and Recurring Embodied Energy (REE), which are also part of LCA/LCE of buildings [6,7,25,29-31,34]. The definition & calculations of this energy have been done by many researchers and have been described as:

Operational Energy (OE)

Operational energy (OE) of the buildings has been calculated by many researchers and found that OE is about 80% - 90% of the LCE of conventional buildings [1,3,9,13,25,26,49,55] due to the consumption of a high amount of energy in various services of buildings due to sufficiently long service life span of buildings [25,55]. There will be considerable variations in the OE values of various types of buildings as per their use, type, desired indoor comfort conditions, climates, fenestrations,

Table 2: Transportation Energy of Construction Materials: BVV Reddy, [27] & Bhattacharjee [43].

S/N	Type of Materials	Embodied Energy MJ/ Kg		
		Production	Transportation up to 50 Km	Transportation up to 100 Km
1	Sand (Cum)	0	87.5	175
2	Crushed aggregates (Cum)	20.5	87.5	175
3	Burnt Clay Bricks (Cum)	255	100	200
4	OPC Cement (Tonne)	5,850	50	100
5	Steel (Tonne)	42,000	50	100

Table 3: Computation of Manual Energy by various researchers.

S/N	Researcher [Reference]	% of Embodied Energy	Watt	MJ
1	Pacheco, et al. [18]	-	0	-
2	Ezema, et al. [16]	-	-	0.75 MJ/hour
3	Oyarzo, et al. [52]	-	80 W	-
4	Keoleian, et al. [2]	-	100 W	-
5	Sharon, et al. [46]	1% - 4% of EE	-	-

Table 4: Embodied Energies of Residential Buildings compiled from Literature by Bansal [3].

S/N	Numbers of Storeys	Type of Building	Country/ Year	Embodied Energy in GJ/m^2	Source [References]
1	1 to multi-story	Residential	India/2012	3.34-5.0	Ramesh, et al. [13,49]
2	8	Residential/RCC	India/2003	4.21	Reddy, et al. [27]
3	19	Residential/RCC	The USA, China/2012	6.3	Chang, et al. [50]
4	40	Residential	Hong Kong/ 2001	6.96-7.15	Chen, et al. [48]
5	High Rise more than 20 floors	Residential	Thailand/ 2011	79.5	Dutil, et al. (quoted Utama) [5,53]
6	High Rise	Residential/RCC	China/2013	9.74	Han, et al. [54]

envelopes, etc., [32-37]. Since, in this present paper, the studied building is demolished before commissioning, this energy is not considered in the present analysis.

Demolition and Recycling energy (DE)

Energy is required in the demolition of buildings & recycling of buildings wastes (DE). This depends on their specifications, configurations, construction materials, numbers of stories, structural systems, sizes, etc. Pinky Devi, et al. [7,31], have calculated that DE is 3% of IEE (Initial embodied energy). Praseeda, et al. [14,37] and Ramesh, et al. [13,49,55] have calculated that DE is 1% of LCE. Ezema, et al. [16] have found DE to be negligible in LCE. When demolition is done through the machines, DE can be as high as 5% - 10% of LCE [2,7,17-19]. Demolition and recycling energy of Indian buildings have been calculated as 1% - 2% to 10% of their LCE [2,7,11-19].

Recurring Embodied Energy (REE)

Buildings also use a significant amount of energy for maintenance/repairs during their service life of the buildings, and this energy is known as recurring embodied energy (REE) of buildings. Since the service life span of the buildings is sufficiently long and can vary from 30-100 years [6-10], the amount of recurring embodied energy is also high, and it can be equal to 86% of its initial embodied energy of some of the buildings, as found by Bansal, et al. [6].

The LCE of the buildings is the sum total of embodied energy of the buildings, operational energy, demolition & recycling energy, and recurring embodied energy of the buildings. This approach is also known as the cradle-to-cradle approach [56,57].

LCE = EE + OE + DE + REE

The embodied energy of Indian high-rise buildings has been calculated as 7.43 GJ/sqm for 40 storied and 6.25 GJ/sqm for 30 storied buildings [3]. Similarly, the construction cost of Indian High-rise buildings (30 storied) has been calculated as per the procedure given in CPWD (Central Public Works Department) DSR (Delhi Schedule of Rates) for the year 2020 as INR 25,200/sqm and as per the year 2021 as INR 26,985/ [3,8] as given in Table 5.

Table 5: Costing of Indian Buildings by CPWD PAR (Plinth Area Rates) year 2019/2020/2021 [16].

S/N	Year	Type of Building	Load Bearing (INR/m^2)	Composite Construction (INR/m^2)	RCC Framed Construction (INR/m^2)				
			Up to 4 storey	Up to 6 storey	Up to 6 storey	Up to 7-12 storey	Up to 13-18 storey	Up to 19-24 storey	Up to 25-30 storey
1	2019	Office/School/College. (Storey height 3.6 meters)	21,700/	-	25,500/	Extra 580/ storey	-	-	-
2	2019	Hospital (Storey height 3.6 meters)	22,800/	-	26,800/	Extra 580/ storey	-	-	-
3	2019	Residential Building (Storey height 2.9 meters)	16,600/	-	19,500/	Extra 580/ storey	-	-	-
4	2020	Office/College. (Storey height 3.6 meters)	-	21,900/	25,800/	Extra 100/ storey	Extra 200/ storey	Extra 300/ storey	Extra 400/ storey
5	2020	Hospital. (Storey height 3.6 meters)	-	23,200/	27,100/	Extra 100/ storey	Extra 200/ storey	Extra 300/ storey	Extra 400/ storey
6	2020	School. (Storey height 3.6 meters)	-	17,800/	20,700/	Extra 100/ storey	Extra 200/ storey	Extra 300/ storey	Extra 400/ storey
7	2020	Residential Building (Storey height 3.0 meters)	-	16,800/	19,700/	Extra 100/ storey	Extra 200/ storey	Extra 300/ storey	Extra 400/ storey
8	2021	Residential Building (Storey height 3.0 meters)			20,685/	105/	210/	315/	420/

However, in this present case study, a 40-storied high-rise building is going to be demolished with the usage of a fair amount of explosive, hence its environmental impact is going to be very high, as this demolition will not only increase its embodied energy but may create environmental issues (noise pollution, the spread of dust & malba/debris, shaking of the ground, thus, may also endanger the safety of life & nearby property, etc.). Further, there will be a lot of energy required for transportation and recycling of these buildings' demolition waste also. This demolition can be saved by retrofitting this building and making it conform to the requirements of local building bye-laws (if possible). However, there are no such studies/data available in studied literature to suggest the amount of energy required in such retrofitting and its environmental effect. Recent studies are available for retrofitting existing buildings to decrease operational energy requirements and make them more sustainable & safer [58,59].

The present research is undertaken to study the potential of retrofitting a high-rise RCC (Reinforced Cement Concrete) framed structure-based building to make it compatible with existing building bye-laws with the change of building use, so that the building may be used without the need for demolition. Few illegally constructed buildings have already been acquired by public agencies previously in the state of Bihar, India, and are being used for public utilities with a change of building use [60-65]. Energy may be required in retrofitting work in buildings, which can be calculated and compared along with the environmental impact of the demolition.

Methodology and analysis

Since detailed Goof for Construction drawings (GFC), specifications, and quantities of construction materials used in the construction of this building are unknown, this preliminary information is prepared based on the following base data:

Buildings

40 storied towers, RCC framed structure, 75,000 sqm built-up area (BUA), the tower height is about 100 meters.

Design forces

Dead loads of the buildings consisting of weights of RCC/PCC/Flooring/Joinery/Fixtures & Fittings, masonry, finishing materials, Live Loads: 200 - 400 Kg/sqm of floor area, Earthquake Forces: Seismic Zone IV as per NBC (National Building Code) of India, Wind Loads: 47 m/s basic wind speed at 15-meter height.

Construction cost

As per CPWD PAR of the year 2020/2021 of RCC framed structure residential buildings of 40 storied constructions in India [3,4,8].

Based on the above data, basic construction materials like Cement, steel, bricks/blocks, sand, and coarse aggregates have been computed as per standard practices given in CPWD-PAR [3,4,8,66]. It is found that these 5 (five) basic main construction materials weigh about 90% in construction cost and 100% in embodied energy based on construction materials in Indian affordable housing. The present study is not in the affordable housing category. It may have expensive finishes like vitrified floor tiles, wooden/uPVC doors/windows, plastic paints, expensive plumbing, and electrical fittings & fixtures. However, this building was not yet finished and was still under construction (it must not have reached the finishing stage at the time of the demolition but finishings were not in place). Hence, these fancy construction materials/finishes have not been included in the computation of construction cost & embodied energy. Computed primary construction materials based on the assumption of Indian affordable housing will also hold good for the studied building also. The required quantities of the basic construction materials for the construction of this building have been computed as per available literature [3,4,6-8,23,25,28-31] as.

Cement - 7 bags (1 bag contains 50 kg of cement), Steel - 80 kg and bricks - 400 Nos/sqm of built-up area. The embodied energies of these construction materials are cement - 342.5 MJ/Bag, Steel - 35.1 MJ/Kg, and bricks - 4.68 MJ/Nos (Table 1). Total Embodied energy per sqm of the floor area of this building is [7*342.5 + 80*35.1 + 400*4.68 = 7,077.5 MJ] or 7.07 GJ/sqm. The total embodied energy of this building is 7.07 GJ*75,000 = 530,812 GJ of 5.30×10^5 GJ. GHGs potential of this energy is 42.46×10^3 MT ($5.30 \times 10^5 \times .08$ MT) as computed by Luisa, et al. [67]. Contribution by sand and coarse aggregates in embodied energy is insignificant [3,4,6,25,29,32]. The average civil cost of construction of the building is INR 202 Crores (75,000 sqm @ INR 26,985/sqm)) as the year 2021 prices [7,8].

Hence, embodied energy, GHGs, and civil construction costs of this building are very high. Further, no accurate data is available on demolition, transportation, and recycling of high-rise buildings, hence computation of demolition energy has been done based on data given in studied literature. From literature studies, it is evident that the demolition energy of a high-rise can be as high as 10% of LCE. The initial Embodied energy of this building is about 10% - 20% of LCE (average of 15%) [2,7,17-19]. It is found that generally REE is not considered in the LCE of buildings and LCE has been calculated as the sum of EE and OE only. However, REE is a very important part of LCE. The recurring embodied energy of the buildings is about to 86% of the initial embodied energy of the buildings [6] and the service life of buildings in India is generally considered 50 years [3,4,6,8,25,29,32]. Thus computation of demolition energy will be $((7.07 \times 1.86/0.15) \times 0.1) = 8.7$ GJ/sqm. So, the demolition energy of the high-rise building (8.7 GJ/sqm) is much higher than the initial embodied energy of the buildings (7.07 GJ/sqm). However, demolition energy by explosives may be much different than the one as computed, as generally buildings are not demolished by explosives. However, as per computations done in this study, at the time of demolition of this building, the energy footprints of this building will be 15.77 GJ/sqm (7.07 + 8.7), which is very high and needs a detailed EIA (Environmental Impact Assessment) study to understand the impact of the destruction of such huge investment. There will be noise, dust, and shock/shaking in nearby areas, which will have a significant impact on buildings, flora, and fauna of the area, but this cannot be quantified due to lack of data.

It is further found from literature studies that old and inefficient buildings can be made sustainable by investing energy to the tune of 10% - 20% of their embodied energy and can last longer [68,69]. A study of retrofitting a public school building in Agra by Yashika Bansal [75], UP, India, shows that cost of retrofitting is about 30% of the cost of new construction and the energy required in retrofitting is 16% of embodied energy of new construction. The life of this school building was extended by another 50 years. Hence, along similar lines, if this studied building can be retrofitted, this will save a huge amount of cost, and energy and save the environment from dust, sound, demolition wastes, and impact-related hazard.

Results and discussions

This high rise RCC framed structure-based building is very high in embodied energy, demolition energy & construction cost and must have been designed & constructed for a service life of about 50 - 75 years, but is being demolished even while still in construction sage, without using it due to serious violations in building bye-laws. The embodied energy of this 40-storied building is about 7.07 GJ/sqm and the construction cost (civil works only) is about INR 200 crores with great potential for GHGs emission. Demolition may also use a significant amount of energy (8.7 GJ/sqm), which will be added to the LCE of this building. Hence, embodied energy footprint of this building is very high as 15.77 GJ/sqm, which is going to waste. GHGs potential of this building having BUA of 75,000 sqm is 94.62×10^3 MT, which is very huge.

Besides the destruction of precious natural resources, there will be lots of noise, dust, and vibration-related pollution due to the demolition of this building by explosives. The effect of demolition on flora and fauna may also be studied as this may create lots of inconveniences and damage to biodiversity. Further, energy will also be required in collecting, transporting, and recycling buildings' debris/malba (building rubbish) and that is also part of the embodied energy of this building. The quantification of this energy can be done based on available information from the site. It is further found that the cost and energy for retrofitting are generally less (10-20% of EE) and feasible. A detailed EIA study is required to be done with the possibility that can this building be retrofitted and made compliant with local building bye-laws with all safety parameters, and if this is feasible, what are energy, cost, and environmental issues in this process? From literature studies, it is found that possibly these buildings can be retrofitted to conform to the requirements of local building bye-laws by providing additional features that will save lots of primary energy, cost, and environmental degradation.

Conclusion

From the current analysis, it is found that since the construction of buildings consumes a significant amount of natural resources, primary energy & money, this is significantly very high in the case of high-rise RCC-based framed construction due to requirements for more construction materials due to more gravity, earthquake and wind loads. Hence, in case of any nonconformity in these buildings with local building bye-laws, builders/developers must be heavily punished, but the buildings may be retrofitted (if it is possible). Various interventions such as structural (construction of more structural elements, staircases, ramps, etc.), PHE (more windows, doors, water sumps & hydrants, earthlings, breakers, etc.), Firefighting (pressurized water pipes, chemicals for firefighting, increasing fire ratings of construction materials, long hose pipes, sprinklers, fire detectors, long ladders, uses of Drones, etc.), etc. and building usages may also be altered (with less population density, less working hours, etc.) to make it fit for the revised building uses, as demolition may cause lots of wastages of natural resources and may create inconveniences to the person living nearby including buildings. EIA studies of the demolition may also be done like it is being done for the construction of new buildings to calculate energy and environmental impact to decide the benefits of demolition of such buildings or to retrofit these buildings. In this particular case, it is found that generally this building is having a tremendous amount of embodied energy and may have more energy embedded in it, due to usages of the heavy amount of energy in demolishing, besides there will be noise, dust, and ground shaking in the demolition of this building, which will be decided only through EIA only.

Future work

Since, sufficient data on embodied energy and demolition energy of high-rise buildings is not available in India, especially for demolition by using explosives and their demolition-related EIA studies, these need to be collected and studied for a more detailed cost-benefit analysis of such demolition.

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