A review on plastic waste as sustainable resource in civil engineering applications

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Abstract: Plastic wastes are non-biodegradable and can stay in the ecosystem for many decades. It can go through aging processes resulting from physical, chemical, and biological actions with the potential to harm habitats and weaken the life-supporting environment. The overwhelming environmental problem created by the indiscriminate disposal of plastic waste containers has led to a search for comprehensive research work seeking a viable alternative to manage, process and dispose of used plastic containers. Hence, researchers have found alternative use to its recovery. The waste can be recycled, reused or reprocessed as substitutes for construction materials because construction applications take up significant amounts of aggregates and cement. Its use is also applicable in bitumen modification, soil stabilization, geosynthetic materials, bricks, plastic reinforcement, and as natural aggregates, which all assist in reducing the quantity of natural aggregates that can be extracted for use in the construction industry. The review covers the collection of relevant information about plastics, the different types of plastics, their corresponding waste and its application in the construction industry from literature. It also examines plastic waste challenges and its sustainable utilization as a construction material. By changing the production design of plastics, it would proffer better ways to manage plastic waste, clean up and improve our natural environment. This review submits that there is an opportunity for the use of plastic waste as an innovative alternative in the construction industry which can stimulate economic growth and could boost the drive of government towards the achievement of some of the sustainable development goals.

Keywords: Municipal Solid Waste, Environmental Pollution, Environmental Sustainability, Construction Materials, Plastic Waste, Soil Stabilization

1. Introduction
The production of plastics and its use dates to 1950 [1]. They have become a crucial part of everyday living [2]. Nigeria is ranked ninth of the rundown of twenty nations, not managing plastic waste in a responsible manner [1]. In 2010, the worldwide volume of plastic waste not properly managed was 851,493 tons, and quantities are estimated to increase to 2,481,008 tons by 2020 [1]. Plastics consist of synthetic organic materials; this is easily shaped in the desired form when compressed then placed within slightly elastic and stiff shapes. The use of plastic is versatile, and examples are found in the medical industry, transportation, construction, household products such as electronics and food
packaging [3]. The consumer motivation to plastics is its economics, lightweight and chemical resistance, resilience to the natural deterioration. Its utilization has a direct connotation with the volume explosion of plastic waste for domestic and industrial use in recent times [4,5,6]. The increasing population in Nigeria is directly related to the increase in plastic waste. The average growth rate for the population between 2000 and 2017 in Nigeria was 2.37% [6]. It is relative to the growth of general municipal solid waste (MSW) as well as plastic waste. The global production of plastics was estimated at 260 million metric tonnes per annum in 2007, with 67% of the production been thermoplastic resins [5,6]. The estimated increase per annum in 2017 was 348 million metric tons [6]. However, single-use plastic such as consumer goods and packaging accounts for 50% of plastic produced [6]. The end of life management of plastics is a global issue, especially in developing countries that have non-existent or ineffective waste management practices. Consequently, the dumping of plastic waste in landfill sites and water bodies is widespread [3,5,6,7,8].

The bottled water industry in Nigeria is growing at an astonishing rate; it is a healthy alternative to carbonated drinks. It is a low-cost and convenient way of getting good quality, easy to open, safe drinking water. The Nigerian government has not been able to provide clean drinking water for its populace; as a result, bottled water is a trusted option [3]. Therefore, the Nigerian private sector has keyed into the United Nations Sustainable Development Goal; access to clean water and sanitation. The industry provides hygienically bottled, safe drinking water in polyethylene terephthalate (PET) containers (this is commonly called 'bottled water'), and it is affordable to the low and middle class in the population. The disposal of the empty bottle containers after use is a significant environmental challenge as it is dumped without prejudice. Plastics are versatile, not susceptible to biodegradation, and can stay in the soil without degradation for 450 years [9]. The large volume per unit mass poses disposal and environmental problem. Although plastics in municipal waste streams account for only 7-9% of the overall waste stream weight, this signifies 20-30% by volume [3,6,9,10,11,12].

It is distressing that in Nigeria and other developing countries, there is a lack of efficient means for dealing with the volume of waste generated. Many consumers are not aware that their choices influence the quantity of waste produced and managed [13]. The government in Nigeria at all levels–federal, state, and local–is facing this massive task in the management of nylon and plastic waste [14]. A popular sight on the highway is bottled water containers, and this blocks drainage and obstructs the free flow of stormwater [15]. Figure 1 shows plastic waste blocking the drainage system. Also, when disposed into natural water bodies, they cause an obstruction and endanger aquatic life. Plastic waste hinders the environment remarkably, triggering a reduction in ecological diversity and the aesthetic quality of urban parks and beaches [16,17]. Therefore, proper management of plastic waste assists in improving the wellbeing of society [6,18]. The overwhelming environmental problem created by the indiscriminate disposal of plastic waste containers has led to a search for comprehensive research work seeking a viable alternative to manage, process and dispose of used plastic containers.

Figure 1. Plastic waste in a drain in Olowu Street Ikeja, Lagos
2. Plastic
In our society, plastics are generally utilized in different categories of daily applications. Plastics are universal materials used in the manufacturing and food industry, transportation, medical, and in households to solve a variety of challenges. Conventional plastic packaging shields our food and goods from pollution [19]. Furthermore, clean water can be provided using plastic water distribution systems and storage containers. Also, plastic materials are used for protective apparels, safety and security apparatus (e.g., textile impervious to fire, head protectors such as helmets, airbags) avert injuries. In the same way, plastic products for medical purposes lead to enhanced health conditions (e.g., tubing, blood bags, prosthesis, and disposable syringes). Equally, low-density plastic materials are used as alternatives for metals and ceramics in airplanes and motor vehicles. The use of plastic in different ways creates a variety of waste streams. Plastic packaging is produced in substantial quantities and usually discarded in the waste stream typically when used once within a limited time of purchase (about 40 percent of plastics products have an average life expectancy of under one month) [19]. This massive waste causes significant environmental management challenges.

2.1 Types of Plastic and Recycled Plastic
The fourth major category of civil engineering construction materials are polymers, and different types are manufactured for an array of uses [20]. Although new forms of polymeric materials are continually emerging on the scene, there are notable improvements in the properties of existing plastics. Recycled plastics are utilized in innovative structure and other construction implementations daily. These recycled plastics can be processed using new plastics to reduce costs without compromising quality. The recycled plastic materials are used to produce polymeric timbers used in fences to picnic tables, thereby assisting in the preservation of trees. Plastic from PET containers is convertible into fiber for the manufacturing of carpets. Plastic waste is utilized for waste-to-energy (WTE) systems, and the method includes converting and recovering the energy value from plastic waste material by applying elevated temperature and precise combustion. The heat recovered is then transformed to electrical energy in steam-driven turbine generators used for equipment, or it can also be sold directly either as steam or heated water within the manufacturing and heating procedures [21].

2.1.1 Thermoplastics
Upon application of heat, thermoplastics can potentially be dissolved into their liquid state and reshaped into the same or different form for the same or a variety of applications [6]. The gross plastic consumption of thermoplastics is about 80 % [6]. Examples of thermoplastics are Polystyrene, Polyvinyl chloride, Polyethylene terephthalate, Polymathic methacrylate, Polypropylene and Polyethylene [19].

2.1.2 Thermosets
These are plastics that are incapable of returning to their original shape once they have been cooled and hardened. They are manufactured through the process of chemical bonding by crosslinking comparable or diverse polymer chains, and they make up 20% of the total global production of plastics. These are tougher, stronger, and resilient in comparison to thermoplastic, although mostly non-recyclable. Recent studies have, however, revealed that some thermosets are recovered from previously cured thermosets by the exchange of bond reactions or as a result of additional reactions at active sites [6]. Epoxy resins, polyurethanes, phenolic, and polyester resins are examples of thermosets.

2.2 Uses of Plastic and Plastic Waste
With a growing dedication to environmental sustainability, the engineering sector is enthusiastic about reusing and recycling plastics and polymers considered as plastic waste. The construction industry is dependent on raw materials; therefore, the motivation for the utilization of plastic waste is an implication of the significant quantities of plastic used, and the exponential volume of plastic waste generated [6,19]. Likewise, the escalating cost of building materials also inspires recovering of plastic waste as a value-added product in construction applications. This emerges as an unconventional alternative solution for the utilization of plastic waste. Instead of littering the environment, plastic wastes have been used in civil engineering, as soil stabilizers and alternative aggregates for concrete and asphalt production. Plastic waste can replace a specific portion of aggregates, conventional
stabilizers, or lightweight concrete pavement, reinforced geo-pavements, or can be used in low-volume asphalt pavements [19]. Consequently, the amount of waste going to the landfill reduces, thereby improving resource management and ultimately reducing the cost of construction. The use of these green substitutes has a positive influence on the environment. Moreover, the adaptability of plastic waste for homes, road infrastructure, or energy generation in the construction industry must be economical, efficient, and safe. Furthermore, some unconventional uses of plastic waste are high-grade polymers such as automobile parts, home equipment, fabrics, building insulation, and films that are manufactured from plastic waste. Consequently, plastic waste treatment and recycling procedures can be distributed into four main classes that are recycling, chemical, mechanical, and waste to energy recovery. Table 1 illustrates the diverse types of plastics and their recycling potential.

**Table 1. Uses of Plastic and Recycled plastic [6,19].**

| Type of Plastic | Properties | Application of plastic | Application of recycled plastic |
|----------------|------------|------------------------|--------------------------------|
| i. Polyethylene Terephthalate (PET) | Transparent solid plastic, suitable for fiber | Water bottle drink and minerals bottles | Transparent soft material for packing items, wrapping film, carpet fibers, rain jackets |
| ii. Low-density polyethylene (LDPE) | Soft, flexible plastic, cloudy white except the pigment is added | Closures of food containers, trash bins, and garbage bags | Wrapping business, soft cling films, for packing plants and nursery bags |
| iii. High density Polyethylene (HDPE) | Normally used plastic in coloured or white | Wrinkled bags for shops, freezer bags (for meat /milk storage) | Manure bins, soap bottles, crates, and mobile trash bins |
| iv. Plasticized Polyvinyl chloride (PPVC) | Flexible, transparent, elastic-plastic | Blood bags and tubing for the medical sector, soles for shoes, pipes and hose for gardens | Factory floors, |
| v. Polypropylene (PP) | Hard, but flexible plastic | Ice-cream-bowls/containers, potato crisp bags, chairs, Cheap, transparent kitchenware, lightweight fittings, bottles, toys, and food containers | Manure-bins, kerbside recycling bin/crates, Laundry pegs, coat hangers, and video/CD boxes |
| vi. Polystyrene (PS) | Stiff but brittle plastic. Transparent in nature and glossy | Tea or coffee cups and food Takeaway bowls | Spoons, rulers and Movies/CD box sets |
| vii. Polyester (EPS) | Foamed, lightweight, energy absorbing, and thermal insulation | | |
| viii. Polyamides (PA) | Nylons | Fibers, toothbrush bristles, and fishing lines | Material for packing items, wrapping film, Bins, shampoo bottles, crates |
| ix. Polymethyl methacrylate (PMMA) | High UV light and chemical resistant, transparency, durability | Motorized lamp covers an alternative to glass in specific applications | |
| x. Polyethylene (PE) | Translucent, tough and semi-rigid, chemical resistance, waterproof and cheap | Packaging (plastic bottles, bags, wraps, and films), construction | Wrapping cling film |
Table 1 shows the following plastics polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyethylene (PE), polystyrene (PS) and polypropylene (PP) these are most recycled types of plastics [19] and are useful in the production of a wide variety of packaging applications, including, tubes, barrels, trays, bags, cups and packets, infant goods and protective packaging. Polymethyl Methacrylate (PMMA), Polyamides (PA), Polyester (EPS), Plasticized Polyvinyl chloride (PPVC) Low-density polyethylene (LDPE), High-density polyethylene (HDPE) are some of the other types of plastics in use. Figure 2 shows the processing of PET bottles for recycling use in a university community.

![Figure 2. Processing of PET bottles for reuse in a University Community](image)

2.3 Problems arising from Plastic Waste Pollution

Plastic pollution in the environment influence air quality as greenhouse gases are released during the production of plastic. Plastic waste burning discharges black carbon (soot); this adds to global warming and contamination of the air. The other toxic chemicals released from plastic waste burning are gases like polychlorinated biphenyls (BCPs), mercury, dioxins and furans. These gases present a hazard to human, animal wellbeing and vegetation when released into the air [22]. These toxic chemicals likewise impact water and soil. After plastic waste is dumped on the ground, it slowly releases phthalates and biphenyls into the soil, groundwater, and other water bodies [22,23]. The world’s plastic production from the 1950s-2014 has increased by 200% [24]. The creation of disposable plastics is growing at an alarming rate, and the world is overwhelmed by its inability to address the problem. About 448 million tonnes of plastic was produced globally in 2015, 58 percent of waste plastic was thrown away or deposited, and about 18 percent recycled in 2015. Plastic production is expected to double by 2050 [25,26]. Every year about 8 million tonnes of plastic waste from activities on land enter the world’s ocean, and this is equivalent to five full trash bags of rubbish along each foot of the global ocean [25]. Millions of birds, fish, and other marine organisms every year die as a result of plastic waste pollution [25].

Consequently, the most pressing environmental challenges in developing countries like Asian and African remain plastic pollution. Plastic pollution is significantly evident because waste collection programs are mostly ineffective or non-existent [14]. Notwithstanding, it is challenging to collect discarded plastics in Europe and America within areas of the country that have low recycling rates. The chemical industry contributes to around 15% to the global anthropogenic GHG (Green House Gas) emissions. The universal collective application of plastic GHG world life-cycle emissions in 2015 was 1.7 Gt (Gigatonne) of CO₂-equivalent (CO₂-e), increasing to a composite annual growth rate of 8.4% by 2050. The global emissions and negative environmental impacts associated with plastic production have triggered the United Nations to start plans to draw up a global treaty [25]. There is, therefore, a need to reduce and creatively discover ways to recycle and reuse plastics waste [26].

3. Plastic Waste as Construction Material

The review focuses on the utilization of recycled plastic waste as a construction material. The incorporation of plastic waste in concrete either as an aggregate or as cement-based materials such as cement mixtures or concrete mixes or as a soil stabilizer are better options for plastic waste disposal [19]. When plastic waste is substituted or replaced within a concrete mix, it has environmental and economic benefits. Also, plastic waste modification is utilized as a lightweight, low-strength concrete pavement, or low volume asphaltic pavements, and soil stabilizers in geo-pavements [19]. Numerous researchers have used plastic waste as cementitious materials or aggregates or as soil stabilizers in the
construction industry. Plastic products such as polyethylene terephthalate (PET bottle), high-density polyethylene (HDPE), glass-reinforced plastic (GRP), expanded polystyrene foam (EPS), polyvinyl chloride (PVC) pipe, spent plastic waste, polypropylene fiber, polycarbonate, and thermoplastic recycled polystyrene [19].

3.1 Plastic Waste Materials Used in Civil Engineering Applications

In civil engineering applications, plastic waste is used as modified bitumen, fine and coarse aggregates in concrete, soil stabilization, geosynthetics, bricks, plastic waste reinforcement, and plastic waste cement.

3.1.1. Modified Bitumen

[27,28] investigated physical properties such as strength, durability using PET (polyethylene-tetraphthalate) in bituminous roads at the various percentage (5%, 10%, 15%) and results reported were satisfactory. [29] evaluated the application of PE (polyethylene) plastic waste as a modifier in semi-dense bituminous concrete. In the research, shredded plastic waste was mixed in the hot aggregate, and the plastic was used to modify the mixture at 5%, 8%, 10%, 12%, and 14% by weight of bitumen. The outcome observed that Marshall stability's highest value was at 12% plastic waste content. [30] investigated the inclusion of HDPE and LDPE (high-density polyethylene and low-density polyethylene) shredded plastic waste in the bituminous concrete, and the result shows a significant increase in the Marshall characteristics and stability value in the combined mixture. The study reported that the utilization of 8% HPPE and LDPE plastic waste in bituminous concrete is secure and suitable for light, medium, and heavy traffic roads. The application of polyethylene terephthalate (PET) as a strength modifier in asphalt road construction was examined [3]. The samples were collected and thoroughly cleaned, naturally dried, and shredded. The results from the sampling regime were compared with the ASTM, Nigeria Federal Ministry of Works, and AASHTO standards and the result showed that optimum binder content (OBC) by weight of aggregate was 1% [3]. The proportion of PET content was 15% by weight of bitumen. Bulk density (BD) 2.38 kg/m³; Void in Total Mix (VTM) 3.33%; Void Filled with Bitumen (VFB) 82.20%; Marshall Flow (MF) 4.00 mm and Marshall Stability MS 17.01 kN [3]. The improved asphalt with 1% PET was observed to be useful for pavement construction and showed better binding properties, strength, density, and water resistance [3]. Utilizing the concrete modified blend alongside treated plastic waste of around 5–10% by weight of bitumen prompts a significant enhancement in the fatigue cycle, strength, and different characteristics necessary in bituminous concrete. As a result, it increases the service life cycle and road surface quality with small but substantial savings in bitumen constructed roads. Likewise, another study coated stone aggregates with molten plastic and concluded that coating aggregates with plastic decrease porosity, moisture absorption, and increased soundness. The combination of plastic waste with stone mastic bitumen demonstrated significant improvements in the mechanical and volumetric properties of the mix. It also revealed that the utilization of plastic waste is efficient and convenient in reducing plastic waste and the associated cost of highway construction [12,31,32,33]. Thus, the inclusion of plastic waste is feasible for the production of modified bitumen for road construction with its adequate binding properties and cost-saving potentials.

3.1.2. Fine and Coarse Aggregates in Concrete

Aggregate plays a vital role in the production of concrete mix and accounts for 65-85% of the standard concrete mix mass volume. The development of concrete strength is dependent on its aggregates and categorized by physical and chemical properties such as fresh properties of the mix, workability, slump test values, compressive strength, flexural strength, and the effects of sulfide attack. The substitution of aggregates with plastic waste either as part or complete replacement acts as an alternative solution. Some studies investigated partly replacing fine aggregates and coarse aggregate with Plastic fiber (PF), sliced polypropylene (PP) debris polyethylene (PE) pellets. Plastic aggregates (PA) have a lower bulk density than basalt, granite, or limestone. Therefore, utilized for lightweight concrete. The effect of fresh concrete density, workability, and hardened concrete density, compressive strength, water assimilation was evaluated [34]. The findings indicated that plastic waste has a beneficial impact on fresh concrete characteristics: the workability of the concrete improves and is lighter. Regrettably, the hardened concrete with high plastic waste content has an adverse effect: the compressive strength was altered and reduced with the increase of plastic waste in the concrete [35], mode of failure changes from brittle (rapid) failure to more ductile failure [36]. However, water
absorption, in turn, increased. However, the result observed, that maintaining the same value of concrete workability, there are opportunities to decrease water and cement ratio, and this, in turn, provide strength loss, and water absorption increase compensation [19,31,37,38,39]. Plastic waste was partly substituted as sand in an innovative mix for structural concrete. For the evaluation of the mix, eleven concrete mixes were assessed, measuring the aspect ratio, plastic content, and particle dimensions to entirely create a suitable material that can partially replace sand. The outcome of the research states that 10% substitution of plastic can replace sand by volume, and will save about 820 million tons of sand yearly. However, plastic waste should be used with the right design mix considering the structure [40,41]. Vehicle plastic waste was studied for possible use in concrete as a substitute for sand. The study found concrete's impact strength properties in 2.5%, 5%, 10%, and 20%, respectively, of plastic waste particles as a substitute for sand at different content. The concrete mix showed the tendency to withstand a significant amount of energy from impact [42]. [37] evaluated the partial substitution of fine aggregates with polypropylene in the mixed model, and the compressive strength of concrete was tested by utilizing test regimes of six concrete mix samples prepared with substitutes of polypropylene varying from 0.5 to 3.0%. With the inclusion of plastic aggregate, the results showed a reduction in compressive strength, and this was regulated as plastic waste content increased the concrete mix. Subsequently, the results from two samples reported attaining the ST5 standard criteria at 28 days for concrete mix compressive strength. The percentage proportion of plastic aggregates used was 1.5% and 2.5%; this confirms the possibility that recycled polypropylene can be used in structural applications as a part by mass of fine aggregate substitute in the concrete mix.

E-waste plastics are utilized to substitute fine and coarse aggregates in concrete. The compressive strength, tensile strength, and flexural strength of concrete are evaluated with replacement ranges from 0, 10, 20, and 30% and without E-waste plastic aggregates [43]. The results from the analysis reported that compressive strength at 10% optimum content of E-waste plastic in the concrete mix yielded stability and a recent compressive strength at grade 53 [44]. [45] examines the impact of plastic on various fresh and hard concrete properties as an alternative coarse aggregate. The thermoplastic polymer polyethylene terephthalate (PET) is evaluated as an artificial aggregate and replaced by natural coarse aggregate such as brick chips. The PET aggregate is acquired when the collected waste PET bottles are shredded, melted, and crushed. Figure 2 showed an example of the shredding process. The focus of the study is to examine PET aggregate concrete (PAC) compressive strength and unit weight along with its workability in comparison to concrete mixed with natural aggregate (NAC) [45]. PAC at 20 per cent PET substitution has a compressive strength at 0.42 w/c of 30.3 MPa; this is 9 per cent lower than the NAC. The observed slump rate of 1.8 cm, indicates PAC has substantially high workability. Low-density polyethylene (LDPE) plastic was utilized as a partial substitution for sand in cement mortar [46,47]. The sand was substituted with LDPE waste at different percentage ratios from 0, 5, 10, 20, 30, 40, 50, and 60%. The mortar mixture was one part of cement to three parts of plastic fine aggregate at water/cement ratio. The sample was then cast into cubes and prisms. The outcome of the experiments showed that performance decreases substantially as the percentage of LDPE in mortar increases, but mixtures containing 50–60% LDPE meet the performance requirements for mortar masonry [47]. However, a model for predicting the compressive strength of mortars containing waste plastics was proposed based on experimental data. The validation of the model generally provided accurate predictions of mortar strengths made from various types of plastics [47]. Subsequently, the addition of plastic waste is viable for the production of fine and coarse aggregates in concrete with satisfactory workability and energy on impact.

3.1.3. Soil Stabilization

For practical application of plastic waste to stabilize unstable and weak soils, the most important properties are shear strength, compaction (CBR; California bearing ratio, MDD; Maximum dry density, OMC; Optimum moisture content), relative density specific gravity, permeability, consolidation, consistency limits, particle size and resilient modulus (for road pavements) [48,49,50]. Several researchers have utilized different types of plastic waste as a soil conditioner, and the influence of compressive strength is that it increases to some extent [51,52]. [53,54] reported that bearing capacities of black cotton soil or silt soil increased with an increasing quantity of waste plastics. [53] studied the effect of plastic waste in black cotton soil, and the test reported a low specific gravity for plastic. [55] measured the specific gravity of dry soils using plastic fibers as an additive for the soils. The outcome of laboratory tests showed that there is an exceptional effect on the specific gravity of clayey soil with plastic fiber. [56] evaluated the properties of dune sand modified with
LDPE waste by Variable Head Permeability test. The outcome of the test demonstrated that the use of LDPE waste between 0.6% and 1% helps to improve the strength of dune sand and assists in altering the dune sand properties, thereby improving the subgrade soil. [57] tested four soils mixed with crushed waste ceramic (CWC) and crushed waste plastics (CWP) and subjected to laboratory conditions to test for subgrade stiffness. The sample soils are mixed with 10 to 120% by weight with these geomaterials. Lateral deformation from modified triaxial compression consistently decreased with the amplified CWC and CWP proportions. [55] studied utilizing plastic fiber as an additive to clay soil for soil stabilization. Atterberg limits tests were conducted on soft clayey soil with and without plastic fiber at 1, 2, and 4% by the proportion of stabilizing material to the net weight of soil. The laboratory tests showed a significant impact on the liquid limit and observed that plastic fiber content has a remarkable effect on the grain size distribution. The modulus (Mr) of clayey soil, and ordinary soil mixed with recycled polyethylene terephthalate (PET), and its impact as soil reinforcement exhibited significant improvement. The repeated-loading triaxial tests reveal Mr of 0.6% PET-reinforced samples increased by 58%. In contrast to Mr of the control sample (0) percent PET [58]. Similarly, resilient modulus Mr, R-value, and stiffness of subgrade soils mixed with crushed waste ceramic (CWC) and crushed waste plastics (CWP) were investigated [54]. It was observed that the soil improved steadily with increased CWC and CWP. Therefore, the inclusion of plastic waste for soil stabilization improved the geotechnical properties of the soil considerably.

3.1.4. Geosynthetics
Plastic waste is used to make geocell and geogrid for soil reinforcement. The geocell and geogrid plastic waste were positioned from the top of the CBR mould at distinct depths. The CBR test was conducted for the unsoaked state of natural soil and reinforced soil, and load-versus-penetration behaviour was examined. Results show that by positioning the reinforcement of plastic waste at varying depths, the strength of the reinforced pavement soil in comparison to natural soil experienced a considerable increase. The confined geocell structure showed a significant improvement in strength compared to the geogrid of plastic waste. The findings indicate that at a certain depth, the considerable enhancement in soil strength using both geosynthetic materials has been successful. This study shows that it is an excellent option to use plastic waste to increase pavement soil capacity. For pavements, plastic waste can be used as an economical solution [59], [60] investigated the reuse of plastic waste bottles to formulate reinforcement comparable to conventional geogrid for prospective application to advance load – settlement behaviour of soil. River sand was used to prepare soil beds at a relative density of 70%. The experiment was conducted using a load plate test compare unreinforced soil, conventional geogrid reinforced soil and plastic reinforced soil. The results in terms of cost efficiency between geogrid and plastic bottle reinforcement specified 60% savings when the plastic waste is utilized for soil reinforcement. The maximum bearing capacity for unreinforced soil is 254 kPa, geogrid reinforced soil 310 kPa (22% increase), and plastic reinforced soil 292 kPa (15% increase). The incorporation of plastic waste in geosynthetics records considerable increase in strength properties and significant cost savings.

3.1.5 Bricks
The research aimed to investigate the appropriateness of the production compressed earth bricks (CEBs) with a mix of soil and differing percentages of shredded plastic waste at (0, 1, 3, and 7%) [61]. Test on the technological properties of the soil, specific gravity, particle size distribution, Atterberg limits, and compaction experiments are conducted on the soil. The CEB’s compressive strengths and erosion levels were established and calculated for the untreated soil and soil mixture at differing ratios of two-sizes (< 6.3 mm and > 9.6 mm) of the shredded plastic waste. Classification of the soil as clayey sand (SC). For the CEB, which contains one plastic waste of sizes < 6.3 mm, the highest compressive strength was obtained, and its compressive strength increase by 244.4% [61]. The specimen comprising 1% waste plastic with sizes < 6.3 mm also had the least erosion level of the CEB specimens stabilized with shredded plastic waste. Correspondingly, provided that the external wall surfaces created using the CEB were safe from erosion, it was advised to use 1% shredded plastic waste with particle sizes ≤ 6.3 mm [61]. Plastic waste that would have been a threat to the atmosphere would create more reliable and more durable bricks to provide affordable housing [61,62]. Plastic waste is used to manufacture concrete paver blocks, and from the results obtained, it is to equal compressive strength of the conventional paver blocks. From the observation, they are used for footpaths and parks [63]. [64,65] studied three types of waste thermoplastics, namely, polystyrenes,
mixed plastics, and polycarbonates to make eco-friendly bricks. Experiments were conducted by using different proportions of waste thermoplastics (0 – 10% by weight) and sand (60 – 70% by weight), keeping a constant 15% (by weight each) proportions for fly ash and ordinary Portland cement. Three separate sets of bricks were placed underwater for 28 days, some of the samples were positioned in the oven from temperatures ranging from 90 °C to 110 °C for two hours to allow the plastics melt and form structure voids. The observation from the experiments states that the thermal conductivity of the bricks reduced, and compressive strength increased sufficiently. Hence, the addition of plastic waste in bricks to produce eco-friendly bricks with acceptable compressive strength.

3.1.6 Plastic waste reinforcement

The principal disadvantage of steel fibers as concrete reinforcement is that it is prone to corrosion. There is the probability that seawater or saltwater can impact steel members if concrete surfaces are left unprotected. Foti [66] investigated the use of plastic reinforcement by conducting a series of pilot tests on concrete beam samples utilizing Polyethylene terephthalate (PET) waste and Carbon Fiber Reinforced Polymer (CFRP). The plastic waste in the form of PET and CFRP was made into strips and bars and arranged in a continuous position in the same manner steel reinforcement is arranged in a reinforced concrete structure. The results from the tests report that they both limit cracks and eliminate/ reduce corrosion in reinforced concrete structures. However, the CFRP samples exhibited improved behaviour. Similarly, plastic waste converted into Plastic fiber (PF) is utilized to reinforce structures by substituting it with traditional steel fibers enhanced structural stability and durability of the concrete element [19]. Therefore, the inclusion of plastic fiber seems to produce functional reinforcement in terms of strength, reduction of corrosion, and durability in concrete.

3.1.7 Plastic cement

High-density polyethylene wastes are combined with Portland cement to examine the prospect of plastic cement production and to test the impact of substituting sand with fine polyethylene wastes with the various proportion of product characteristics [34]. The tests were conducted utilizing the waste of polyethylene packages as a short reinforcement structure, including bottle and food crates in the span of 10% to 80% by volume as reinforcement with compact structure. The outcome of the test indicated that by using 60% and 40%, respectively, plastic cement can be made from polyethylene waste and Portland cement. Furthermore, the density of plastic cement reduced, there was an increase in ductility, and workability improved; hence, lightweight materials were produced [44]. [67] Formulated a cement that was made from recycled plastic waste. The recycled plastic bounded concretes (RPBCs) containing zero asphalt binder, and zero Portland cement was studied to evaluate the Mechanical properties of the RPBCs concerning Portland Cement Concretes (PCCs) and Asphalt Concretes (ACs). The compressive strength of some RPBCs is like ACs; however, some are like strong PCCs. The RPBCs samples showed significant moisture resistance compared to ACs. It observed that RPBCs shows improved stiffness and flexural strength, about three times compared to that of PCC and five times ACs. The RPBCs’s crack healing performance is 92 percent compared to 9 percent, according to AC’s. The RPBCs establish much reduced thermal sensitivity and improved moisture resistance than the ACs. [68] examines the dry density characteristics of concrete utilizing plastic waste and polymer fiber to substitute cement. Tests conducted on concrete samples for compressive, tensile, and flexural strength, and lastly, a comparison reported on the concrete quality that utilized plastic waste and polymer fiber against the concrete with plastic waste. A detailed experimental study was conducted using plastic waste in concrete with a proportion range of 10%, 20%, and 30% and polymer fiber proportion range of 2%, 4%, and 6%, respectively. The finding exhibited a lower density pattern in altered concrete in the polymer [67]. The utilization of plastic waste to replace cement decreases concrete compressive and flexural strength. This is possible as a result of fibers bridging activity that stores more energy and halts the concrete from sudden failure. However, low mechanical properties of the modified concrete that utilized plastic wastes and polymer fibers were documented [68]. Consequently, the production of plastic cement in concrete produces an effective, lightweight material with sufficient mechanical and strength properties.
4. Conclusion

The use of plastic waste for construction applications in the engineering industry holds a high capability of decreasing worldwide ecological contamination and environmental pollution. Researchers generally are interested in discovering materials that can cut the budget of construction and increase the strength of engineering infrastructure. Plastic aggregates, cementitious materials, soil stabilization additives, and other construction resources obtained from plastic waste was examined. The examination demonstrated that the engineering properties of the construction materials improved. This creates an opportunity for recycling, reuse, and reprocessing of plastic waste materials. Given the review, the accompanying conclusions were drawn: The behaviour of plastic waste in construction materials is innately unique concerning the synthetic manufactured materials. Nevertheless, construction materials made from plastic waste can provide comparable or better outcomes than traditional construction materials. The use of plastic waste will gradually empower the reduction in the utilization of conventional construction materials, subsequently diminishing the carbon footprint associated with the production of such materials.

Several, researchers have used different compositions of plastic waste unaided, or as a combination with other materials; however, the use of plastic as a nanostructured material is not reported. The non-biodegradable properties of plastic waste are able to assist the long-term workings of construction materials. It is appropriate for improving concrete mixes and soils of multiple classes. It is also suitable for different engineering design requirements, consequently upgrading the scope of concrete, aggregates, and stabilizers that can accomplish great products. However, these long-term effects of plastic waste in construction materials and its environmental impact after its service life and financial implications are in limited in the literature. There ought to be more examinations on the viability of plastic waste that produce high strength and load-bearing capacity in different types of structures to institute their appropriateness as good engineering construction materials. Plastic waste requires extensive research in their usage as construction materials because of the sheer volume of waste generated each year. Thus, more examination of the less investigated aspects of plastic waste and an introduction of engineering standards to evaluate its properties can open a broader use of waste in the construction industry.

Research should start now rather than later, so the issue of the control of plastic wastes are regulated by reasonable proportions. These proportions need to remain within applicable ranges for reuse as construction materials. Recycling of plastic waste in the manufacture of compressed earth bricks can give less expensive options to conventional blocks [34]. Plastic compressed earth bricks give strength characteristics that are similar to or higher than traditional bricks. Still, the research is inadequate as the investigation into the durability characteristics of such earth bricks has not been evaluated. Some other reuse applications of plastic waste areas strength modifiers in asphalt mix, and as part of flexible asphalt pavements, wood, plasters, plastic lumber (timber), in concrete production, plastic cement, sand, energy resource, soil backfill material and so on needs to be explored.

The utilization of plastic waste is anticipated to reduce the cost of pavement construction. This will improve the economic and environmental significance in underdeveloped and developing countries. In
future research, construction applications with emphasis on economic valuation can be accomplished for pavement construction as well as for other engineering applications. The plastic waste construction materials should be examined in more detail under a wide variety of conditions to promote the acknowledgement of its use in industrialized civil engineering applications. The overall research activities should not exclusively be constrained to papers. However, pilot-scale undertakings should be organized and execution assessed to guarantee industry sustainability.

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