Using Plastic Sand as a Construction Material toward a Circular Economy: A Review

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Abstract: Recently, research on innovative approaches to and practices for plastic waste management in a circular economy has gained momentum. Plastic waste pollution poses a serious environmental concern. At the same time, the cement industry is among the biggest sources of CO_2 emissions, which poses another environmental challenge. This makes plastic sand bricks an attractive alternative to concrete blocks and bricks. This paper looks at the recent studies regarding the development of plastic sand bricks and the different percentages of plastic and sand used in the bricks. The literature review reveals that there is a lack of studies that evaluate plastic sand construction materials from an economic perspective. Such studies are essential if the industry is to invest in and adopt this alternative construction material. Plastic sand bricks could be a workable solution for combating issues related to solid waste. The compressive strength decreased with increasing ratios of plastic to sand. Plastic sand bricks weighed less than the conventional bricks. Issues requiring further investigation include: dealing with varying proportions and types of plastic, the lack of understanding of the long-term performance of plastic sand bricks, the flammability and fire resistance of plastic sand bricks, and the absence of appropriate standards and regulations for recycling plastic into plastic sand bricks. This paper allows us to look ahead in terms of some specific technical needs, the translation of the emerging technology into practice, and new ideas to decrease plastic pollution.

Keywords: circular economy; HDPE; LDPE; PET; plastic sand bricks; plastic sand blocks; plastic sand paving; plastic waste

1. Introduction

The circular economy presents an alternative to the linear "take, make, use, dispose" system. It attempts to keep resources in use for as long as possible, maximize their value while they are in use, and recover and regenerate products at the end of their useful lives [1]. The production and use of plastic sand bricks and blocks is a good example of the innovation required to establish a circular economy.

Plastic waste (e.g., plastic bottles, bags, and sheets) is not readily biodegradable, which makes it one of the most challenging sources of pollution. Worldwide, plastic waste exceeds 25 million tons per year [2]. From 1950 to 2015, only about 10% of plastic waste was recycled; the rest was disposed of in landfills or elsewhere in the environment, according to the United Nations Development Program (2019). Figure 1 shows plastic waste generation from 1950 to 2019 [3]. By 2050, landfills and the natural environment will contain approximately 12 billion tons of plastic litter due to current consumption patterns and waste management practices [1]. Hence, there have been various efforts around the world, particularly in developed countries, to turn plastic waste into useful products [4]. There is great potential for creating new construction materials from plastic waste, since the construction industry dominates most economies and consumes the most raw materials [5].
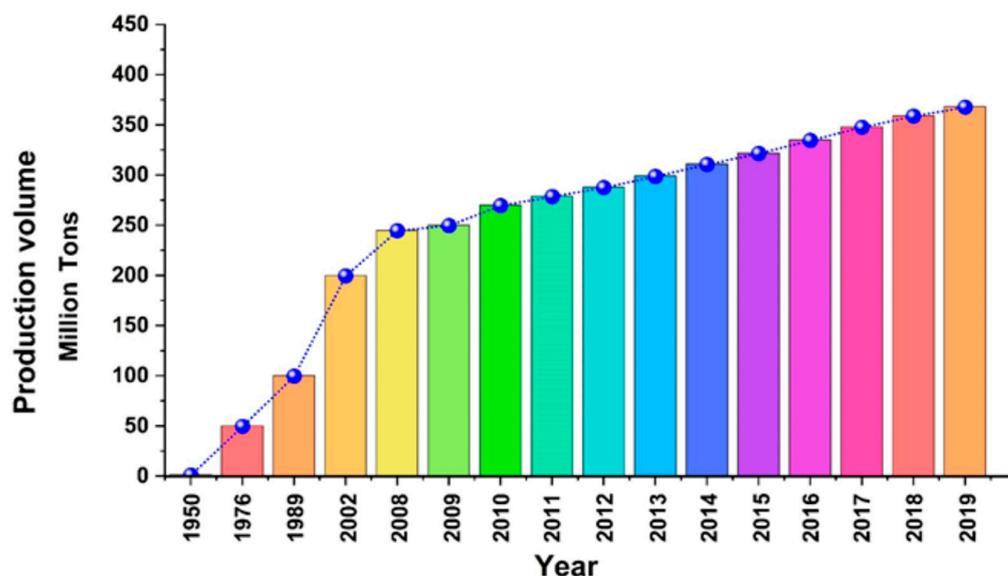
Figure 1. World plastic waste generation 1950 to 2019 [3].

An additional benefit of replacing widely used concrete (cement) blocks and bricks with plastic sand blocks or bricks is that this could contribute to reducing cement consumption and the associated carbon dioxide (CO_2) emissions. The cement industry's CO_2 emissions are among the highest of all industries [6], with the cement manufacturing process producing about 8–10% of global CO_2 emissions [7].

The wide use of sand is unsustainable, which poses another environmental challenge [8]. According to the United Nations Environment Program (UNEP) (2019), the extraction of sand and gravel is one of the greatest challenges to sustainability in the twenty-first century. Yet, in many regions, these materials are among the least regulated of all the resources extracted and traded. Consequently, rivers, river deltas, and coastlines erode, while sand mafias prosper and demand increases [9]. Plastic sand is a sustainable construction material, since it can be easily recycled, whereas recycling sand cement (concrete) is more challenging and less economically feasible.

In addition to advances being made in recycling plastic to reduce plastic pollution, research has been conducted on mixing plastic waste with sand to produce alternative construction bricks and blocks [10–13]. Moreover, some studies have focused on adding plastic waste to concrete mix to improve its physical characteristics [14–19]. Considerable research has been conducted in countries such as the USA and the UK on adding plastic waste to concrete mix [15]. Other studies have examined sand-filled plastic bottles as a construction system [20]. The idea of producing a construction material by mixing plastics with concrete goes back to the 1980s. In 1986, a patent was granted by the United States Patent and Trademark Office that involved mixing plastic with concrete [14].

This paper presents recent developments in the use of plastic and sand mixtures in construction. The applications of plastic sand bricks are numerous in civil engineering, namely precast bricks, partition walls, roof tiles, canal linings, and paving bricks. A notable feature of these applications is that they aid in the disposal of plastic wastes that accumulate across the globe and remain non-degradable. Studies on the use of plastic waste to improve the properties of concrete are not within the scope of this paper, since the subject has been well discussed, as shown in Table 1.

The literature regarding plastic sand bricks is very limited. The motive of the study is thus to emphasize the need for more research development of plastic sand bricks. Plastic sand construction materials (e.g., bricks, blocks, tiles) will create an alternative sustainable material, lower costs, improve performance, and promote sustainable waste management in the construction industry.

Table 1. A list of literature review studies discussing the use of plastic in construction materials.

Title	Review Scope
"Use of Recycled Plastics in Concrete: A Critical Review" [21]	Use of plastic in concrete mix
"Potential Use of Plastic Waste as Construction Materials: Recent Progress and Future Prospect" [22]	Use of plastic in construction material (general)
"Use of Recycled Plastic as Fine Aggregate in Cementitious Composites: A Review" [23]	Use of plastic as fine aggregate
"Engineering Properties of Concrete with Waste Recycled Plastic: A Review" [24]	Use of plastic in concrete
"Mortar and Concrete Composites with Recycled Plastic: A Review" [25]	Use of plastic in cement and concrete
"Use of Plastic Waste as Aggregate in Cement Mortar and Concrete Preparation: A Review" [26]	Use of plastic in cement and concrete
"Application of Plastic Wastes in Construction Materials: A Review Using the Concept of Life-Cycle Assessment in the Context of Recent Research for Future Perspectives" [27]	Use of plastic in construction material (general)

2. Methodology

The mind map used in this literature review (Figure 2) revolves around a circular economy and the practicality of using plastic sand bricks as an alternative construction material. Therefore, it specifies that background information about the circular economy and the main ingredients of plastic sand bricks (plastic and sand) must be included to introduce the subject. Accordingly, the background section briefly addresses the circular economy, plastic, and sand. To determine the practicality of utilizing plastic sand bricks and if they are at least comparable to conventional bricks, it is important to assess the characteristics of plastic sand bricks. It is also necessary to examine the effect of the plastic type. Thus, studies on plastic sand bricks that have utilized various types of plastics have been reviewed here, with an emphasis on their physical characteristics. Comparing the cost of using plastic sand bricks and conventional bricks is also essential for assessing plastic sand bricks as an alternative construction material. Therefore, an effort has been made to report the findings from the literature on the cost of plastic sand bricks.
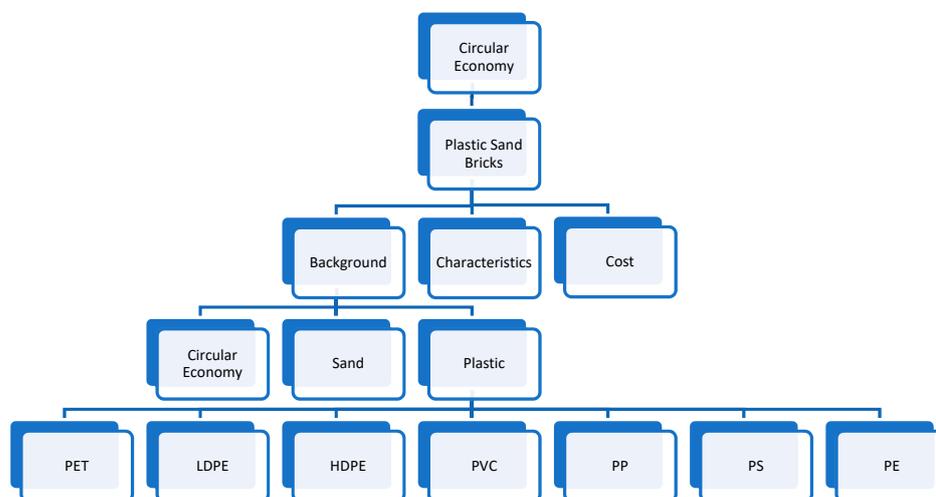
Figure 2. The mind map used in this literature review.

The literature review was conducted mainly using keywords. These included plastic sand, plastic sand brick, plastic sand block, plastic waste in construction, polyethylene terephthalate (PET) sand bricks, low-density polyethylene (LDPE) sand, high-density polyethylene (HDPE) sand, polyester (PE) sand, and nylon sand.

The various types of plastic and sand are described in the background section. Then, all relevant papers, except those excluded due to lack of originality, are described.

3. Background

3.1. Circular Economy

Geissdoerfer et al. [28] defined the circular economy as "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling."

In a circular economy, however, everything that is extracted is somehow returned into the cycle. In this type of economy, the aim is to increase the life stages of each product through a continuous development cycle. This process conserves and supports the durability of natural capital [3].

The circular economy as a concept emerged in the 1960s. However, the concept gained popularity after the European Union (EU) introduced its vision of a circular economy in its 2014 report entitled, "Towards a Circular Economy: A Zero Waste Program for Europe" [29]. In 2013, just prior to the EU releasing its 2014 report, the Ellen MacArthur Foundation published a report prepared by McKinsey & Company entitled, "Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition" [30].

In its 2014 report, the European Commission [29] addressed construction and demolition waste (as well as plastic waste) as a specific waste challenge. To increase the recycling rate of construction and demolition waste, the European Commission recommended that markets for recycled materials and the inclusion of recycled content from construction waste in construction materials be a part of a framework for assessing the environmental performance of buildings. Among the measures that the Commission recommended for improving plastic waste management were increasing recycling and abandoning landfilling.

It is worth noting that the circular economy concept ignores the social dimension; however, this is a vital component of sustainability [31]. A circular economy does not guarantee positive social, economic, and environmental performance. Nevertheless, a circular economy could be a tool for attaining the United Nations Sustainable Development Goals, and vice versa [32].

3.2. Types of Plastic

There are two types of plastic: thermoplastic and thermosetting. Once they are hardened, thermosetting plastics remain in a stable, solid state, unlike thermoplastics, which can be reshaped, remolded, and recycled [33]. Thermosetting plastics are not affected by heat and therefore, cannot be remolded or recycled [34]. Thermoplastics account for approximately 80% of the commonly used plastics, and thermosetting plastics account for about 20% [34]. Table 2 lists the different type of plastic, their uses and characteristics, as well as their potential application as recycled construction materials [3,35,36].

Polyester (PE; 36%), polypropylene (PP; 21%), and polyvinyl chloride (PVC; 12%) dominate non-fiber plastic production, followed by polyethylene terephthalate (PET) and polystyrene (PS) (<10% each). Combined, these seven groups make up 92% of all plastics. Packaging accounts for over 42% of all non-fiber plastics, which are primarily PE, PP, and PET. With 69% of all PVC plastics used by the construction sector, 19% of all non-fiber plastics are consumed by this sector [37].

Recycling plastic can be accomplished mechanically, chemically, and thermally. Plastic waste is mechanically recycled by grinding and/or shredding to break down its components. Plastic waste subjected to chemical recycling can be converted into monomers or chemically modified for further use as a substitute for virgin raw materials to produce new

plastics. It is also possible to recycle plastic waste by melting it at elevated temperatures and then pouring it into a mold to form a new product [5]. A significant improvement in the thermal properties of bricks can be achieved through the addition of recycled plastics. This improvement can be attributed to plastic's low thermal conductivity. Despite its great potential, the use of plastic waste in construction is still limited [3].

Table 2. Types of plastic.

Plastic Type	Characteristics and Use/Construction Application
Polyethylene terephthalate (PET or PETE)	Strong, clear, hard, and absorbs very little water. Example of use: beverage bottles and food bottles. Can be utilized in different types of construction materials, concrete, unfired clay brick, soil-cement block, asphalt-concrete mixture, mortar.
Low-density polyethylene (LDPE)	Soft and flexible. Example of use: garbage bags. Can potentially be used in the production of blocks and bricks.
High-density polyethylene (HDPE)	White or colored, withstands high temperatures, has a high strength-to-density ratio. Examples of use: buckets and detergent bottles. Can be used in the manufacturing of tables, plastic lumber, chairs, and other furniture.
Polyvinyl chloride (PVC)	Rigid, hard, clear, extremely good tensile strength, and very dense. Examples of use: plumbing pipes and fittings. Can be used as an aggregate/gravel in cement-based materials.
Polypropylene (PP)	Hard, flexible, non-toxic, transparent, resistant to different chemicals, and withstands high temperatures. Examples of use: lunch boxes and potato chip bags. Can be utilized as aggregates/gravel in asphalt mixtures.
Polystyrene (PS)	Transparent, relatively hard, lightweight, and colorless. Examples of use: toys and disposable plastic cutlery and dinnerware. Can be used as insulation materials (parts that are not highly stressed mechanically).
Polyester (PE)	Stable, strong, lightweight, shock absorbing, highly thermally efficient, energy absorbing, and resistant to most chemicals. Examples of use: safety belts and fabrics for conveyor belts.

3.3. Sand

Sand and clay are formed from rocky materials over thousands of years. Eroded sand is deposited on beaches, dunes, or deserts [38]. The majority of the earth's surface consists of sand and quartz, usually composed of silica, and it also contains mineral particles and finely dispersed material. The chemical composition and physical characteristics of sand vary from one location to another. Non-tropical continental inland and coastal areas contain the greatest proportion of quartz silica dioxide (SiO_2). Calcium carbonate is another common sand; for example, coral and shellfish form aragonite [37].

Although sand can be classified in various ways, it is usually classified by origin (e.g., beach, river, marine, and desert), chemical composition (e.g., heavy mineral sand, silica sand, and gypsum sand), and grain size (coarse sand, 2–0.6 mm; medium sand, 0.6–0.2 mm; and fine sand, 0.2–0.06 mm) [38]. According to the United States Bureau of Reclamation's Engineering Geology Field Manual, sand is defined as rock particles that pass through a No. 4 (4.75 mm) sieve and are retained by a No. 200 (0.75 mm) sieve. Fine sand passes through a No. 40 (425-μm) sieve and is retained by a No. 200 (0.075 mm or 75-μm) sieve. Medium sand passes through a No. 10 (2.00 mm) sieve and is retained by a No. 40 (425-μm) sieve. Coarse sand passes through a No. 4 (4.75 mm) sieve and is retained by a No. 10 (2.00 mm) sieve [33].

Due to its low cost, versatility, and ease of acquisition, sand is used globally in construction. Although access to this resource is currently relatively easy, there are indications that it may pose a significant barrier to sustainability in the future, and the true costs of uncontrolled sand mining may be revealed. The natural replenishment of sand exceeds the rate of extraction [9]. Hence, recycling construction materials, such as concrete, is a way to ensure the sustainable use of sand. However, recycling concrete bricks is challenging and costly [39]. In contrast, recycling plastic sand bricks could be cost-effective.

4. Plastic Sand as a Construction Material

The utilization of plastic in construction materials is compatible with sustainable development and promotes the improvement of environmental conditions. In the following section of the paper, the use of plastic as a raw material in producing bricks is presented. The articles chosen based on the literature selection process are shown in Table 3.

Table 3. List of the research title, type of materials, and scope of studies included in the review.

Title	Year	Type of Material	Scope of Study
"Plastic Wastes, Glass Bottles, and Paper: Eco-Building Materials for Making Sand Bricks" [33]	2020	PET, LDPE, and HDPE	plastic sand bricks
"Experimental Study on Strength Behaviour of Plastic Sand Bricks" [11]	2021	PET, LDPE, and HDPE	plastic sand bricks
"Study of Sand-Plastic Composite Using Optimal Mixture Design of Experiments for Best Compressive Strength" [40]	2021	LDPE and HDPE	plastic sand bricks
"Recycling Waste Plastic Bags as a Replacement for Cement in Production of Building Bricks and Concrete Blocks" [36]	2020	melted plastic bags	bricks and concrete blocks
⎸Utilization of Low-Density Polyethylene (LDPE) Plastic Wastes in the Production of Paving Tiles" [34]	2020	molten plastics	paving tiles
"The Effect of Composition of Plastic Waste Low Density Polyethylene (LDPE) with Sand to Pressure Strength and Density of Sand/LDPE Composite" [41]	2019	LDPE	plastic sand bricks
"Recycling High-Density Polyethylene (HDPE) into Construction Materials as a Key Step in Plastic Waste Reduction" [2]	2018	HDPE	pavers
"Comparative Study on Conventional HDPE Paver Blocks with M-Sand and Bagasse Ash as Constituent Materials" [42]	2021	HDPE	paver blocks
"An Experimental Study on Brick Manufactured Using M-Sand, Sawdust, and Recycled Plastic" [43]	2019	PP	plastic sand bricks
"Fabrication and Testing of Plastic Sand Bricks" [44]	2019	PET	plastic sand bricks
"Experimental Study on the Use of waste Polyethylene Terephthalate (PET) and River Sand in Roof Tile Production" [45]	2019	PET	roof tiles
"Manufacture of Tiles Using Waste Plastic and River Sand" [46]	2019	PET	roof tiles
"Effect of Waste PET on the Structural Properties of Burnt Bricks" [47]	2020	PET	burnt bricks
"Manufacturing of Bricks from HDPE and PP Plastic" [48]	2020	HDPE and PP	plastic sand bricks

4.1. Plastic (PET, HDPE, and LDPE) Sand Glass and Paper Brick

Ursua [33] examined eco-bricks that were 55–65% sand by weight, 29–39% plastic by weight, 5% crushed glass bottles, and 1% shredded paper. River sand was sieved through 4.75–0.075 mm sieves. The plastic waste was a mix of bottles (PET), grocery bags (LDPE), and soft drink and milk bottles (HDPE). The researcher did not specify the percentage of each plastic type utilized [33].

The results indicate that all the plastic sand brick samples exceeded the American Society for Testing and Materials (ASTM) C129 (standard specification for non-load bearing concrete masonry) minimum requirement of 500 psi (3.45 MPa) per brick. During the water

absorption test, the samples gained less than 20% of the water absorbed by the various sand brick samples, and all the sand brick samples were classified as ≤10% using the efflorescence test. Finally, when the brick surfaces were scratched, there was only a very light impression made by a four-inch common nail. When plastic waste was used as a binder, with sand and crushed glass bottles as fillers, extremely dense bricks were the result. Therefore, all the plastic sand brick samples were classified as "hard." Ursua [33] concluded that plastic sand bricks could be a potential alternative building material. The use of plastic sand bricks is also a workable solution for combating issues related to solid waste [33].

Suriyaa et al. [11] used recycled PET bottles, LDPE carry bags, and HDPE thermocol to make plastic bricks. The research did not indicate the percentage of each type of plastic used. The waste materials were cut up into small pieces, which were then melted at temperatures of 90–110 °C. River sand was sieved to 600 microns and added to the liquid plastic. The mixture was stirred continuously, poured into a mold, compacted, and cured for either 7 or 28 days [11].

The plastic bricks were compared with conventional bricks using the following tests: compressive strength test, water absorption test, efflorescence test, hardness test, and soundness test [11]. It was found that a conventional brick's compressive strength for a maximum load of 32 KN was 1.27 Mpa, while that of a plastic sand brick decreased with increasing ratios of plastic to sand. Economically, a brick-like conventional brick can be produced using a 1:4 ratio. Table 4 shows the crushing values and water absorption for various mix proportions of plastic and sand.

Table 4. Compressive strength and water absorption of various mixes.

Plastic: Sand Ratio	Maximum Load (KN)	Compressive Strength N/mm^2	Water Absorption
1:2	232	9.17 Mpa	0.346%
1:3	162	6.4 Mpa	1.57%
1:4	88	3.5 Mpa	1.467%

The water absorption of the conventional bricks was 7.08%. According to the efflorescence test results, the plastic bricks had no alkali, while the conventional bricks did. The hardness test demonstrated the hardness of the brick. The soundness test produced a clear ringing sound, indicating good quality. Finally, the plastic sand bricks weighed less than the conventional bricks.

4.2. Plastic (LDPE and HDPE) Sand

In a study by Tufa et al. [40], the effect of plastic (LDPE and HDPE) weight percentages on compressive strength variation were evaluated using Design-Expert software. An analysis of variance (ANOVA) table and fit summary were used to verify the setup model. In addition to diagnostic case statics, graphic representations of the model were assessed using adjusted R-Square, predicted R-Square, DFFITS, and Cook's D graphs. The greatest compressive strength of a sand and plastic mixture was predicted through graph analysis to be 4.95 MPa. The result was achieved with a plastic weight percentage of 60% (40% LDPE and 20% HDPE). The plastic was melted and blended with sand at a weight percentage of 40% (25% 1.18 mm sand and 15% 0.5 mm sand). The results were negatively impacted by a plastic waste content higher than 70%, and this was likely due to impurities within the materials. Compressive strength was negatively affected by sand when its percentage weight was >42%; this was due to pores created in the bricks by the noncoherent plastic and sand mixture. Sand plastic composite bricks (SPCBs) derived from plastic waste have many environmental and economic advantages, according to the authors.

4.3. Plastic (LDPE) Sand

Abdel Tawab et al. [36] replaced cement in the production of bricks and concrete blocks with melted plastic bags. The bricks were produced from melted waste plastic and sand, while the blocks were created by mixing melted waste plastic, sand, and gravel. The resultant molded materials were found to differ in thermal conductivity based on their plastic content. The thermal conductivity of both the bricks and the concrete blocks decreased as the plastic content increased. Table 5 Shows the bending moment, bending stress, and thermal conductivity of plastic sand brick with various percentages of LDPE.

Table 5. Physical characteristics of plastic sand bricks with various plastic percentages.

Plastic:Sand	Bending Moment N·m	Bending Stress N·m^{-2}	Thermal Conductivity W/m·k
2:1	1711.25	10.26	1.43×10^{-3}
1:1	721.55	4.32	1.53×10^{-3}
1:2	540	3.24	1.71×10^{-3}

In both bricks and blocks with similar plastic content (50%), the thermal conductivity values were similar. For both bricks and blocks, the bending moment and therefore, the bending stress increased with the plastic content. By increasing the plastic content of the blocks from 20% to 50% (150%), the bending moment increased from 901.40 N·m to 1442.55 N·m (60%), and the bending stress increased from 5.40 N·m^2 to 8.65 N·m^2 (60%).

It was found that plastic waste could be used for making bricks and blocks because of its high versatility, its ability to be tailored to meet specific needs, and its light weight, which reduces fuel consumption during transport. Substituting cement with plastic waste will further reduce environmental problems associated with both plastic waste disposal and cement production.

Osarumwense et al. [34] conducted a study in which molten plastics were mixed with sand to produce paving tiles at varying plastic to sand ratios (1:1, 1:2, 1:3, and 1:4). Curing took place over 28 days. Figure 3 shows the compressive strength of various plastic to sand ratios.
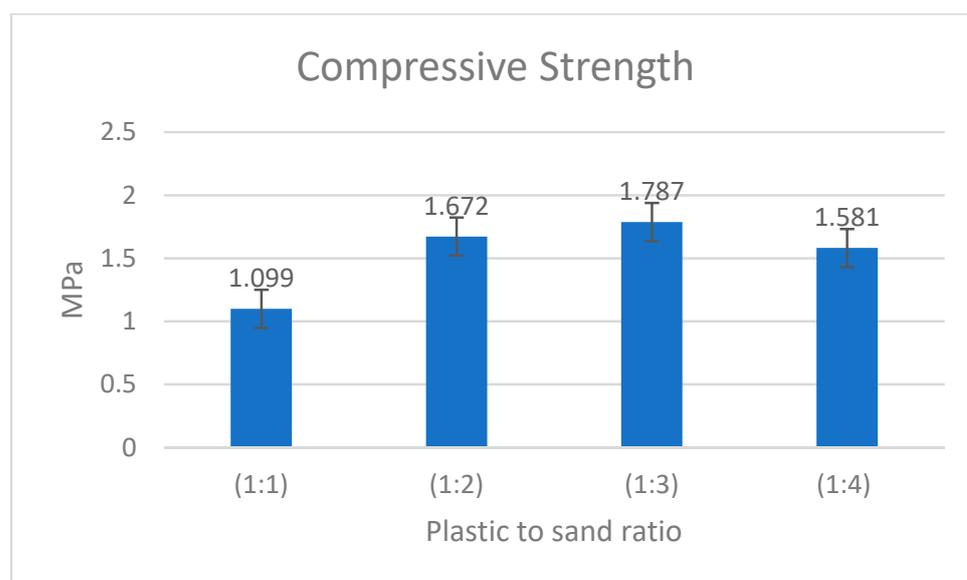
Figure 3. Compressive strength with various plastic to sand ratios [34].

A conventional sand-cement composite (control) could withstand a maximum load of 29 KN. The tile (sample) could sustain a maximum load of 39 KN at a 1:3 ratio. The frictional

coefficients for the sample and control were 0.372 N/kg and 0.289 N/kg, respectively. This is an indication that a 1:3 ratio is optimal for LDPE-based tiles. The authors concluded that for constructions, plastic sand-bonded tiles can replace sand-cement composites.

Susila et al. [41] examined the compressive strength of samples with 1:3, 1:5, and 1:7 ratios of LDPE plastic to sand at 200 °C. The samples with a 1:3 plastic to sand ratio and 3 mm sand grains were found to have the greatest average compressive strength of 32.7 Mpa (see Figure 4). The samples with a 1:7 plastic to sand ratio and 3 mm granules had the lowest average compressive strength 12.0 Mpa. The higher the ratio of plastic to sand, the lower the compressive strength of the composite; the higher the ratio of plastic to sand, the higher the density of the composite. The authors emphasized the need to recycle plastic waste, especially plastic bags, and suggested that paving blocks could be made from plastic waste instead of cement.
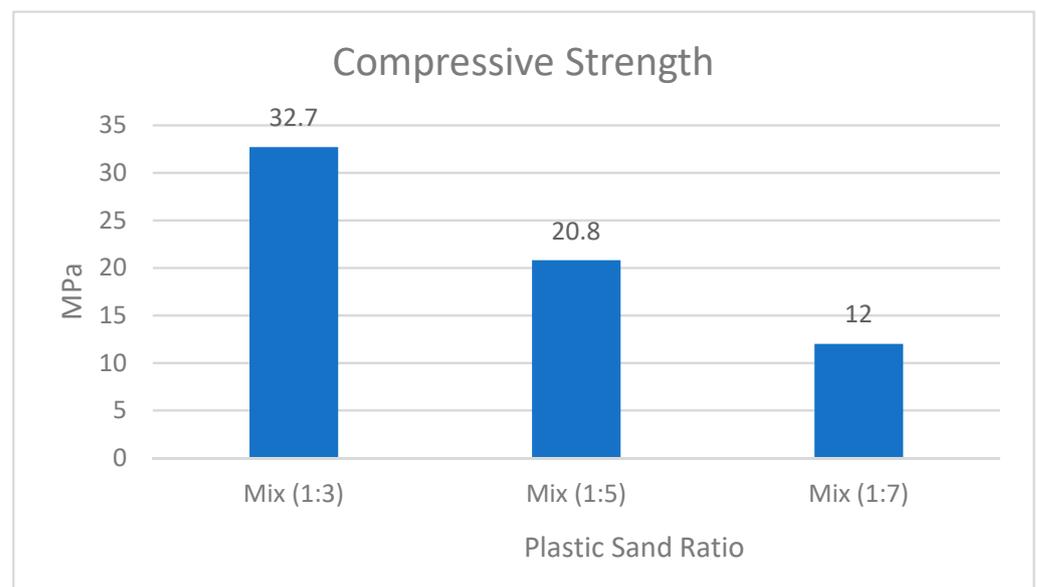
Figure 4. Compressive strength average of the specimen with plastic and sand mixture [41].

4.4. Plastic (HDPE) Sand Paving Material

Dominique [2] mixed HDPE plastic and sand to produce pavers and then tested their compressive strength. Three sand to plastic ratios (1:3, 1:4, and 1:5) were tested. The samples were placed in molds (100 mm diameter and 65 mm height), heated in a closed drum, and their temperatures were observed at 30 min intervals. It was observed that HDPE melts at 120–400 °C. Table 6 shows the compressive strength for the three sand to plastic ratios after compaction and shows the compressive strength after exposure to 35 °C for 12 h.

Table 6. Compressive strength of various ratios after compaction and after 12 h of 35 °C exposure [2].

Plastic:Sand Ratio	Compressive Strength MPa	Compressive Strength (after Heat Exposure) MPa
1:3	21.73	17.79
1:4	26.15	22.37
1:5	4.79	3.52

A standard water absorption test was conducted. After measuring the dry weights, the three samples with the highest compressive strength were immersed in water for 24 h. The results showed that the water absorption value was 0.052% higher than that of cement concrete pavers [2]. This mix was found to reduce construction costs, especially those for repairs, as well as reduce environmental impact.

Valarmathy and Sindhu [42] compared conventional HDPE paver blocks with paver blocks containing manufactured sand (M-Sand), sugarcane bagasse ash, and HDPE plastic. The blocks were coated with lime hydrate after molding because plastic is not a good heat insulator, and lime acts as a good thermal insulator. It was determined that the paver blocks manufactured with HDPE plastic waste are more durable and more resilient than many other types of paver blocks, creating an exceptionally low-cost, renewable, and eco-friendly alternative.

4.5. Plastic (PP), M-Sand, and Sawdust Brick

Clement et al. [43] evaluated brick samples (190 × 90 × 90 mm) made from plastic waste (PP), wood dust (sawdust), and M-Sand. The sawdust was used to reduce brick weight. The five molded samples were all 20% plastic (PP), and the percentages of sawdust and sand were 5% and 75%, 10% and 70%, 15% and 65%, 20% and 60%, and 25% and 55%. The study found that a mix of 20% plastic, 10% sawdust, 70% M-sand provided the maximum strength of 9.3 MPa out of the five proportions. It was concluded that plastic bricks are stronger than normal bricks, which provide compressive strength of 6.6 MPa.

4.6. Plastic (PET) Sand Brick

Chauhan et al. [44] conducted a study to assess plastic waste (PET) and river sand bricks with 1:2, 1:3, and 1:4 ratios of plastic to sand. The bricks were 230 × 100 × 75 mm. The compressive strength test results are shown in Table 7.

Table 7. Compressive strength test results [44].

Plastic:Sand Ratio	Maximum Load (KN)	Compressive Strength (kg/cm^2)
1:2	500	193.87 (19.01 MPa)
1:3	350	135.71 (13.31 MPa)
1:4	165	63.97 (6.27 MPa)

Water absorption reached a maximum of 4.56% in the 1:4 ratio specimen, and it was as low as 0.95% in the brick with the 1:2 plastic to sand ratio. Water absorption in conventional clay bricks is around 15–20%.

According to the study, plastic bricks are less conductive than clay bricks. Despite this, continuous exposure to temperatures above 350 °C caused partial melting of the bricks. Therefore, these plastic bricks are not suitable for use where fire risks exist.

4.7. Plastic (PET) Sand Roof Tile

Bamigboye [45] tested the performance of roof tiles manufactured from river sand and recycled PET in varying proportions (10%, 20%, 30%, 40%, 50%, 60%, and 100% PET). The study found that 10% PET composites had the highest water absorption (2.94%), while 30% PET composites had the lowest (0.15%). Additionally, the study reported that the tile samples with the lowest density were 100% PET (852.07 kg/m^3), and the samples with the highest density were 10% PET (1899.56 kg/m^3). Finally, it was found that the highest value among the composite tiles was for those with 40% PET (1.59 Mpa), followed by those with 50% PET (1.48 MPa) (see Figure 5).

Reta and Mahto [46] conducted a study to assess roof tiles made of a plastic waste (PET) and sand mix. Three samples containing 20%, 30%, and 40% PET were assessed. The compressive strengths of the 20%, 30%, and 40% PET samples were 25 MPa, 23.5 MPa, and 18.2 MP, respectively. The findings indicated that plastic sand tiles are more cost-effective than conventional concrete tiles.
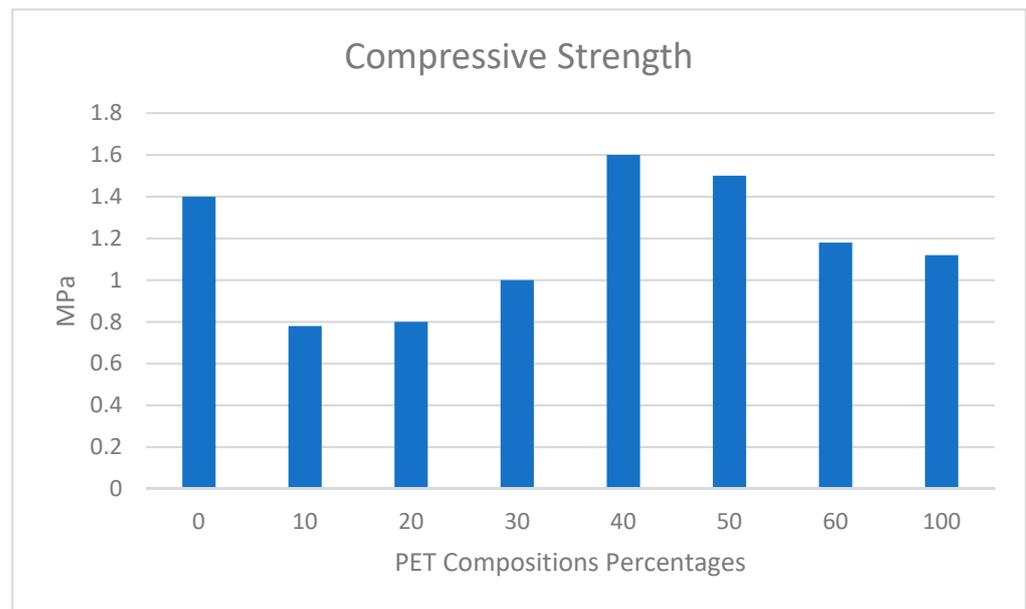
Figure 5. Compressive strength values of the respective samples [45].

4.8. Plastic (PET) Brick

Akinyele et al. [47] tested PET as a replacement for burnt bricks. They reported that PET-containing materials melted during firing because the PET melting point is only 250 °C. During firing, a sample containing more than 10% PET collapsed, whereas one with less than 10% PET deformed, but did not collapse. The PET bricks also had low compressive strength. Nevertheless, bricks containing <5% PET can perform well. Based on the study, replacing burnt bricks with PET is feasible, provided that the amount of PET is <5% and the temperature is closely monitored.

4.9. Plastic (HDPE and PP) Brick

Mohan et al. [48] examined the viability of using HDPE and PP plastic waste to create bricks. The mix was heated up to the plasticity zone, then transferred into a mold and compressed to attain the final brick product. Table 8 shows the compressive strengths of the bricks with HDPE:PP with various ratios, and the percentage of water absorption.

Table 8. Compressive strength of various HDPE:PP ratios [48].

HDPE:PP Ratio	Compressive Load (KN)	Compressive Strength MPa	Water Absorption %
50:50%	157	7.5	0.44
40:60%	97	4.64	0.25
70:30%	128	6.12	0.23

Converting waste plastic into useful building materials (e.g., interlocking bricks) could alleviate the problem of plastic waste in society and effectively reduce environmental pollution.

5. Discussion

Most of the studies on plastic sand bricks have been conducted in India, with some performed in Africa. One probable reason for researchers in these areas being particularly interested in plastic sand bricks is the waste management challenges they face. In 2021, the UNEP reported [49] that waste collection services in most African countries are insufficient. For example, the average collection rate of municipal solid waste (MSW) is 55%, and 13% of MSW in Africa is plastic waste. Only 4% of MSW is recycled in Africa, even though

70–80% of MSW is recyclable [49]. Africans have begun to recycle more because of poverty, unemployment, and socioeconomic needs rather than public or private sector initiatives.

The studies on plastic sand bricks, blocks, and tiles included in this literature review were conducted in several different countries. These countries and the associated references are listed in Table 9.

Table 9. Country of origin of studies included in this literature review.

Reference No.	Country	Number
[10]	Algeria	1
[11–13,15–18,42–44,48,50–54]	India	16
[33]	Philippines	1
[40,46]	Ethiopia	2
[36]	Egypt	1
[5,34,45,47]	Nigeria	4
[41]	Indonesia	1
[18]	Paraguay	1
[55]	Poland	1
[2]	Rwanda	1
[37]	Malaysia	1
[56]	Colombia	1
[7]	Iraq	1
[57]	South Africa	1

Figure 6 shows a graphical representation of the proportion of studies from each country included in this literature review.
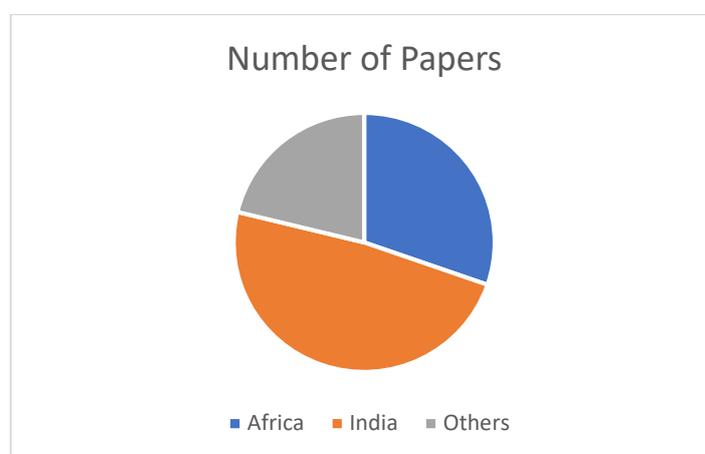
Figure 6. The proportion of studies from each country used in this literature review.

The studies examined the following physical characteristics of samples with various plastic to sand ratios: compressive strength, water absorption, efflorescence, hardness, and conductivity. Figure 7 shows the compressive strengths of various compositions and lists the associated studies.

There is a lack of standards and uniformity in conducting the experiments, which could lead to a significant disparity in the results. For example, while Reta and Mahto [46] reported a compressive strength of 35 MPa for PET sand roof tile with a 1:4 ratio, Bamigboye [45] reported a compressive strength of 0.8 MPa for PET sand roof tile with a 1:4 ratio. Comparing both studies could not reveal the reasons for this significant disparity.

Some studies mixed various types of plastic waste (e.g., PET, HDPE, and LDPE) with sand without specifying the percentages of each plastic type [11,33,40].
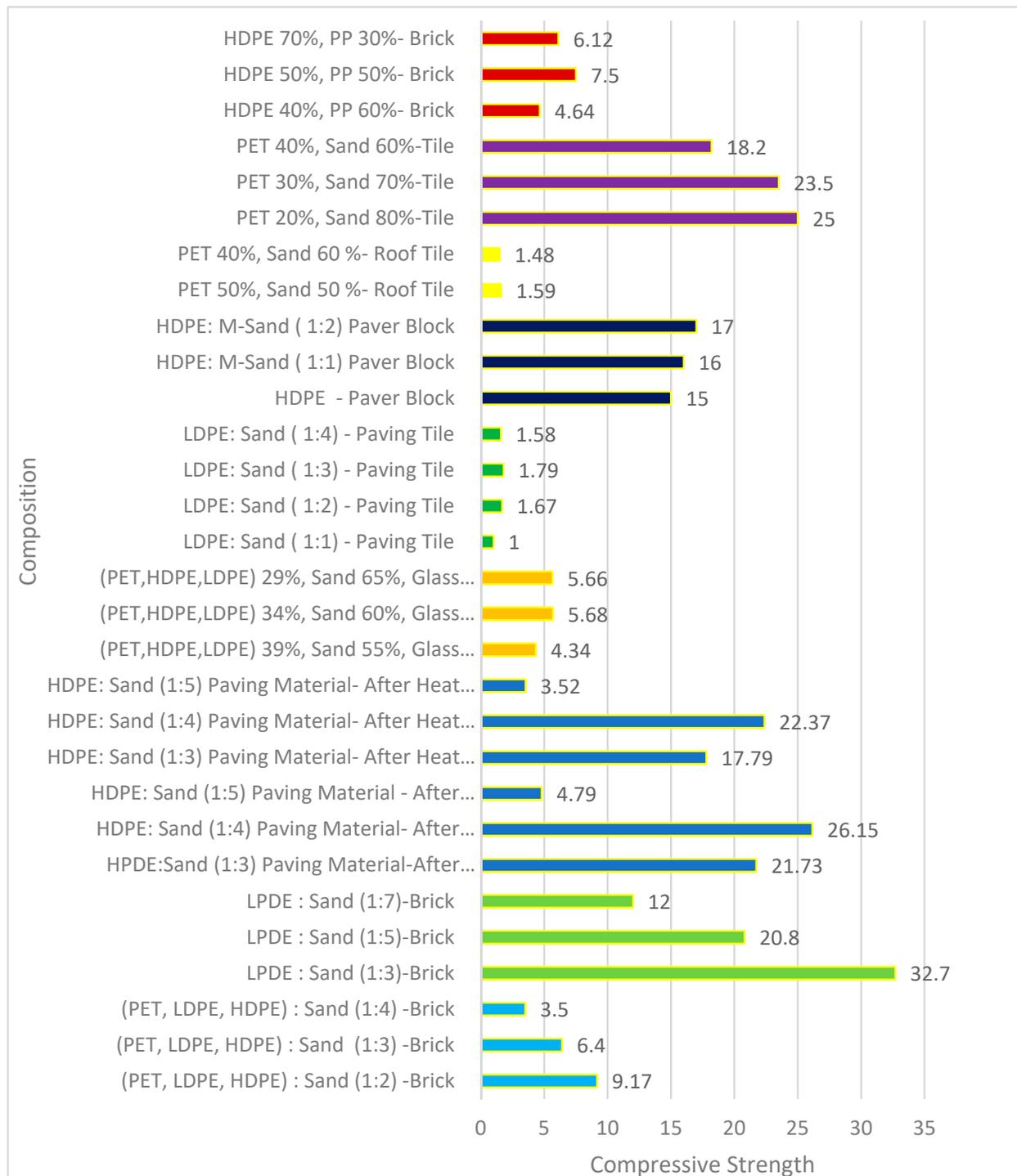
Figure 7. Compressive strength of various compositions [2,11,33,34,41,42,45,46,48].

Various studies [11,12,33,40] confirmed that plastic sand bricks with certain plastic to sand ratios provide a good nonbearing alternative to conventional bricks and concrete blocks, especially in terms of compressive strength, maximum load crushing, water absorption, and efflorescence testing.

We did not find any prior studies that addressed the flammability and fire resistance of plastic sand bricks, which are important characteristics for practical utilization in construction. Only Selvamani et al. [53] indicated that waste plastic sand bricks can easily catch fire; however, they did not report the actual results of their test. In addition, Ab-

del Tawab et al. [36] reported the thermal conductivity of plastic sand bricks, noting that conductivity decreases as the plastic percentage increases.

A study conducted in India compared the costs of plastic sand bricks and conventional bricks [53] and indicated that the cost of plastic sand bricks was almost double that of conventional bricks. The comparison was based on the cost of a sample of plastic sand bricks, which might be misleading in the case of mass production. Another study conducted in Ethiopia indicated that plastic sand tiles are more cost-effective than conventional tiles [46]. In any case, it is essential that producing and using plastic sand bricks be cost-effective for their successful commercial use as an alternative construction material. In addition, one study claimed that, in general, using PET waste in construction materials reduces the price of such materials [51]. That plastic waste is cheap, however, does not mean that plastic sand construction materials will inevitably be competitive. The collection, transportation, and storage of plastic waste could be infeasible in some economies. Accordingly, economic evaluation studies are required to assess the feasibility of the construction industry adopting plastic sand bricks, blocks, and paving materials [51]. In addition, there is a need for studies that address industrializing plastic sand bricks, blocks, and paving materials. Without such studies, plastic sand construction materials will remain valid alternative construction materials only in theory. The significance of studying the commercial evaluation of plastic sand bricks and blocks is justified by the concrete blocks and bricks manufacturing market being estimated at USD 1700.55 billion in 2019, and projected to reach USD 2563 billion by 2027 [58].

6. Conclusions

The management of plastic waste is facing increasingly rigid controls due to sustainability issues. The challenges are being addressed by different institutions which are shifting toward a circular economy. This paper has synthesized the findings of recently published research related to the production of alternative sustainable construction materials (i.e., bricks, pavers, and roofing tiles) that combine plastic waste and sand. This review has revealed the following points:

Plastic sand bricks could be a potential alternative building material that is not only environmentally friendly, but also competitive with conventional bricks and paving materials in terms of physical properties (e.g., compressive strength).

- Plastic sand bricks could be a workable solution for combating issues related to solid waste.
- The compressive strength decreased with increasing ratios of plastic to sand. The plastic sand bricks weighed less than the conventional bricks, and had no alkali, compared to the conventional bricks. The thermal conductivity of the bricks decreased as the plastic content increased.
- Low-density polyethylene (LDPE) and polyethylene terephthalate (PET or PETE) are the types of plastic that can potentially be used in the production of bricks and blocks.
- There is a lack of research related to practical issues, such as fire resistance, cost-effectiveness, thermal conductivity, manufacturing, and commercial aspects of plastic sand bricks.
- Almost all the reviewed studies were conducted on a small scale. The industrial manufacturing of plastic sand bricks will require a major investment to move to mass production.

The findings of this review, which outline the state of the art of plastic sand bricks/blocks, allow us to look to the future in terms of translating this new technology into practice, as well as finding new initiatives for reducing plastic pollution. Using plastic in construction materials can play an important role in reducing global warming, while prospectively protecting the environment. Some of the issues/challenges that need to be addressed in future studies are:

- Dealing with varying proportions and types of plastic;
- The lack of understanding of the long-term performance of plastic sand bricks;

- The flammability and fire resistance of plastic sand bricks;
- The absence of appropriate standards and regulations for recycling plastic into plastic sand bricks.

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