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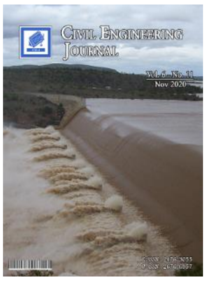

Review Article

Exploration of Waste Plastic Bottles Use in Construction

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Abstract

The vision of this study is geared towards the exploitation of waste plastic bottle use in construction. This review paper is centers on the recycling of waste plastic bottles as a construction material as an effort to help solve the housing deficit in most developing countries including Ghana and to save the depletion of natural resources construction materials. In Ghana, plastic wastes are discarded randomly after usage, hence scatter around in cities, choking drains, and end up threatening our ecosystem. These predominant effects from the plastic wastes have necessitated the need for countries precisely developing countries including Ghana to seek more sustainable methods to reduce the drastic amount of plastic wastes in the environment. In view of the above, this paper focused on the recycling of waste plastic bottles as a construction material as an effort to solve the housing deficit in most developing countries including Ghana and to save the depletion of natural resources construction materials (stones and sand) are very much critical. In the reviews, an effort has been made to utilize the waster plastic bottles in construction by filling the bottles with soil, sand, solid waste materials as brick or block bounded with mortar as a masonry wall or the filled bottles are used as a substitute for the production of the masonry unit production. In summary, it was concluded based on varying test result that: (1) Plastic waste bottles are cheaper to acquire than most conventional construction materials and as such concrete or brick containing any amount of plastic bottle is noted to reduce the total quantities of conventional materials required, thereby reducing the cost as well. (2) The use of plastic waste bottles in construction contributes to environmental friendliness and energy savings since buildings with walls constructed of plastic bottles maintains room temperatures and contribute to energy saving and the cost of providing an artificial thermal control system.

Keywords: Waste Plastic Bottles; Construction; Materials; Masonry Unit.

1. Introduction

The vision of this study is geared towards the exploitation of waste plastic bottle use in construction. This review paper is centers on the recycling of waste plastic bottles as a construction material as an effort to help solve the housing deficit in most developing countries including Ghana and to save the depletion of natural resources construction materials.

According to Zaman and Lehmann (2011) [1], in the surface of the world, cities cover only 2% however generate about 70% of the world's waste. This presupposes that more wastes are generated in the urban areas as compared to the rural areas. Wilson (2007) [2] is of the view that a considerable upsurge in the volume of wastes produced commenced around the sixteenth century when people started to migrate from rural settings to cities due to industrial

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revolution. Further to that, Williams (2005) [3] opines that it was then that objects like glass and metals appeared in large quantities in municipal waste stream. In support of the ongoing, the findings of Tchobanoglous et al. (1993) [4] suggest that the great population of people in cities has resulted to littering and open dumps till date as most countries continue to battle with effective waste management to curtail the outbreaks of epidemics with high mortality rate. Nonetheless, the nineteenth century saw public officials discarding waste in a meticulous manner with the aim of protecting public health [4]. In addition to the above, Rajput et al. (2009) [5] observe that the swift of escalation in production and consumption has resulted to the state where most urban societies reject and rather generate solid materials regularly. According to the researchers, such situation has contributed significantly to the increment in the volume of waste produced from several sources comprising institutional wastes and industrial wastes, commercial wastes as well as domestic wastes. Furthermore, wastes that may arise from a typical urban setting may constitute garbage, rubbish (package materials), construction and demolition wastes coupled with leaf litter, hazardous wastes among others. In a study by Oteng-Ababio (2014) [6], Accra the capital city of Ghana will produce about 4419tonnes of waste by the year 2030. This looks threatening to mankind and the environment if sustainable waste management (SWM) policies are not implemented. Consequently, the Supreme Court Committee Report (1999) [7] establish that the level of service in many Indian urban setting is very poor that there may be a threat to the public health and environmental quality. However, Oteng-Ababio (2014) [6] postulates SWM policies that will ensure efficient waste collection, segregation, transportation, re-use, recycle, storage, treatment and disposal are noted to promote health and environmental safety in any given urban area.

Waste in simple term can be defined as something that its holder has gotten rid of, that is disposed of or discarded. Brunner and Rechberger (2014) [8] establish that most human activities are bound to produce waste. Regardless, Chandler et al. (1997) [9] aver the generation of wastes continue to be a key source of concern from pre historic times. More so, recent times have seen an increment in the rate and quantity at which waste is generated. To this effect, the study of Vergara and Tchobanoglous (2012) [10] proves that as the volume of wastes increases, similarly does the diversity of the waste increase. It is however imperative to establish that during the pre-historic era, wastes were perceived as a nuisance that had to be discarded without any thought of recycling. Tchobanoglous et al. (1993) [4] reveals that effective waste management was not of prime concern in the pre-historic era given that the population was relatively smaller with massive amount of land available to the population at that time. According to the researchers, in those days, the environment effortlessly absorbed the volume of waste generated without any form of degradation. Most importantly, this is not the case in the 21st century where there is a wider application of science and technology in every jurisdiction of man's life and his society which calls for the effective recycling of waste. In throwing more light on the concept of waste for a better comprehension, the Basel Convention (1989) [11] explain that wastes are viewed as materials or substances, which may have been disposed of or are intended to be disposed of by means of provisions of national law. More so, the United Nations Statistics Department (2001) [12] expands that waste may refer to things that are not principal products in which the producer has no more use in terms of their own aims of production, transformation or consumption, and of which they may want to dispose. In corroboration to the foregoing, the European Union (2008) [13] avers waste is a material that the holder rubbishes, intends to rubbish it or is intended to be discarded. In making substantive deductions from the ongoing submissions, the underlying factor herein is that waste is an unwanted substance or material that ought to be disposed of. This position is also held by Basu (2009) [14] where he avers that waste is any product or substance that is unserviceable to the producer. In a similar angle, Dijkema et al, (2000) [15] advances, wastes are substances that individuals would want to discard even when costs are necessitated for their discarding. It is rather noteworthy that waste is a critical product of human activities, this also presupposes that it is as a result of ineffective processes during production whose constant production is a loss of vital resources [16]. In Ghana, most of the wastes generated are largely from municipals or households where various human activities are observed. Studies has shown that about 55-80% of total wastes generated constitute household waste with the lesser percentages produce from commercial areas including markets, streets, institution, etc. The composition of these generated wastes are mainly food, wood, plastics, papers, metals, leathers, rubbers, batteries, textiles, construction and demolishing materials and others Miezah et al. (2015) [17]. Inferring from the latter assertion, White et al. (1995) [18] points out that waste could be categorized largely into three principal types according to their physical states; liquid, solid and gaseous waste. The most predominantly used classification are;

- Physical State – solid waste, liquid waste and gaseous waste;
- Source - Household/Domestic waste, Industrial waste, Agricultural waste, Commercial waste, Demolition and construction waste and Mining waste;
- Environmental Impact – Hazardous and Non-hazardous wastes

Plastics are reported to be the second largest quantity of total wastes generated in Ghana after organic wastes Miezah et al. (2015) [17]. Since organic wastes are highly biodegradable hence does not pose much threat to the environment. On the contrary, plastics are noted to be non-biodegradable with lifespan of about 300years hence considered as a sustainable waste and environmental pollutant Battistelli et al. (2020) [19].

Plastic is defined by UNEP (2018) as a lightweight hygienic and resistant material capable of being fabricated in various ways and exploited in a wide range of applications. They are mainly grouped into thermoplastics (plastic that can be melted when heated and hardened when cooled and thermosets (plastics that undergo a chemical change when heated). Furthermore, thermoplastics such as Polyethylene Terephthalate (PET), Polypropylene (PE), Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE) and Polystyrene (PS) are reversible whereas the thermosets which includes Polyurethane (PUR), Phenolic resins, Epoxy resins and Silicone are not reversible UNEP (2018). It was further reported that the production growth rate of plastic is higher than any other material and as such its packaging is mostly single – use, hence making plastic constitute about 50% of global waste generated in 2015 about 300million tonnes UNEP (2018). According to Hassanpour and Unnisa (2017) [20], plastic products in enlightening and developing countries are increasing by the day partly due to financial requisite and human demand. The authors further postulate while just a portion of the total plastic wastes are recycled in many emerging nations, roughly 95-75% of them appear to be retrieves in developing countries. The study of Hammer et al. (2012) [21] expatiates that the term plastic traces its roots from the Greek word 'plastikos,' which denotes capable of being formed or molded. It thus goes to say that plastic has become a general term (GESAMP, 2015) [22] denoting to the large variety of substances made from polymers and additives that can be formed and cast into various shapes [23]. To this effect, the study of Kershaw (2016) [24] explains that polymers could be synthetic or natural whereby the natural polymers include materials such as cellulose, protein fibre (silk, wool) and starch. In addition, the investigations of Edmondson and Gilbert (2017) [25] elucidate that the polymers that constitute plastics appear as long molecular chains created from joining short recurring sub-units in a chemical reaction termed as polymerisation. The researchers further opine that the physical characteristics of these exceedingly long, intertwined and flexible chains of molecules provide many plastics with their strength and flexibility.

Given the versatility of utilizing plastics, Freinkel (2011) [26] is of the view that almost all walks of human life entail plastics in diverse forms with various applications going from cling film to bullet-proof fibers such as Kevlar. Also, the studies of Andrady and Neal (2009) [27] in corroboration to that of Gilbert (2017) [28] affirm that plastics find application in many products through every industry not limited to construction, electronics, transportation, agriculture and healthcare. Due to the fact that plastics are strong, lightweight, low-cost to produce and effortlessly formed into various shapes and colours, Giacovelli (2018) [29] avers plastics are mostly employed for single-use items, like food and beverage packaging, straws, plates and cutlery, cigarette filters and disposable cups. It is however noteworthy that because such items are manufactured as low-cost objects, they are often disposed of rapidly as trash. Evidence from the findings of Geyer et al. (2017) [30] proves that plastics that make up the majority of the world's total plastics manufactured comprise polyethylene (PE), polypropylene (PP), polystyrene (PS), polyurethane (PUR), polyethylene terephthalate (PET) and polyvinylchloride (PVC).

According to Geyer et al. (2017) [30], the rise in the production of global plastics has overtaken that of almost other material in history. This is partly due to the immense growth of plastics employed in everyday applications. It is noteworthy that the year 2015 saw 407 million tonnes of plastics manufactured worldwide with over 302 million tonnes of plastics disposed of as waste. Should these statistics in the growth rate of the plastics industry persist, the World Economic Forum, Ellen MacArthur Foundation, and McKinsey & Company (2016) [31] are of the view that the global production could generate approximately 1124 million tonnes of plastics yearly by 2050. In addition, European Bioplastics (2019) [32] assert while bioplastics may also contribute just a meagre portion of the general plastics industry, it is evident that the global bioplastics industry is also rising steadily. To this effect, it is envisaged to increase to roughly 2.6 million tonnes by 2023. For instance, data from StatsNZ (2019) [33] reveal that New Zealand imported more than 300 thousand tonnes of plastic resin to be employed in the production of products in the year 2017. The statistics further indicate that plastics also constituted a major factor in 49% (by worth) of textile and textile article imports 85% of footwear imports, and 27% of fishing rods imports. Further to that, it is revealed that in the same year, New Zealand exported 41.5 thousand tonnes of plastics as unwanted.

The UNEP (2018) report additionally indicated that, the end life of plastics is widely 9% recycled, 79% landfilled and 12% dumped in the environment. Subsequently, it was cautioned in the reported that if the current consumption patterns and waste management practices are not improved, about 12 billion tonnes of plastic litter in landfills and the environment will rise tremendously by 2050.

2. Methodology

This study adopts the qualitative content analysis approach to review related literature geared towards the exploitation of waste plastic bottles use in construction. By this, the researcher is able to identify the feasibility in the usage of the waste plastic bottles in construction. As epitomised by Mayring (2000) [34], this type of research approach defines itself as a method of empirical, procedural meticulous analysis of texts contained by their framework of communication, following content analytical rules, devoid of hasty quantification. In simple terms, the goal of qualitative content analysis could be all manner of documented communication not limited to documents, transcripts of interviews, discourses, protocols of observations among others. Similarly, Krippendorff (1969) [35] adds that content analysis denotes the utilization of replicable and effective method for making definite extrapolations from text to other states or properties of its source. In summation to the above, qualitative content analysis connotes the methodical reading and extrapolation of a body of texts and symbolic matter, not essentially from an author's or researcher's perspective [36].

3. Effects of Plastic Waste

According to Clunies-Ross (2019) [37], plastics make up for hundreds of millions of tonnes of unwanted materials annually. This is buttressed by Geyer et al. (2017) [30] where they affirm more than three hundred million tonnes of plastic were disposed of in the year 2015. In light of this statistics, the packaging contributed for approximately half of the waste. Empirical studies from the authors above indicate that across the globe, plastics discarded through managed waste streams are mostly sent to landfill, recycled or incinerated. The research conducted by Barnes et al. (2009) [38] indicates that the mainstream of plastics manufactured are still in existence. Advancing on this status quo, Kershaw (2016) [24] believes that it is just this past 15 years that investigators have begun to comprehend the complication and magnitude of this issue. In citing a typical scenario, Derraik (2002) [39] contents plastics lost to our natural environment could pose ecological effects by altering the structure of the soil thereby, upsetting the plant life and microbes there. Consequently, plastic pollution may have adverse impairment on habitats thereby causing a reduction in biodiversity. Subsequently, this could impact negatively on health and welfare. This threat according to Gall and Thompson (2015) [40] could persist, and get worse, should there be continuous input of plastics into the environment. Inferring from the assertions of Edmondson and Gilbert (2017) [25], they are of the position that the impacts of plastics on seabirds and marine animals are best comprehended. Data from the Ministry of the Environment and Statistics, New Zealand (2016) establishes that several species have been affected and are uncommon and threatened, including some of New Zealand's marine birds and mammals. The study of Williams (2006) [41] reveals that the presence of plastic waste could impact negatively on life force and the environment. Implicit in the foregoing, it is evident that such circumstances could have dire effects on cultural health and wellbeing. In buttressing the ongoing submissions, it is evident in the work of Gregory (2013) [42] that plastic pollution could endanger animals through entanglement. This often impacts negatively on the ability of an animal to move, escape predators, eat and effectively undergo reproduction. This presupposes that in most cases, such animals are bound to die if they are unable to escape the entanglement. This global issue could affect many species, comprising marine mammals, turtles and birds.

Regarding environmental and heat effects, most plastics under the influence of light, heat or mechanical pressure can decompose and release hazardous substances. Also, some of the plastic when burnt is noted to pollute the environment with bromine emissions – including CO_2 emission being major contributor to global warming. Others produces pigments or colorants which can contain heavy metals such as chromium, copper, cobalt, lead and cadmium that are highly toxic to humans. In Ghana, plastic waste (polythene, PET bottles, sachets rubbers, etc.) are discarded randomly after usage, hence scatter around in cities (Figure 1), choking drains (Figure 2), and end up threatening our eco system, damaging soils and polluting our beaches (Figure 3).

The predominant effect from the plastic wastes has necessitated the need for countries precisely developing countries including Ghana to seek more sustainable methods to reduce the drastic amount of plastic wastes in the environment Ghansah et al. (2015) [43]. Two methods were proposed by Ghansah et al. (2015) [43]: (1) preventing waste generation by ensuring less primary materials are used in production processes and designing products that are recyclable and (2) recycling of waste products in order to be reused for other purposes. Recycling the plastic waste was however reported by same author as the most sustainable method because it's noted to be environmentally friendly.

Focuses on recycling of plastic wastes (preferably PET Bottle wastes) as construction material to help solve the housing deficit in most developing countries including Ghana and to save the depletion of natural resources construction materials (stones and sand) are very much critical.

Figure 1. Street Polluted with Plastic Waste

Figure 2. Drain Choked with Plastic Waste

Figure 3. Beach Polluted with Plastic Waste

4. Studies on Plastic Waste Bottles Use in Construction

Chaurasia (2019) [44], conducted a study aimed at ascertaining the benefits of using municipal plastic waste in building with emphasis on comparing the behaviour of plastic waste bottle panel with brick, ceramics and concrete blocks. To ensure a stable, eco-friendly structure and cheap construction, a plastic waste bottle masonry wall and roof were constructed with soil, plastic waste bottle, cement, nylon robe and water as the basic materials. Furthermore, a toilet structure of circular shape, 1000 mm internal diameter, 1450 mm height and 270 mm thick wall was constructed. The study also included the construction of two number (2No.) hanging garden walls of size 4000×4000 mm using same basic materials. In all, a total of 825 number of plastics waste bottles of 70 mm diameter and 270 mm length were utilized in the project. In the same study, a test was conducted on the plastic waste bottles filled with soil to ascertain its properties with respect to compressive strength, water absorption, weight and volume. The corresponding results are presented on Table 1.

Table 1. Test Results from Soil Filled Plastic Waste Bottle [44]

Type of Test	Result
Compressive strength	45 N/mm^2
Water Absorption	0 %
Weight	1.5 kg
Volume	0.001 m^3 (1L)

Based on the results in Table 1, the following conclusion was drawn from the study:

- **Water Absorption:** The 0% water absorption property of the soil filled plastic waste bottle makes it a more versatile construction unit that possess more advantages. For example, its inclusion in concrete will apart from cost reduction, also reduce the quantity of additives required to improve its water absorption properties. Furthermore, such concrete can help fight frost defects (freezing and thawing) especially when the soil for filling the plastic bottles is well dried. In addition, the good water absorption property of the soil filled plastic waste bottle unit, the thermal and sound insulation properties of a room with walls constructed of this product can be improved.

- **Weight:** Regarding the weight, this can vary based on structural purposes. For lightweight structures, the soil for filling can be replaced with lightweight materials such as saw dust and palm kernel shell or used empty without filled. However, for structures which requires heavy weight such as gravity retaining walls, the soil for filling can be replaced with cement sand mortar, water, concrete, damp sand, etc.

- **Volume:** The data from the study indicate that, the soil filled plastic waste bottles, occupied 0.615 m^3 (615bottles of 1litre per bottles) of the required wall of volume 0.6391m^3 representing 96.2% with mortar as joint representing 3.8%. This indicates much cost savings since its will cost very less to acquire the plastic waste bottles as well as the soil for filling.

In another study by Dhage-Niranjan et al. (2018) [45], plastic PET bottles were used as a replacement for conventional bricks. In the methodology, waste plastic bottles sourced from hotels, stores and waste collections were filled with local available sieved soil and sealed after compaction with tamping instrument. The cost and structural strength of the soil filled waste PET bottles were determined and compound to the conventional clay burnt brick. In conclusion, it was reported that:

- No curing time is required in using the waste PET bottles as a masonry unit;
- Emission of CO_2 into the atmosphere in baking conventional burnt bricks is eliminated with the adoption of waste PET bottles bricks;
- PET bottle takes over 300 years to decay, hence more durable than standard bricks;
- Since waste PET bottles are cheaper to acquire, the PET bricks are more economical than the standard brick.

The compression strength of the PET bottles brick was nearly equal to standard brick hence ideal to be used for both internal partitions and external walling in frame structures.

Safinia and Alkalbani (2016) [46] performed a study by using plastic waste bottles in concrete blocks with the prime aim of examining the possibility of utilizing the plastic waste bottles as a substitute in concrete block production. Traditional hollow concrete blocks of size 200×200×400 mm were obtained from market and tested for compressive strength. Furthermore, concrete blocks of same size embedded with plastic bottles placed vertically were produced according to ASTM C140 requirements and tested at 7, 14 and 28 days respectively. The average result after 28days indicates weight of 20.08kg and compressive strength of 6.38MPa for the traditional hollow blocks, whereas 24.85kg and 10.03MPa were recorded from the plastic bottles block. It was noted from the study that, the use of the waste plastic bottle in concrete block masonry do not only contribute in solving the problem of seeking alternative use for the plastic waste, but also improves the properties of the masonry in terms of weight and strength.

Mokhtar et al. (2016) [47] conducted a research on the application of plastic bottles as a wall structure for green house as an alternative solution to reduce CO_2 emission into the environment. In the study, sand was used to fill waste plastic bottles and compacted with tamping rod. The properties with respect to compressive including both indoor and outdoor temperatures where determined and compared to traditional clay bricks. The maximum compressive strength of the 38.34N/mm^2 was recorded for the plastic brick, which was about 3-4 times higher than the standard clay brick (maximum of 8.58N/mm^2). Additionally, the plastic bottle bricks, and the clay bricks were each used to construct an eco-house. The indoor and outdoor temperature readings recorded from the eco-houses indicates similar results. In conclusion, the study confirmed the ability of the waste plastic bottles bricks to replace the traditional clay bricks based on the corresponding results on the strength and temperature properties comparisons.

Research on reusing plastic bottles as an alternative sustainable building material was conducted by Mansour and Ali (2015) [48]. From experiment, waste PET bottles blocks were prepared and bonded with cement and sand mortar. The waste bottles were initially filled with dry sand, saturated sand and others with air filled to produce three (3) different blocks samples which were later subjected to structural and thermal examination. The corresponding results are presented on Table 2.

Table 2. Test Results from Filled Plastic Waste Bottle [48]

Sample Description	Compressive Strength (kN/m^2)	Bulk Unit Weight (kN/m^3)	Thermal Resistance (ºC/W)
Bottles block filled with sand	623	17.67	9.09
Bottles block filled with saturated sand	609	19.59	1.93
Air filled bottle block	670	11.02	18.97

The deduction drawn from the result presented on Table 2 demonstrates that the strength of the air-filled plastic bottle block is a little higher and additional has a better thermal resistance than the other types of bottle fillings. Furthermore, the result confirms that the waste PET bottles has the potentials to be used as building materials and as such contribute to the solving of the waste disposal burdens. However, the used of air-filled plastic bottle blocks will greatly contribute to energy saving cost in providing artificial thermal control systems in rooms.

Fataniya et al. (2015) [49] conducted a study to check the compressive strength of cement masonry block substituted with waste plastic water bottles of 1000 mL capacity. The following four types of blocks of same size, 400mm long, 200mm wide and 200mm height was produced.

- Block without plastic bottle (solid blocks);
- Blocks with empty plastic bottles;
- Blocks with plastic bottles having solid plastic waste (polyethene bags and wrappers);
- Blocks with plastic bottles having solid waste and wrapping of net around bottle.

The compressive test result after 28days is indicated on Table 3.

Table 3. Compressive Test Result of Blocks Types [49]

S/N	Type of Block Spacemen	Compressive Test Result (N/mm^2)
1	Block without plastic bottle (solid blocks).	10.97
2	Blocks with empty plastic bottles.	7.9
3	Blocks with plastic bottles having solid plastic waste (polyethene bags and wrappers).	10.03
4	Blocks with plastic bottles having solid waste and wrapping of net around bottle.	10.58

Comparing the compressive strength of blocks type 1, 3, and 4 from Table 3, the corresponding result is near about the same. However, in terms of cost savings, block type 3 is more economical to produce. In addition, bock type 2 and 3 can results in improved compressive strength if the substituted plastic bottles are filled with high dense fine materials.

Kamaruddin et al. (2017) [50] conducted a study to ascertain the potential use of plastic waste as construction materials. To this effect, they sought to focus on a review of recent studies and future prospects. Findings from their study revealed that two forms of plastics are commonly employed as building materials. These are plastic aggregate (PA) and plastic fibre (PF). PAs are predominantly utilized to substitute coarse aggregates (CA) as well as fine aggregates (FA). It revealed that, the PA rather holds a lesser bulk density in comparison to granite, or basalt. In support of the ongoing findings, Gu and Ozbakkaloglu (2016) [51] affirm that plastic aggregates are rather being utilized for lightweight concrete. PAs could be gotten by employing mechanical recycling method. In contrast to the foregoing, Yin et al. (2015) [52] are of the view that plastic fiber (PF) are employed as reinforcement and this could substitute common steel fibre. In such cases, it could lead to an improvement in mechanical and strength durability. Inferring from the works of the authors mentioned here, it is evident that empirical findings indicate that the utilization of recycled plastic aggregates and fibers as fractional aggregate substitute is rather gaining substantial interests from many researchers. The findings of the review of Kamaruddin et al. (2017) [50] also points out that the utilization of these materials could enhance concrete properties given suitable mix composition. Of course, the main motive here is to identify other destination of the plastic wastes rather than discarding directly. The researchers hold a position that if the best solution of plastic waste could be reached, it is projected that roughly 30% of total waste discarded from solid waste could be declined.

Jalaluddin (2017) [53] investigated the use of plastic waste in civil constructions and innovative decorative material (eco-friendly) where he establishes the fact that plastic roads largely employ PET bottles as central ingredients of the construction materials. Implicit in the findings of the research, it is observed that by employing plastic waste as modifier, we could realize a decline in the quantity of cement and sand by their weight, thereby reducing the total budget of construction. The researcher avers that at 5% optimum modifier content, strength of modified concrete was found to be greater than the plain cement concrete.

In the study of Raghuchandra et al. (2017) [54], they sought to investigate the application of plastic bottle as a sustainable material in building construction. To this effect, their findings proved that that recycling plastic bottles as the building materials could have considerable impacts on saving the building embodied energy by employing such plastic bottles rather than using bricks in walls and this could further cause a decline in the CO_2 emanation in the production of the cement thereby, causing a decline in the proportion of cement utilized. Based on their findings, this has gotten the attention of the construction industry. In general, the bottle houses are bioclimatic in design. This presupposes when the weather condition is cold outside, individuals feel warm inside and when climatic conditions are warm outside, individuals rather feel cold inside. Findings from Raghuchandra et al. (2017) [54] establish that building a house using plastic bottles for the walls and concrete column provides 45% reduction in the overall budget.

Saxena et al. (2013) [55] concluded that by employing PET bottles in construction recycled materials, the thermal comfort could be attained in relatively low cost housing. This therefore becomes beneficial to residents who may not have enough money to buy and operate heating and cooling systems. In corroboration to the above findings, Ramadevi (2012) [56] conducted an experimental investigation into the properties of concrete with plastic PET (Bottle) fibers as fine aggregates. In his findings, it is observed that this gives much relief for the poor masses in India thereby, provide low-cost and finest houses for living.

In summing up to the ongoing submissions, Froese (2001) [57] concludes that when plastic bottles are filled with soil or sand, they are able to function as bricks and hence, form a framework for walls or pillars. In the study of Froese (2001) [57], various types of walls ranging in size and orientation of the bottles are built. Subsequently, the researcher makes a comparative analysis of compression strength and fracture behaviour of each wall. It was observed that PET bottle walls can bear up to 4.3 N/mm² when the bottles are filled with sand which is the weakest filling material. More so, the bottles are able to take up one third of the load while the plaster bears two thirds. It is however noteworthy that plaster made of clay or a cement mixture is made to occupy the space between all bottles. At this juncture, a roof made of wood or in some cases corrugated metal finishes the house. Also, owing to the fact that regional products are employed, the houses are rather low-cost and as such even poor families could afford. Most importantly it is observed that such construction method insofar has demonstrated to be resistant to earthquake and permits shorter construction periods.

5. Conclusions

The use of waste PET bottles in construction cannot be overemphasis. The over reliance on plastic due to wider range of applications and as such has higher growth rate than any other material, make it to be more sustainable material. The plastic per its physical and structural properties render it mostly single use thereby making it become waste in abundance. Per UNEP (2018) report, plastic constitute about 50% of global waste generated. Furthermore, it is noted to last about 300years before decaying. These therefore make it sustainable waste and as such environmental pollutant which required much attention due to its side effects that such as:

- CO_2 emission from heating and burning contributing to global warming;
- Toxic to humans and aquaculture;
- Polluting of cities and water bodies due to its lightweight hence easily carried by air and ran water;
- Choking of drains causing stagnate water which end up breeding mosquitos.

Effort to reduce or eliminate these burdens from the plastic waste is to seek sustainable disposal methods of which recycling of the plastic waste into other use is reported to the best option for now. The construction industry has taken keen interest of its much-reported advantages of current state of the plastics waste, which is being lighter in weight, readily available, cheap to obtain, longer lifespan than most building materials, etc., to be a potential construction material. This paper centered on the use of plastic bottles waste in construction. Findings observed from the reviews on previous works are summarized below:

Cost Savings: In Ghana and most developing countries, plastic waste bottles are cheaper to acquire than most conventional construction materials such as sand and crushed rocks. In addition, concrete or brick containing any amount of plastic bottle is noted to reduce the total quantities of conventional materials required, thereby reducing the cost as well.

Environmental Friendliness: The use of plastic waste bottles in construction also contributes to environmental friendliness and energy savings of buildings. It is reported that building with walls constructed of plastic bottles maintains room temperatures and contribute to energy saving and cost of providing artificial thermal control system.

Making substantive deductions from the empirical and experiential findings herein, it is evident the menace and complications associated with waste plastic in our natural environment. To this effect, researchers have sought for diverse ways to recycle waste plastic to benefit mankind and the environment. This has led to the exploitation of waste plastic in areas such as the construction and architecture industry. Further to that, evidence from the review has shown that the plastic bottles as a potential construction material or unit, has come to stay. Most imperatively, additional studies on how to fuse the plastic bottles into the diverse form of design construction methods are therefore required to maximise its potentials. It is therefore of paramount interest to investigate into the feasibility of the latter statement.

6. Acknowledgements

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7. Conflicts of Interest

The authors declare no conflict of interest.

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