Ecological Footprint Assessment of Small Residential RCC Building

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Abstract.

The aim of this paper is to evaluate the environmental imprint of single-store RCC buildings on the planet, through the use of the Ecological Footprint (EF) indicator. Urbanization requires a significant amount of energy, materials and resources for building construction. Energy, materials and resources consumption are responsible for greenhouse gas emissions that affect the ecosystem of the planet. To find the effect of this activities on ecological system this study becomes more important. The natural impression of building development can be decreased by utilizing ecologically modest materials, environmentally friendly power assets, and by improving bio productive land use through the development of small residential RCC building structures.

Keywords. Ecological footprint, Embodied Energy, Sustainable Construction, Sustainable building, Environmental Assessment.

1 INTRODUCTION

The construction sector is accountable for about 40% of the worldwide primary energy utilization as well as one-third of the total greenhouse gases (GHG) emissions [1]. The Indian construction sector has been raised at the rate of double digits during the last decade. The dwelling stock in India has been increased from 250 million to 330 million units during the period of 2001 to 2011[2]. In India, the primary energy consumption for building materials manufacturing is approximately one-fourth of the total primary energy consumption, and the building materials demand is surpassing 2 billion tonnes per year. Simultaneously, the GHG emissions due to construction are responsible for 30% of the total GHG emissions of the country [3, 4].

Various researchers worked on sustainable building construction [5, 6, 7]. Ramesh et al. examined the life cycle energy (LCE) of different residential buildings. The LCE of a residential building is in the range of 240 - 380 kWh/m^2, however, the construction phase consumes 10-20 % of the total LCE of the building [8]. Pinky et al. examined that the building construction responsible for 22-36% of the total LCE depends upon the lifecycle of the building [9]. Husain and Prakash experimentally investigated on the constructional Ecological Footprint (EF) of the conventional fire ash brick wall and conventional RRC roof, have concluded that for fire ash brick wall (EF) is 0.0074 gha/m^2 and for RRC roof (EF) is 0.0074 gha/m^2, respectively [10]. The EF of a constructional phase of the building is 36.16% of the total life cycle EF of the building [11].

1.1. Ecological Footprint (EF) Indicator

The EF indicator was developed by Mathis Wackernagel and William Rees in the mid-nineties [12]. This indicator can be utilized for study as well as for estimating the various types of sustainable measures such as the viability of proper distribution of resources of the planet. It includes all resources as input parameters and transforms them into a single output (i.e., bio productive land). The unit of EF (i.e., global hectare; gha) define as "One gha is equivalent to one hectare of bio-productive land with world average productivity".

This case study emphasizes assessing the environmental imprint of a typical residential RCC building on the planet. In coming decade there will be massive development in infrastructure to improve the lifestyle of people and hence the EF assessment of the residential building become more important. However, the natural resources (i.e., EF) demand has exceeded the existing bio-capacity (i.e., bio productive lands) of the country. This study helps to assess the total bio-productive lands requirement for building construction in India. The study may also be helpful for exploring the feasible EF reduction opportunities in the construction sector.

2 METHODOLOGY

The bio productive lands are significant factors for building construction. In this study, the constructional EF of small residential building are examined. The details of the EF assessment of small residential building construction are as follows:

2.1 Ecological Footprint of Building Construction (EFB):

The Ecological Footprint of a small residential RCC building has been estimated in this study. The Ecological Footprint assessment of a small residential building comprises four components: (1) Raw materials & Manufactured materials (2) Energy/ Machinery Use (3) labor and (4) Physical land. The transportation of materials is not considered in this case study. The system boundary for the EF assessment of small residential building construction is shown in Figure 1

2.1.1 EF of Building Materials (EFm)

Building materials of small residential RCC building are accountable for significant resource consumptions, therefore, the environmental impact of building materials should be examined. The EF_m has been calculated by Eq. 1 [10]:

$$\mathrm{EFm} = \sum\left(\frac{Ci.Emi}{Af/(1-Aoc)}\right) e_{CO2\,land} + \sum\left(\frac{Cwi}{Ywi}\right).\, E_i \tag{1}$$

manufacturing impact natural impact

Where, C_i is represented material consumption of the material, E_{mi} is embodied emission of the material, the average world forest carbon sequestration rate is estimated to be 0.73±0.37 tC/ha [13]. Therefore, A_f absorption factor of forests is considered to be 2.7 tCO_2/ha, A_{oc} is fraction of annual oceanic emission sequestration (i.e., 0.3 [14]), C_{wi} is consumption in the natural material, and Y_{wi} is materials productivity. The ei is equivalence factor (gha/ha) of different land types {i.e. $e_{cropland}$ (2.52 gha/ha), $e_{pasture\ land}$ (0.43 gha/ha), $e_{forest\ land}$ (1.28 gha/ha), $e_{CO2\ land}$ (1.28 gha/ha) and $e_{marine\ land}$ (0.35 gha/ha) etc.}[15].

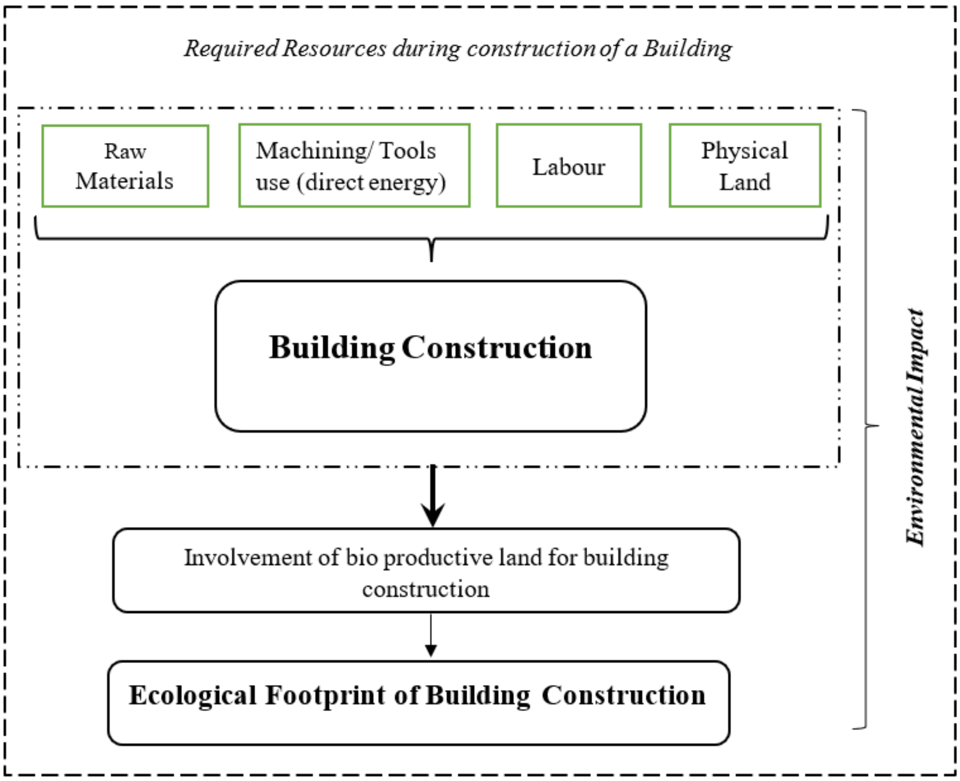

Figure 1 System boundary of a building construction

2.2.2 EF of Energy/ Machinery Use (EFe)

The EF_e depends on machinery used and labour required during the construction.

The estimation of EF_e is given by Eq. 2:

$$EF_e = \sum(Ei.ai).(\frac{1-Aoc}{Af}).\ e_{CO2\ land} \quad (2)$$

Where, E_i is the amount of energy/fuel consumed during the use of machineries; α_i is theemission factor of energy/fuel sources.

2.2.3 EF of Labour (EF_l)

The EF_l is associated with the metabolic rate of labour/manpower for the different type of activities [6]. The total labour requirements during building are estimated in terms of full time equivalent (FTE). The EF_l is determined by Eq. 3

$$EF_l = FTE.\ (annual\ EF\ of\ labour) \quad (3)$$

The EF of labour for one working-day (8 hr) is 0.0009 gha/day [16].

2.2.4 EF of Physical land (EFp)

The environmental impact of physical land engaged by the residential RCC buildingis considered in this section. The EF_p is calculated by Eq. (4):

$$EFp = Ap.e_{built\text{-}up\ land} \quad (4)$$

where, A_p is the total physical land (hectare) and $e_{built\text{-}up\ land}$ represents the equivalence factorof built-up land (i.e., similar as cropland).

Figure 2 Building and Google Map image.

3 BUILDING DESCRIPTION

This study is done on one of the small residential RCC Building located in Dhule District of Maharashtra, India. The total built-up area is about 60.78 m^2. It consists of a Hall, Kitchen and 2 Bedrooms, Floor to Ceiling height of the building is 3 m. This building is located in a hot and humid climatic zone of India. The building and Google image are shown in Figure 2.

4 RESULTS

4.1 *Ecological Footprint of Building Construction (EFB)*

For the estimation of the EF_B, all parameters such as EF_m, EF_e, EF_l, and EF_p are assessedexclusively and after that added to evaluate the EF_B of the small residential RCC building. The details of all the construction works and building materials use this building are shown in the Table. 1. The EF distribution of different construction works of the building is shown in Figure 3. The EF_B of the small residential RCC building is about 7.011 gha (i.e., 0.115 gha/m^2 floor area of the building).

The constructional EF of the small residential RCC building depends upon the building material consumptions, resources and constructional activities involved during the building construction. The EF of small residential RCC building is estimated as follows:

4.1.1 EF of Building Materials (EFm)

The EF_m of the small residential building as calculated by the Eq. 1 is 6.738 gha (i.e.,96.1% of the total EF of the building).

4.1.2 EF of Energy/ Machinery Use (EFe)

The environmental impact of direct energy/machine use during the buildingconstruction is about 0.021 gha (i.e., 0.26% of the total EF of the building).

4.1.3 EF of Labour (EFl)

The total labour requirement is 282 labour-days. The EF_l as estimated as 0.250 gha (i.e., 3.5%of the total EF of the building).

Table 1 EF of different types of construction works and building materials.

Description	Quantity of Item	Construction materials			Labour (Working-day)	Brick (Nos)	Machine use	EF (gha)
		Cement (50kgbags)	**Sand (m^3)**	**Aggregate (m^3)**				
Earth work in excavation	14.04 m^3				4.68			**0.004**
PCC in Foundation	1.17 m^3	10	0.646	1.293	4			**0.060**
RCC	21.249 m^3	168	8.808	17.617	30		Concrete Mixer-1Day	**1.070**
Brick work	27.20 m^3	39	8.16	0	70	13604		**2.315**
Internal Plaster	272.951 m^2	30	4.258	0	34.11			**0.218**
External Plaster	182.238 m^2	20	2.84	0	22.77			**0.145**
Plinth Filling	48.625 m^3				12.15		Dumper-2 Days	**0.025**
Plinth PCC	6.078 m^3	48	3.359	6.719	4			**0.300**
Flooring	60.782 m^2	31	7.90		10.13			**0.202**
Internal Painting	41.9 litre				10.91			**0.019**
External Painting	28.03 litre				7.28			**0.012**
Steel work	2791.68 kg				30			**1.882**
Wiring	50 m				6			**0.006**
Ply Door	15.12 m^2				5			**0.340**
Wooden Door frame	37.05 m				2			**0.152**
Aluminium sliding Window	9.09 m^2 (approx. 5kg/m^2)				6			**0.065**
Wall Tiles	26.59 m^2				6			**0.136**
Tap	9 Nos				1			**0.007**
Plumbing Pipe	25 m				4			**0.005**
Drainage Pipe	18 m				4			**0.015**
Kitchen Platform (Granite)	4.5 m^2				3			**0.011**
Land	60.78 m^2							**0.015**

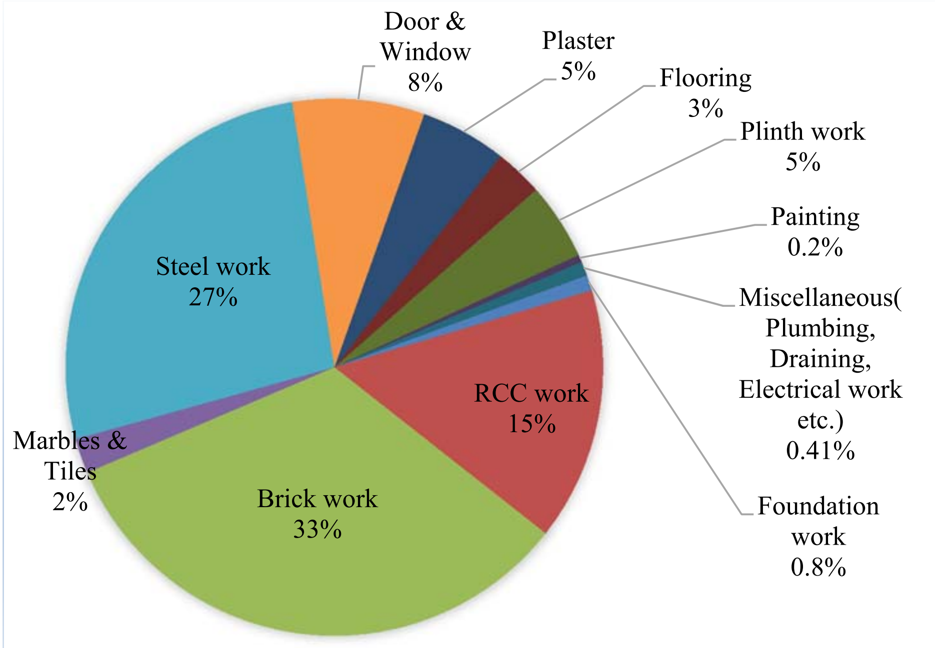

Figure 3 The EF distribution of different construction work of the building

4.1.4 *EF of Physical land (EFp)*

The total land expended must be considered that are used for the small residential building. The EF_p of the building calculated by using Eq. 4 is about 0.015 gha (i.e., 0.22 % ofthe total EF of the building).

5 CONCLUSIONS

The total construction EF of a small residential building is about 7.011 gha. The EF of a small residential building per floor area is about 0.115 gha. The results indicate that materials impact is most significant than the rest of other parameters like machine use, labour impact and physical land etc. The environmental impact of cement is maximum (i.e., 2.13 gha) for the building followed by brick impact (i.e., 2.01 gha). The EF of brickwork contributes the highest impact among all the construction work of the small residential building.

The lower constructional EF should be accepted for achieving the United Nations Sustainable Development Goals; therefore, the sustainable building materials may help to reduce the environmental impact of a residential building.

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