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Costing and Quantum Analysis on Utilization of Re-Usable Solid Waste As Construction Material in India

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***Abstract*— Major population shift from rural to semi urban or urban areas in India, for the search of employment and better living condition has exponentially increased housing shortages in cities within two decades. The high cost of house rent, and unaffordable rate of housing market has forced the Economical Weaker Sections (EWS) and Low-Income Groups (LIG) to encroach around periphery of cities, resulting in slum development. Researchers and environmentalists encouraged in using re-usable solid waste material for constructing houses to make it as affordable as possible for the under-privileged. In this research article, a comparative cost analysis is carried to understand the cost of a single dwelling unit constructed with PET bottles and the other with brick. This was possible by calculating the cost of a prototype dwelling unit with carpet area of 37 sqm, which is preferrable carpet area range under government scheme. Considering the price of PET bottles to be zero and introducing self-employment strategy, the total cost of construction is reduced by 20%, compared to brick construction. This method can further be used for multi-storied building and included in the government policy framework.**

Keywords—Affordability, costing, PET bottles, solid waste, housing

I. INTRODUCTION

Affording a decent house at reasonable price has become a major talk of the 21st century in developing nations like India. But with rapid increase in population, the world saw an imbalance in proportion of people versus housing development in urban areas due to several factors. In the decade 1991-2001, informal sectors in urban areas of Indian cities, had increased due to the increase in marginal workers from 2.2% in 1991 to 7.9% in 2001 (Government of India, 2007). But during 2001-2011 the decadal growth of India’s urban population grew with 32 percent rising from 285 million to 377 million (Census 2001 & 2011; KPMG & NAREDCO, 2012). With such magnitude of high density rise in urban areas, shortage of housing is now taking its toll in the face of government policies. 99% of this shortage pertains to Economically Weaker section (EWS) and Low-Income Groups (LIG) sector (Government of India, 2007). It’s also evident that financial constraints have been the main factor for unaffordability in India. Some lowly paid workers end up living in slums, illegally encroaching over restricted areas (Pati et al, 2014).

II. BACKGROUND

According to the Housing Policy 2007, the government focuses on facilitating accessibility to serviced land and housing for EWS and LIG and increasing the supply of land (Government of India, 2007). Yet, there seems to be least concerns about the affordability rate by EWS and LIGs due to price rise of materials for the construction of building. In India, the cost of cement during 1995 was Rs. 1.25/kilogram while in 2005 the price increased around three times, but currently the average price is Rs. 5.6/kg. Similarly, in case of bricks, the price was Rs. 0.66 per brick in 1995, Rs. 1.9 in 2005 (Pappu, Saxena & Shyam, 2007) and the present rate is Rs. 5 to Rs.7 per brick. High transportation cost has also affected the people at the outskirts or periphery of towns / cities. In view of saving energy and conservation of resources, it is necessary to investigate application of alternative construction material with extensive research work, which can help reduce major cost.

III. SOLID WASTE GENERATION AND ITS EFFECT

Human activities create waste. In urban areas, especially in the rapid urbanizing cities of the developing world, problems, and issues of Municipal solid waste management (MSWM) are of immediate importance (Zhu, Asnani, Chris, Anapolsky & Mani, 2007). With around 48 metric tonnes (MT) of Municipal Solid Waste (MSW) being generated annually, it is believed that by the year 2047, MSW generation in India, is expected to reach 300 MT and land requirement for disposal of this waste would be 169.6 km^2 (Pappu, Saxena & Shyam, 2007). Despite many attempts to solve the problems towards Solid Waste Management (SWM), many municipalities are still stuck with storage, collection, and segregation and disposal method of management. Of late, recycling of non-bio-degradable waste such as plastic, glass and other waste has become a major solution of tackling SWM problems however, according to Central Pollution Control Board (CPCB) emission of toxic gases still takes place during the process of recycling which could pose a threat to health of those who dwell around the industry (CPCB, 2000).

IV. OBJECTIVES

i. To find the quantum of plastic waste bottles that can be used for constructing a standard dwelling unit.
ii. To compare the cost between buildings constructed by conventional materials and solid waste.

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V. LIMITATIONS

i. This research relies on data available as per the latest survey and other sources.
ii. The research analysis is limited to only Plastic waste bottle masonry.
iii. Earthquake mitigation research has been kept out of scope in this article.

VI. RESEARCH METHODOLOGY

To understand the nature of this research, it was necessary to review previous studies on possible use of Plastic-Glass-Metal (PGM) waste as alternative construction materials. An extensive literature review and analysis was conducted in this research to consider the use of Plastic bottle waste as a replacement to brick. A prototype dwelling unit of 37 m^2 carpet area is designed to calculate and compare the cost of both.

VII. SOLID WASTE AS RESOURCE FOR ALTERNATIVE CONSTRUCTION MATERIAL

Researchers of today are trying to find more effective way of handling the solid waste in construction methods. For example: plastic shreds used for road construction, glass powder used as an alternate ingredient to the aggregates in making building blocks, incineration of waste, use of ash to make fly-ash brick and so on. It is a fact that these solid wastes have no commercial values after being discarded. Thus, using solid waste as a part of building construction including wall, roof and adobe, without labor cost will evidently reduce the overall cost of construction by at least 50% as compared to conventional method of construction and simultaneously reduce the bulk of waste to landfill (Valencia, Perez, Cortes & Froese, 2012).

VIII. LITERATURE REVIEW

Recently, there have been applications of waste PET (polyethylene)/plastic bottle, waste glass bottle and waste metal cans in building construction in different parts of the world as a replacement to traditional masonry (Pati, Iki & Homma, 2014; Inspiration Green, 2021). Plastic bottle waste has been genuinely utilized in Pilot project for Rural Housing in Honduras, requiring only 8 trained farmers of the local area (Andreas Froese, 2014). Other NGOs has been using discarded PET bottles as construction materials for a school in Lake Atitlan, Guatemela (Eyes of Gaia, 2015). It is evident that such buildings are strong and durable. Similarly, Glass bottle waste and metal can waste have been used as a replacement to the conventional building block as shown in Figure 2 and Figure 3. Though there is no accurate amount of number of solid wastes used in any of the construction, yet it has given evidence about being affordable to urban poor due to its low-cost benefit.

A. Application method of PET / plastic bottles in construction

Discarded PET / plastic bottles are filled with dry soil and air-tightened with its cap as shown in Figure 4. Dry soil can come from construction waste, excavated soil etc., if they are sieved and free from pebbles and other aggregates which exceeds the required size. They are laid alongside the layout in the same manner as the bricks are laid (Eco-technologia, projects, 2014) (Figure 5). Cement and sand are most appropriate materials for binding. Other locally available binding materials can also be of great help in reducing cost. To strengthen the structure of the construction, a Biomimetisches 4 Punkt Verknüpfung System shortly called as Bi4PVS, is used as shown in Figure 6. In this technique, a nylon rope is tied to each bottleneck to avoid the collapse or inclination of the structure (Eco-technologia, projects, 2014). This technique gives better result when stacked alternatively above each other.

According to several researchers, compressive strength is one of the most important properties of masonry in structural design (Kalumire, 2011). A unit compressive strength test analysis carried out by Kalumire K. from Uganda Martyrs University, June 2011, revealed that Plastic bottles has the unit compressive strength varying between 10.9 N/mm^2 and 23.1 N/mm^2 (Kalumire, 2011); whereas the unit compressive strength of brick falls in the range between 3.5 N/mm^2 to 10.5 N/mm^2 (The Construction Civil, 2021). Thus, it shows that the former is still applicable for the construction purpose.

Fig. 1. Construction with PET bottles, Honduras

Fig. 2. Prince Edward Island Bottle House Using empty Beer bottles

Fig. 3. Using Aluminium Tin Cans for wall construction

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Fig. 4. Plastic bottles filled with dry soil (Samarpan foundation, 2021)

Fig. 5. Plastic bottles being laid for wall construction (Volker et al., 2012)

Fig. 6. Plastic bottles tied with nylon rope and binded with construction waste and other local binders (Eco-technologia, projects, 2014)

IX. QUANTIFICATION AND ESTIMATION

A. Planning:

According to new scheme under Jawaharlal Nehru National Urban Renewal Mission (JNNURM), the carpet area of dwelling units (DUs) for EWS category can be taken between 21-27 sqm and 28-60 sqm for LIG categories (MHUPA, 2013). Thus, assuming a 37 sqm carpet area for a family of 4, a plan was drafted with minimum basic space requirement that includes: One Living room, one Bedroom, one bathroom and kitchen with dining space as shown in Figure 7, thus satisfying the requirement for LIG with above given categories.

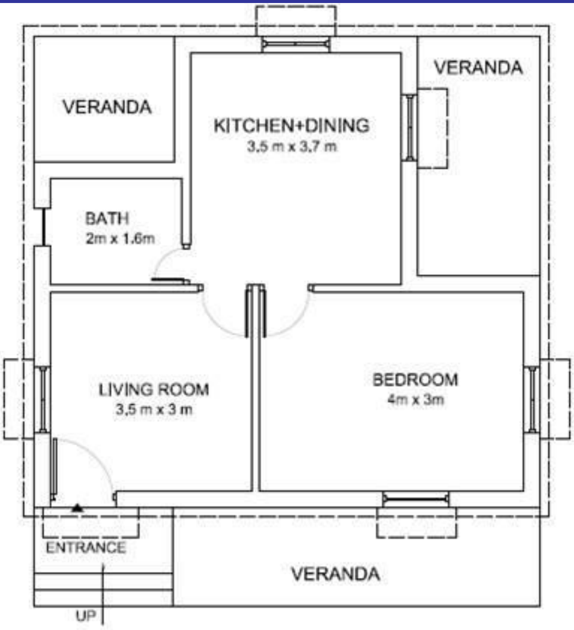

Fig. 7. Plan of a single dwelling unit of 37m^2 area for a family of four [Auto-cad drafting]

B. Costing

Considering the materials to be conventional and traditional method of construction; a fair draft of cost and estimation was carried out provided all the cost of materials to be as per the market price. In this research, the cost of superstructure / masonry has been the focus of study. Table 1 shows the part of costing and estimation of cement work. Total cost of cement concrete works was Rs.1,82,264 (USD 2958). Taking the average cost of the brick of (25 x 12 x 8) cm size for the construction and other necessary ingredient the approximate cost of brick masonry was found to be Rs.2, 49, 206 i.e., USD 3941.

Similarly, for the estimation of Bottle masonry construction, keeping all the materials as per the data; brick estimation was replaced with bottle estimation using 1.5 Litre capacity bottles of length = 30 cm and diameter = 9 cm each. Considering the cost of the waste bottle to be Rs.0, the approximate cost of the masonry was found to be Rs.2, 14,388 (USD 3480).

C. Quantity

The only advantage of brick is the manufacturing continuity in the industry and its availability in bulk, unlike Plastic bottle waste, which depends on the quantity of the discarded items by the households, commercial and other institutional places. Hence, it is important to calculate the total number of waste bottle that can be used in the given plan of the dwelling unit. The laying of the bottles is same as brick laying with the shorter side of the bottle along the length of wall. The number of bottles is calculated based on 1m x 1m square portion of a wall in which around 110 bottles can be stacked as shown in Figure 8. Taking similar arrangement on all sides of the wall, the total number of waste bottles was calculated.

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TABLE I. COST ANALYSIS OF CONCRETE WORKS

Sl. No.	Description of items	Quantity	Unit	Rate	Amount
1	*Rigid and smooth centring and shuttering for R.C.C works including false works and dismantling the after casting including cost of materials.*				
a	Column & Floor Beam	6.958	Sqm	₹ 322.00	₹ 2,240.41
b	Lintel	2.507	Sqm	₹ 152.00	₹ 381.11
c	Roof Slab, Chajja	462.333	Sqm	₹ 225.00	₹ 1,04,024.87
d	Steps from entrance	2.473	Sqm	₹ 259.00	₹ 640.52
2	R.C.C Work of Proportion (M20)	8.242	Cu.m	₹ 4,566.00	₹ 37,631.74
3	Straightening, cutting, bending, binding bent or coiled M.S/Tor Steel bars	8.892	Qtls	₹ 4,200.00	₹ 37,345.56
Total Cost of Cement Concrete Works					**₹ 1,82,264.21**

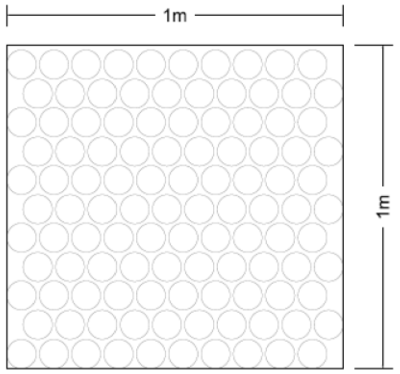

Fig. 8. Elevation of the wall portion of 1m x 1m size [Auto---cad drafting]

X. RESULT AND DISCUSSION

A. Quantity

Excluding the area of staircase, door, windows and ventilator, the total number of waste bottle that can be used in a dwelling unit with an area of 37 m^2 was found to be 8286.

B. Benefit

Mathematically, the percentage decrease between the two methods of construction was found to be around 14%. The other item of work like self-labor and local available materials can play an important role in reducing the cost (Valencia, Perez, Cortes & Froese, 2012). Considering the self-employment, labor cost was taken as Rs.0, which resulted in the total cost of bottle work masonry to be Rs. 1,98,652 (USD 3233); and the percentage decrease was found to be 20%. Moreover, the wooden planks which are used for centering and shuttering of formwork can be replaced by disposed pipes or metal boards, as they can be reused for several times compared to the traditional method. This research has dealt with only cyclone and storm-resistant aspect of structure. The nature of double floor is unknown yet due to lack of structural experiment.

XI. CONCLUSION

The challenges imparted in both - housing affordability and solid waste management; can also be tackled with sustainability in the form of Re-usability of discarded resources. This research has attempted to highlight the potential of the waste container like plastic bottle, glass bottle and Metal Cans that can be used in many purposes.

The waste material varies with different cities depending on the type of raw material used by the households, commercial and industries. Waste glass bottles and metal container can also be re-utilized in a similar manner instead of applying the high-cost materials.

The number of discarded containers (plastic, glass, and metal) that can be used for building a unit will vary according to the size of the material. Availability of such materials would differ from city to city according of the lifestyle of inhabitants.

Simplified method of construction can help the weaker section to encourage self-employment where little or no skill is required.

In future the scope of study can extend to following:

i. Quantum of plastic bottles, glass bottles and metal cans waste generation
ii. Cost-benefit of constructing multi-storied buildings using in-fill method.

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