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Cost Effective Residential Building Using Plastic Bottles - A Home for the Future

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Abstract – Disposal of plastic waste is one among the biggest challenge faced by the society nowadays. Decreasing quantity of the conventional building resources and the hike in its price is yet another issue. Providing an affordable housing for the needy is, therefore, becoming an issue of major concern that needs to be addressed seriously. The current study aims to find a solution for the highlighted challenges by maximum utilization of plastic waste in construction industry and to propose cost effective construction materials and techniques. Experimental investigations were done in order to develop building components for foundation and roof using plastic bottles. Plastic bottles were filled with demolished concrete waste for foundation, demolished waste and saw dust for walls and plastic wrappers for roof. The obtained results were compared with the conventional building materials. Architectural plan for a 400 sq. ft. residential building was prepared. Bill of quantities for the same was prepared and compared with the conventional building. From the prepared BOQ, it is understood that percentage economy in material cost can be achieved by using plastic bottles, i.e., 400% more economical when compared with conventional building materials. A prototype of the residential building according to the plan was also constructed. From the studies conducted, it is clear that plastic can be used effectively as an alternate building material, both in terms of strength and durability.

Index Terms – Plastic bottle, Innovative foundation, Innovative roof, Sustainable housing, Affordable housing.

1. INTRODUCTION

A small house to live in is the basic necessity and a cherished dream of every human being along with food and water. Housing is also considered as a criterion for the development of every individual of a nation. But a significant percentage of urban population is facing housing shortage which is becoming an acute problem in the modern age of development [1]. It is seen that the decreasing quantity and increasing cost of the building materials is amongst the reasons of housing shortage.

Disposal of non bio-degradable substance is a major challenge of the present era. The changing human culture replaced glass bottles by plastic bottles and thereby, plastic bottles became one of the most disposable materials in the modern world. It makes up much of the street side litter in urban and rural areas. It is rapidly filling up landfills and choking water bodies. Plastic bottles make up approximately 11% of the content landfills, causing serious environmental consequences [7]. Plastic bottle, an urban junk has many sustainability characteristics. Plastics are produced from the oil that is considered as a nonrenewable resource. Plastic, an environmental pollutant, has an insolubility of about 300 years in the nature and so it is considered as a sustainable waste. The best solution for the challenging problem of plastic waste disposal is reusing, for which no additional energy is required and does not contribute to pollution. Indeed, when we reuse junk, we are helping to save the obtained energy which would otherwise be wasted. So reusing of the thrown away plastic bottles can be effectual in mitigation of environmental impacts relating to it [4] [7]. It has been proven that the use of plastic bottles as innovative materials for building can be a proper solution for replacement of conventional materials and thereby solving the disposal problems.

2. LITERATURE SURVEY

With population growth in today's world, the need of buildings has increased and to respond to this demand, the countries tend to use the industrial building materials and caused decline in the use of indigenous and traditional materials. These factors in spite of increasing the energy consumption in the industry section; they also raised the cost of homes and are considered as the barrier for users to obtain the basic needs of the life [4].

Modern buildings consume energy in a number of ways. Energy consumption in buildings occurs in five phases. The first phase corresponds to the manufacturing of building materials and components, which is termed as embodied energy. The second and third phases correspond to the energy used to transport materials from production plants to the building site and the energy used in the actual construction of the building, which is respectively referred to as grey energy and induced energy. Fourthly, energy is consumed at the operational phase, which corresponds to the running of the building when it is occupied. Finally, energy is consumed in the demolition process of buildings as well as in the recycling of their parts, when this is promoted. It is found that the cost-effective and alternate construction technologies, which apart from reducing cost of construction by reduction of quantity of building materials through improved and innovative techniques or use of alternate low-energy consuming materials, can play a great role in reduction of CO2 emission and thus help in the protection of the environment [5].

Despite increasing the efficiency of proper solid waste management in India, there are significant amount of non-biodegradable waste that are left untreated or dumped into the landfill. In developing countries like India, as landfill has been the major option of disposing solid waste, there would be ever expansion of landfill in future which might put constraints over finding land for further dumping of garbage, unless there is a way to reuse those solid wastes which has significant potential to be utilized again for other purposes. Fortunately, many environmentalist and researchers have come up with new ideas of utilizing these wastes in construction of building. Discarded plastic bottles are now being used for construction of dwelling unit in the form of building blocks replacing conventional bricks and concrete reducing the overall cost of construction drastically to at least 20% to 40% as compared to conventional method of construction [1]. It is expected that by utilizing pet bottles in construction, thermal comfort can be achieved, benefiting residents who cannot afford to buy and operate heating and cooling systems. This give relief for the poor people of India to provide cheap and best houses for living [6]**.** The benefits of plastic bottle masonry wall include good construction ability, low cost, non - brittle characteristic, absorbs abrupt shock loads and green construction [7].

In present days, construction, demolition and restoration sites are a big source of large amounts of construction and demolition waste, which is in nowadays, simply dumped in landfills [3]. Using crushed concrete from demolition waste as concrete aggregate instead of natural materials on a large scale can make a significant contribution to preserving natural resources and to the reduction of the amount of demolition waste [2].

The selection of building materials can promote better quality of structures, faster construction solutions and foster new economic development. This selection will have to deal with “appropriateness” and “adequacy” within energy efficiency and environmental approaches for local conditions (social, economic, financial, institutional, environmental, etc.) [8]. Depending on the availability of the materials in a particular region, these materials can be selected as transportation consists of approximately 30% of total construction budget. In most developing countries, the challenge is to organize and initiate measures that promote these materials as well as train local artisans and masons in the construction techniques involving these materials. There have been several attempts at local levels to make use of bamboo, mud or natural fibers but it still lacks scientific precisions and proper techniques to be used precisely. Also the usage of industrial wastes still needs study on their better usage toxicity. These materials if studied and developed properly hold the key to address the current housing needs [9].

3. EXPERIMENTAL

3.1. Materials used

Plastic bottles of aerated drinks (600ml), plastic waste, saw dust, demolished concrete waste, bamboo sticks, chicken wire mesh, cement, P- Sand, steel wires and plastic wires.

Figure 1 Materials used

3.2. Bottle block for foundation

Experimental investigations for an innovative foundation block was done with two filler materials, namely, saw dust and demolished concrete waste. The filler materials were filled inside the bottles in 5 layers with 25 times compaction for each layer. It was carefully ensured that no voids enter the bottles while filling. After filling, the bottles were used to make block samples. A bottle block sample consisted of 4 bottles tied together.

3.2.1 Bottles filled with saw dust

The sample tied using thin steel wires (Figure 2) was then wrapped around in a casing made of chicken wire mesh. The voids in between the bottles and in the casing were filled using plastic wrappers (Figure 3). The sample made is of size 24 x 14 x 14 cm and weight 1.656 kg. It was, then, placed in a suitable cardboard box to make easiness for the test. The sample was tested for compressive strength (Figure 4).

3.2.2 Bottles filled with demolished concrete waste

Two blocks were made using demolished concrete waste as the filler material. One block - Sample 1 (Figure 5) consisted of four bottles filled with demolished concrete waste and tied using thin steel wires. The size of the sample is 24 x 14 x 14 cm and weight is 5 kg. A chicken wire mesh was placed in between the bottles of sample 1 to make the second block - Sample 2 (Figure 7). The size of the sample is 24 x 14 x 14 cm and weight is 5.12 kg. Sample 1 (Figure 6) and sample 2 (Figure 8) were tested to note its compressive strength.

Figure 2 Bottles filled with saw dust

Figure 3 Block placed in chicken wire mesh cage

Figure 4 Block loaded in CTM

Figure 5 Bottles filled with demolished concrete waste (Sample 1)

Figure 6 Sample 1 after testing

Figure 7 Chicken wire mesh placed in between the bottles (Sample 2)

Figure 8 Reading of sample 2 in CTM

3.3. Bottle panel for roof

Experimental investigations for an innovative roof panel was done by filling the plastic bottles with plastic wrappers and using bamboo sticks as reinforcing members (Figure 9). Holes were inserted in the bottles to insert the bamboo sticks (Figure 10). The 6 bottle units were then kept inside a mould made of wooden frame. A chicken wire mesh was placed above the bottle units and the voids were filled using baby metals (Figure 11). The upper layer was plastered with cement: sand ratio of 1:4 (Figure 12). The size of the bottle panel casted was 42.5 x 32 x 8 cm and the weight was 9.3 kg. The bottle panel was tested to note its flexural strength (Figure 13 & Figure 14).

Figure 9 Two bottles and one bamboo stick for a single bottle unit

Figure 10 Bottle units made using plastic wrappers as the filler material and bamboo sticks as reinforcement

Figure 11 Bottle units placed in wooden frame and chicken wire mesh placed above

Figure 12 Plastering the upper layer of the bottle panel

Figure 13 Bottle panel at its breaking pint when loaded in UTM

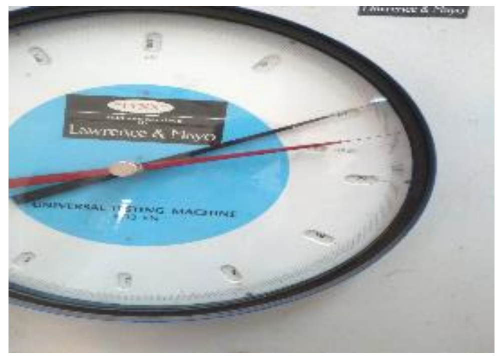

Figure 14 Reading shown in UTM

3.4. Conventional building blocks

A concrete block of size 30 x 20 cm and weight 19.38 kg (Figure 15) and a clay brick of size 20 x 10 x 10 cm and weight 2.8 kg (Figure 16) were tested for compressive strength to compare with the test results of the innovative block made using plastic bottles.

Figure 15 Concrete block loaded in CTM

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Figure 16 Clay brick loaded un CTM

4. CONSTRUCTIONAL DETAILS OF THE HOUSE

4. 1. Architectural plan of the house

The architectural plan (Figure 17) of a 400 sq. ft. single storey residential building was drawn satisfying all the primary requirements and the vasthu criterions of a basic housing. The house consists of a living cum dining room, a bedroom, a kitchen and a toilet.

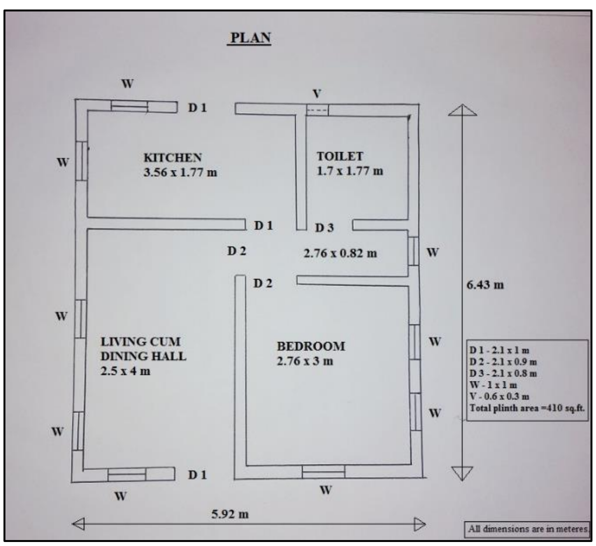

Figure 17 Plan of the house (1BHK)

4. 2. Materials and specifications for a cost effective house

4.2.1 Foundation and basement

Foundation and basement can be constructed using the innovative bottle blocks found through the experiments. Bottles filled with demolished concrete and a chicken mesh in between the bottle layers may be used for construction. Bottle blocks of size 24 x 14 x 14 cm may be used. The height and width of foundation and basement is 45 cm and 50 cm respectively. The estimated cost for a bottle block is ₹ 6 per block. The total number of bottle blocks required for foundation and basement are 2,532 bottle blocks.

4.2.2 Superstructure

The details of the materials and specifications for walls, columns, lintel, sunshade, doors and windows are given below.

Walls - The bottles can be filled with saw dust and demolished waste. The bottle bricks are laid following a suitable pattern, tied with nylon thread and bonded together with cement mortar with cement: sand ratio of 1:3 or clay as per the availability. Outer walls can be constructed using bottle bricks of size 24 x 7 x 7 cm and inner walls using bottle bricks of size 18 x 5 x 5 cm. The height of the walls is 3 m, the outer wall thickness is 26 cm and the inner wall thickness is 20 cm. The estimated cost is ₹ 2 per 4 bottle bricks and the total number of bottle blocks to be used for the outer walls are 4,670 bottle bricks. The cost is ₹ 1 per 4 bottle bricks and the total number of bottle bricks to be used for the inner walls are 14,040 bottle bricks.

Columns **-** The four corners joining the outer walls are constructed with columns. The columns may be constructed using brick masonry.

Lintel **-** Lintels made up of conventional concrete mix of M20 with 3 number of steel reinforcements wound in the form of a cage can be used. Lintels are to be provided only above doors and windows.

Sunshade **-** The sunshade is provided to a length of 60 cm from the wall. Sunshade is provided only above the windows, ventilation and exit doors.

Doors and windows **-** Medium class or Second class quality wooden doors and windows may be used. The size of the exit doors can be 2.1 x 1 m and the other doors may be of size 2.1 x 0.9 m and the bathroom door may be 2.1 x 0.8 m. The windows may be of size 1 x 1 m and the ventilation may be 0.6 x 0.3 m in size.

4.2.3 Roof

Roof may be constructed using the innovative bottle panel found through the experiments. A bottle panel consists of 6 bottle units filled with plastic wrappers as the filler material and treated bamboo sticks as the reinforcement. The size of a bottle panel is 42.5 x 32 x 8 cm. The bottle panels can be connected by holding the ends of the bamboo sticks in the grooves of the wooden rafters. The thickness of the roof may be decided as per the site conditions. Polythene sheet films and bituminous water proofing can be used, additionally, if required. The cost is ₹ 30 for a bottle panel. The number of bottle panels to be used for the roof are 280 bottle panels.

5. PROTOYPE OF THE HOUSE

A prototype of the plastic bottle house was constructed, according to the plan, in a reduced scale of 1:4. The materials used for the prototype were plastic bottles, dry sand, cement, M - Sand, construction waste, bamboo sticks and wooden frames. Around 1,500 bottles of capacity 250 ml and 100 bottles of capacity 600 ml were collected and used for making the house. The bottles for basement and walls were filled with dry sand and was given light compaction. After selecting a suitable location, the plan of the 400 sq. ft. house was transferred to the floor. Since foundation is an underground structure, the prototype was constructed starting from its basement. Basement, walls, and roof was constructed in different stages.

Bottles of capacity 600 ml filled with sand was used to make the basement (Figure 18). The bottles were bonded using cement mortar in the cement: sand ratio 1:5 (Figure 19). The outer walls were made using bottles of capacity 250 ml. The bottles were bonded using cement mortar in the cement: sand ratio 1:5 (Figure 20). Small concrete prisms were used as pillars in the four corners of the house (Figure 21). Cycle rims were used for lintels above doors and windows (Figure 22). The four sides were completed leaving space for the door and window openings (Figure 23).

Roof was made using bottles of capacity 250 ml. Holes were made on both ends of the bottles and bamboo sticks were inserted. The ends of the bamboo stick project outside from the bottles. The rafters for the roof were made using wooden frames. Connection was made by hammering the two ends of the bamboo sticks onto the wooden frame (Figure 24 & Figure 25). The roof was then placed above the walls (Figure 26). The elevation of the. prototype is shown in Figure 27.

Figure 18 Construction of basement

Figure 19 Completed stage of basement

Figure 20 Construction of outer walls

Figure 21 Concrete prisms placed in four corners

Figure 22 Cycle rims placed above openings

Figure 23 Completed stage of walls

Figure 24 Construction of roof

Figure 25 Completed stage of roof

Figure 26 Roof placed above the walls

Figure 27 Elevation of the prototype

6. RESULTS AND DISCUSSIONS

6.1 Foundation

The results of the experiments conducted to find an innovative block for foundation is tabulated in the table 1. The comparison of compressive strength of the various blocks is summarized in table 2.

Sl. No :	Filler material used	Weight of the block (kg)	Dimension (cm)	Load taken (KN)	Compressive strength (N/mm^2)
1.	Saw dust	1.608	24 x 14	80	2.38
2.	Demolished concrete waste - Sample 1	5	24 x 14	300	8.9
3.	Placing chicken wire mesh in between bottles of sample 1 - Sample 2	5.12	24 x 14	700	20.83

Table 1 Compressive strength of bottle block using various filler materials

Sl. No:	Component tested	Compressive strength (N/mm^2)
1.	Bottle block - Saw dust as the filler material	2.38
2.	Bottle block - Sample 1	8.9
3.	Bottle block - Sample 2	20.83
4.	Concrete block	3.5
5.	Clay brick	8

Table 2 Comparison of compressive strength

The obtained results indicate that the bottles filled with demolished concrete waste and a chicken wire mesh placed in between the layers yields the best results by giving a compressive strength of 20.83 N/mm^2. The sample can be used as a building block for foundation.

6.2 Roof

The result of the experiment to find an innovative panel for roof is given in table 3.

Sl. No:	Sample	Weight (kg)	Size (cm)	Breaking load (KN)	Modulus of rupture (N/mm^2)
1.	Bottle panel	9.3	42.5 x 32 x 8	24	4.98

Table 3 Flexural strength of the bottle panel

The obtained results indicate that the bottle panels yield the best results by giving a flexural strength of 4.98 N/mm^2. The sample can be used as a building panel for roof.

6.3 Estimation

The estimation of the house was done according to the plan of the house. The material cost and the overall cost of the plastic bottle building was estimated. The result is summarized in table 4 along the material cost and overall cost of a conventional house. The material cost and overall cost of a conventional building may vary according to the existing economic conditions.

Sl. No:	Type of house	Total plinth area (sq. ft.)	Material cost (□)	Material cost per sq. ft. (□)	Overall cost (□)	Overall cost per sq. ft. (□)
1.	Plastic bottle house	400	30,000	75	2,70,000	675
2.	Conventional house	400	1,30,000	325	4,00,000	1,000

Table 4 Comparison of the estimated cost of building

The obtained results indicate that the overall cost of a plastic bottle house (□ 675 per sq. ft.) is very low as compared to that of a conventional house (□ 1,000 per sq. ft.). Houses made of plastic bottle building components can, therefore, be used for construction of a low cost sustainable house.

7. CONCLUSION

- Conventional building materials can be replaced suitably with innovative building components without compromising the strength and durability of the structure made by it and satisfying cost efficiency criteria.
- Use of innovative materials with sustainable application such as plastic bottles can have considerable benefits including finding the best optimization in energy consumption of the region, reducing environmental degradation. Plastic bottles can cause the green construction by saving energy and resources, recycling materials, minimizing the emission, having significant operational savings and increasing work place productivity.
- Bottle block and bottle panel found out through the experiments, can be suitably adopted for a building. Structures built by these bottles show a good response against earthquake. Due to the compaction of filler materials in each bottle, resistance of each bottle against the load is 20 times higher as compared to bricks. The compressed filler materials, makes the plastic bottle building, a bullet proof shelter.
- Architectural plan of a 400 sq. ft. single storey residential building was drawn satisfying all the primary requirements of a house. Prototype of the plastic bottle house was also constructed according to the plan.

- Cost efficiency in construction sector can be achieved by adopting economically cheaper and locally available building materials, thereby reducing the usage of high quantity of conventional building materials and components.
- Cost comparison studies through the experiments show that the plastic bottle building achieve a good percentage economy in both material cost and overall cost.
- The challenging problem of plastic waste disposal is solved by using plastic bottle building components in construction industry so that cost efficiency is achieved simultaneously with decreased usage of conventional building materials.

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