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Architectural Solution to Economic and Environmental Challenges: The Generic Plastic Villa

Oluwole Alagbe^{a *}, Department of Architecture, Covenant University, Ogun State 103101, Nigeria.
Olaleye Busola^b, Department of Architecture, Covenant University, Ogun State 103101, Nigeria.
Aboderin Deborah^c, Department of Architecture, Covenant University, Ogun State 103101, Nigeria.
Audu David^d, Department of Architecture, Covenant University, Ogun State 103101, Nigeria.
Ladapo Jesupelumi^e, Department of Architecture, Covenant University, Ogun State 103101, Nigeria.

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Abstract

This paper proposes the use of waste plastic polyethylene terephthalate (PET) bottles as a construction entity instead of standardised bricks. Waste plastic bottles are a major cause of solid waste disposal. Today, the construction industry is in need of finding cost-effective materials for increasing the strengths of structures. The benefits of the use of PET bottles are improved ductility in comparison with raw blocks and inhibition of crack propagation after its initial formation. One of the main disadvantages in construction of houses is the high cost involved. Plastic bottle is considered as an urban junk with sustainability characteristics that can be used for construction of buildings. This paper investigates the application of plastic bottles for sustainable development. The solution offered in this paper is one of the answers to the long-standing menace of unemployment, waste disposal and poor conditions of living.

Keywords: Plastic bottle, sustainable material, sustainable development, urban wastage, construction material.

* ADDRESS FOR CORRESPONDENCE: **Oluwole Alagbe**, Department of Architecture, Covenant University, Ogun State 103101, Nigeria.

E-mail address: oluwole.alagbe@covenantuniversity.edu.ng/Tel.: +243 903 355 00 46

1. Introduction

The use of plastic bottles in construction is not new, but is one that is yet to become accepted and implemented by the citizens of Nigeria.

Through this research it is our hope that the highlighted issues in the nation, whether environmental or economic, gain a permanent solution.

A general overview of how to construct a plastic bottle building by Kutner (n.d.) is given as follows:

1. Make sure your community is involved and that you have a safe/approved location to build.
2. Make sure you have a budget and enough funding.
3. Collect and stuff bottles and gather lots of inorganic trash. Each bottle and all of the stuffing material has to be rinsed in water and dried. Paper, dirt and rocks cannot be used.
4. Set up a frame, foundation and roof comprised of either wood, metal or cement columns.
5. Start putting chicken wire on the outside of the frame, then work on the inside in sections, putting in the bottles, while you slowly connect the inside layer of chicken wire to the outside, securing the bottles tightly.
6. Continue section by section, until the bottles are placed, then stuff all empty leftover spaces with inorganic trash.
7. Test the cement mixture (no limestone) to make sure it sticks. Then start placing the first layer of cement.
8. When this dries, start a second layer.
9. Finish with a third layer, then lay the flooring.
10. Inaugurate and celebrate! (Keiren, 2017)

However, the twist to this comes in at step 3, where we intentionally place a seedling of the English ivy plant in the bottles at specific locations facing the exterior of the building, allowing the creeping plant to grow on the exterior of the building.

2. PET Plastic

Full name: Polyethylene terephthalate, Molecular formula: $C_{10}H_8O_4$

Polyethylene terephthalate ethylene (PETE) bottles are thermoplastic materials. This type of plastic are polymers and with or without cross linking and branching, and they soften on the application of heat, with or without pressure and require cooling to be set to a shape.

The following are the properties of plastic bottles.

Structure:



Figure 1. Shape of plastic bottles (Shoubi, Shoubi, & Barough, 2013)

Composition: Polyester of terephthalic acid and ethylene glycol (Begley, Dennison, & Hollifield, 1990; Freire, Castle, Reyes, & Damant, 1998).

Properties:

- White or light cream material
- Density 1.33220 gm/cm³
- M.P. – 255 to 2650C
- Solubility – insoluble in water
- It is heat resistant and chemically stable. PET is resistant to acid, base, some solvents, oils and fats. Difficult to melt and transparent.

2.1. Type of Soil that Can Be Used to Fill a PET Bottle

Table 1. Diameter of soil particles (Raut, Patel, Jadhwar, Khan, & Dhengare, 2015, p. 4)

Soil particle	Diameter (mm)
Gravel	>2.0
Sand	0.05–2.0
Silt	0.002–0.05
Clay	<0.002

3. Column and Beam Construction

Columns are vertical structural members of any building connected to beams and horizontal structural members, to see to its proper framework. There are two common methods used in the construction of the structural members of a plastic bottle building:

- Construction of columns and beams using reinforced concrete only.
- Construction of columns using reinforced plastic.

3.1. Construction of Columns and Beams Using Reinforced Concrete only

In this method of construction, cement, sand and aggregate in the mixture ratio of 1: 1.5: 3, respectively, are poured into the formwork for the column and beam with reinforced steel within the formwork, and allowed to cure for about 7 days before the formwork is removed.



Figure 2. Column and beam in plastic bottle masonry construction

3.2. Construction of Columns Using Reinforced Plastic Bottles

This entails the use of plastic bottles braced together by steel reinforcement and cement to form the structural framework of the plastic bottle building construction. The columns are mostly circular or square shaped. The circular columns are constructed by locating the centre and fixing a steel reinforcement there. The plastic bottles are then placed with respect to the center, thereby forming a circular pattern. Other sets of plastic bottles are then laid on each other in layers in such a way that each layer is anchored to both the layers above and beneath with cement and steel reinforcement. This is done over and over again until the required height is reached.



Figure 3. Circular column using reinforced plastic bottles
Source: Building support columns from plastic PET bottles.

The square column is derived by laying plastic bottles side by side and braced together with the use of cement and steel reinforcement following the square-shaped pattern. The layers that form the height of the column could either be placed in opposite directions as shown in Figure 5 or in the same direction.



Figure 4. Square column using reinforced plastic bottles
Source: The houses that PET plastic built – Recycle bank.

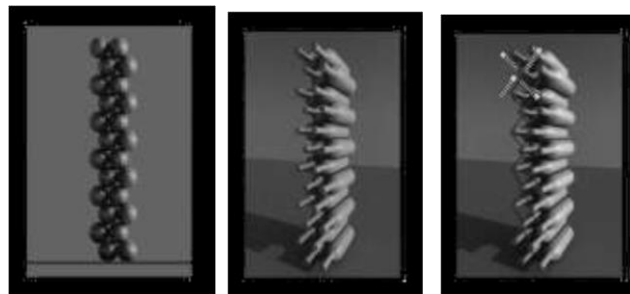


Figure 5. The way of putting the bottles on each other (Shoubi, Shoubi, & Barough, 2013)

4. Wall Construction

Wall masonry construction with the use of plastic bottles requires some basic materials that provide a stable and eco-friendly structure. They include soil, plastic bottles, cement, nylon rope and water. The plastic bottles are filled with earth or gravel and anchored with cement to the already laid foundation. They are further placed on each other to form a small thin line on the surface such that they support themselves and then are braced together with cement and steel reinforcement. While the masonry process with the plastic bottles is going on, the placement of windows and doors are also taken into consideration. Figures 1 and 5 describe the shape of bottles and how they should be put on each other respectively. They were simulated in the 3D Max software (Shoubi, Shoubi, & Barough, 2013).

It has been proven that walls built with filled bottles are lighter, cheaper and more sustainable than walls built by brick and block, thereby making these buildings show good response against structural disaster. It is important to note that the larger the building, the more the bottles required to raise the wall.

5. Climbing Plants

These are a versatile group of plants known for their ability to climb up trees and other objects. Climbing plants are used to screen unsightly areas, cover fences, walls, pergolas, etc. Climbing plants provide a form of shade when utilised in structures as well as a cooling effect on structures due to photosynthesis. Climbing plants come in a variety. Some climbing plants need support to host them while climbing while other climbing plants possess the ability to cling to surfaces naturally without the need for support. A good example of climbing plants that climb without support is the English ivy. The English ivy possesses attractive attributes when they spread over a surface area. They spread through the use of air roots and branching shoots that generate an adhesive substance enabling English ivy to climb without the need for support.

5.1. Properties of English Ivy

- They possess shallow roots, making them less likely to cause damage to buildings.
- The wide spread of ivy in the form of a blanket while climbing enables it to block sunlight from penetrating into structures, which could bring thermal discomfort within the interior.
- The possession of a sticky substance (sap), which helps the English ivy to cling to surfaces, allows shoots to extend for 20 feet or more in search of sunlight and water.

5.2. Root System

The root system of the English ivy is a combination of main soil-based roots. These roots cater to the major stems of the plant and air roots formed along the branches. As the shoots begin to form, air roots produce a sticky substance that helps the ivy plant to climb and cling unto surfaces. This also contributes to plant photosynthesis.

5.3. Plant Placement

When planting a climbing plant, ensure that they are spaced 30–45cm away from the base of the wall to enable them receive enough rain water supply to the roots.

Ensure a sturdy support for the structure to avoid adventitious roots causing collapse to the structure.



Figure 6. Picture showing green effect of ivy on buildings

Source: <https://goo.gl/images/ObtJgT>

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Figure 7. Picture showing air roots along an ivy stem

Source: <https://pestid.msu.edu/weeds-and-plant-identification/english-ivy-hedera-helix/>

6. Case Study

Location: Sabon Yelwa, Kaduna Nigeria.



Figure 8. Generic plastic bottle used to construct the structural elements of this building

Source: Field study (2016).

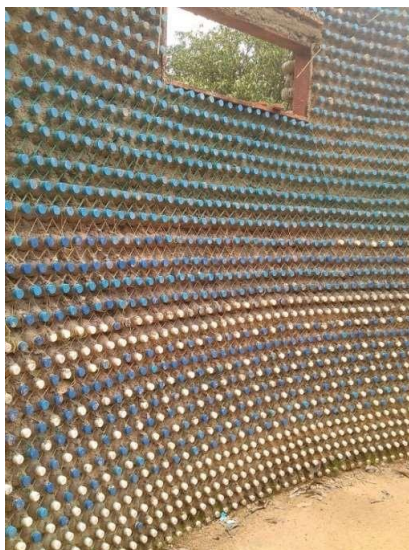
The project was initiated by the Kaduna-based NGO Development Association for Renewable Energies (DARE), with help from foreign experts from the Africa Community Trust, a London-based NGO. AFP PHOTO it is in many ways a marvel to look at. The idea undoubtedly seemed strange at first: take the plastic water bottles that litter Nigeria's roads, canals and gutters and allow people to live inside them. Not literally, but almost. What a group of activists did was come up with a plan to build a house using these bottles, providing what they say is an environmentally smart strategy of chipping away at a housing shortage in Africa's most populous nation. With the prototype near the northern Nigerian city of Kaduna now well underway, the group wants to extend its efforts and build more, aiming to unleash what they say is some long bottled-up potential. Unconvinced? Supporters say those yet to see the structure on the outskirts of the village of Sabon Yelwa can throw stones if they want to. This house is being built to last.



**Figure 9. Column arrangement and adjoining wall made with plastic bottles, cement and steel reinforcement
Source: Field study (2016).**

‘This is the first house in Africa built from bottles, which could go a long way in solving Nigeria’s huge housing need and cleaning the badly polluted environment’, project initiator Christopher Vassiliu said during a tour of the building.

A man builds on a wall with plastic bottles in the village of Sabon Yelwa, near the northern city of Kaduna. The idea undoubtedly seemed strange at first: Take the plastic water bottles that litter Nigeria’s roads, canals and gutters and allow people to live inside them. Sitting on 58-sq m (624 sq ft), the two-bedroom bungalow looks like an ordinary home, but it differs in many ways. When completed, the house whose construction started in June will be used to train masons in building such structures. It is made from capped, sand-filled plastic bottles, each weighing 3 kg, or nearly two pounds. The bottles are stacked into layers and bonded together by mud and cement, with an intricate network of strings holding each bottle by its neck, providing extra support to the structure. Bottle caps of various colours protrude from the cement-plastered walls, giving them a unique look. Those behind the project claim the sand-filled bottles are stronger than ordinary cinder blocks. ‘The structure has the added advantage of being fire proof, bullet proof and earthquake resistant, with the interior maintaining a constant temperature of 18 degrees C (64 degrees F) which is good for tropical climate’, Yahaya Ahmad, the project coordinator said. ‘Three million bottles daily – With the right adjustments to the supporting pillars the building can be as high as three stories, but can go no higher due to the weight of the sand-filled bottles’, Ahmad said. Situated amidst an expansive irrigation farm, the building consists of a rotunda-shaped living room which connects to the interior via a short corridor. Two rooms stand opposite, with a bathroom and a toilet between them. A side door leads to an open courtyard and the kitchen. The house is also designed to produce zero carbon emissions as it will be wholly powered by solar panels and methane gas from recycled human and animal waste.



**Figure 10. Stacks of already laid bottles forming a wall structure
Source: Field study (2016).**

‘Nigeria has a serious waste and energy problem, and this project is one small step towards making positive changes’, said Katrin Macmillan, a British environmental activist involved in the project. ‘Plastic bottles take hundreds of years to bio-degrade in landfills’. Construction, which has reached 70% completion, is estimated to require 14,000 bottles. Huge piles of empty plastic bottles litter the site from donations from embassies, hotels and restaurants.

Environmental experts say Nigeria, a country of some 160 million, throws out about three million plastic bottles daily. The country is also grappling with a deficit of 16 million housing units that requires a staggering 45 trillion naira (\$300 billion) to meet, according to Nigeria’s Federal Mortgage Bank. Plastic houses are cheap to construct as it costs a quarter of the money required to build a conventional house, said Vassiliu, a Greek national who has been working in Nigeria as a water drilling engineer for 30 years. The project is to cost two million Naira (\$12,700), Vassiliu said. A second plastic bottle project is due to commence in January at a primary school in need of more classrooms in the town of Suleja near Nigeria’s capital Abuja. ‘The project would take 200,000 bottles out of landfills into education’, said Macmillan.

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