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A Review on Recycled Materials Used in Construction

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Abstract**—**Construction waste, along with that of many other industries, contributes significantly to the world's annual solid waste totals. Most of these materials, such as ash from rice hulls, slags, cement kiln dust, tire ash, plastic waste (PW), and silica fumes, end up in landfills or waterways. Some of them might even end up polluting the air from high in the atmosphere. It is sustainable, cheap, and environmentally friendly to recycle these items into new building supplies. When constructing a "green" structure, the materials employed have the potential to either exacerbate environmental imbalance or maintain a stable ecosystem. The purpose of this research is to take stock of what is already known about recycling's potential in the construction industry and to identify its deficiencies. Therefore, this study systematically reviews the wide range of recycled materials that go into building construction. In the construction industry, the utilization of recycled materials plays a significant role in environmental conservation, and a thorough investigation into these materials could potentially yield substantial economic benefits if appropriately harnessed.

Keywords**—**Paper waste, rice grain husks, recycled materials, waste management.

I. Introduction

THE construction of roads, buildings, and bridges is an essential aspect of any sustainable development. To achieve sustainable development, present needs must be met without jeopardizing future generations. For this reason, it is important to take the necessary steps to guarantee the supply of building materials for future construction.

The amount of waste people produce (whether solid or liquid) continues to rise [1]. Research suggests that burning waste adds an extra 5% to global carbon emissions [2]. The amount of waste produced is predicted to increase by 2025 compared to 2000 [3]. Municipally solidified waste materials (MSWM) commercialized and industrially sourced wastes (C and I), and constructions and demolitions waste (C and D) comprise the three categories that make up the world's collection of solid waste material [4], [5]. Rapid urbanization increases construction activity worldwide [6], which is problematic for the environment. This raises concerns, such as the need for more natural raw materials to be extracted and the production of a great deal of C and D waste [7]. The construction industry consumes the most resources overall, accounting for over 32% of all inputs. This includes up to 40% of all energy inputs and 12% of all water inputs. 40% of all raw materials and 25% of all harvested timber are used in buildings [8]. Also, it is hard to get to zero waste because of how the industry works and how much waste is always being made [9].

Circular economy is becoming increasingly important as resources become scarce [10]. That is why it is so important to focus on reusing, repairing, and recycling (3R Principle) to extend the lifespan of building materials [11], [12]. The 3R principle is crucial to leading a sustainable existence [13] and it is essential that the next generation acknowledge the importance of the 3 R's. Reuse refers to the practice of recycling materials that have already been utilized. Reduce involves less use of a material. Recycling involves transforming waste into useful materials. Recycling is an alternate strategy for waste removal that can save resources and cut down on greenhouse gas emissions. By keeping more materials out of landfills, recycling can help preserve natural resources and save money. As a result, energy use, pollution (from burning), and water contamination (from land filling) can decrease. Glass, textiles, plastic, paper, cardboard, metal, tires, and electronics are all examples of recyclable materials.

In many countries, the building industry also consumes the rawest materials, making it an attractive sector in which to involve recycled waste. Applications for recyclable waste in structure construction are varied. The construction industry may benefit greatly from the incorporation of recycled materials, but progress has been painfully slow thus far. Therefore, this paper aims to explore the most recent use of recyclable materials in construction works.

II. Methodology

This research employs a systematic literature review to assemble information on how recycled products are utilized in building projects. Specifically, the PRISMA [14] and five critical phases for systematic reviews [15] served as foundations for this method. In order to accomplish this, up-to-date information regarding the application of reusable and recyclable materials in construction projects was sought. "Building", "construction", "recycled materials", and "waste management" were the keywords used in the searches. Relevant research outputs were located by searching three major research engines (Scopus, Google Scholar, and Science Direct).

Research articles closely aligned with the research objectives were selected based on the following criteria:

1. Journal articles indexed in databases; systematic reviews published in peer-reviewed publications;
2. Research conducted after 2010 that accurately reflects the

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present state of the industry; and,

3. Research papers written in English.

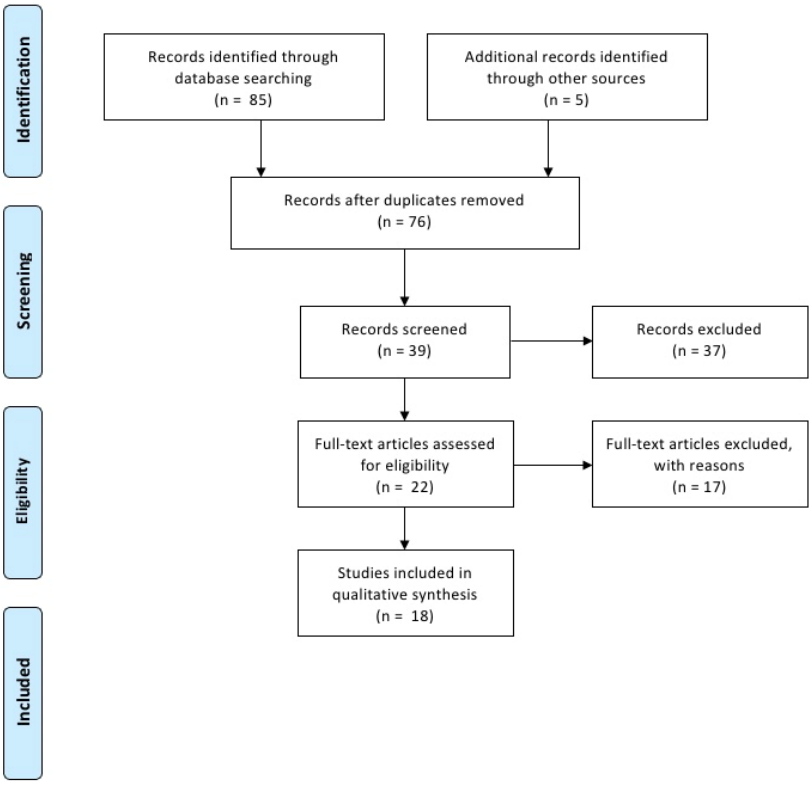

Fig. 1 PRISMA flow diagram [14]

TABLE I
RESULTS

Type of Material	Source	Findings
MSWM	[16]	When making burnt bricks, *paper mill sludge* (PMS) is ideal because of its high strength and durability.
MSWM	[17]	Soft clay soil enhanced with *seashells and eggshells* can be utilized in road construction.
MSWM	[18]	Use of *palm bunch ashes* recycled using nanotechnology as a soil addition at lower concentrations will produce significantly subpar outcomes when applied to lateritic soil.
MSWM	[19]	Building products, including as roofing and insulating panels, could benefit greatly from the incorporation of *paper waste* in the development of lightweight components with higher strength qualities and less water absorption.
MSWM	[20]	Improved construction methods based on use of *rice husks* can enhance the thermal and acoustic performance of buildings.
MSWM	[21]	Wall and ceiling coverings made of *rice grain husks* and an earthy matrix can improve a building's hygrothermal comfort and health without breaking the bank.
MSWM	[22]	When used in asphalt mixtures made of limestone and granite, *recycled paper mill sludge* raises the tensile properties.
C and I	[23]	The physical-mechanical qualities of building supplies can be enhanced by including *foam glass and high-impact polystyrene* as additives.
C and I	[24]	Up to 60% *recycled concrete aggregates* substitution in porous asphalt mixtures had satisfactory performance.
C and I	[25]	To create cheaper paving blocks for use in non-traffic moderately rigid pavement projects, *recycled PW* can be used as an alternative.
C and I	[26]	Fiber structures produced from *polyethylene terephthalate* recycled rings mimics the properties of commercialized synthetic fabrics.
C and I	[27]	Compression molding, which uses postindustrial *textile waste* has the potential to be a cost-effective method of producing heat insulating materials
C and I	[28]	*Sisal fibers* can enhance the thermophysical characteristics of clay bricks used in building projects.
C and I	[29]	*Plastic* is used in conjunction with bitumen and stones to improve the performance of roads. Coating aggregates with a polymer reduces voids and water absorption. Due to this, ruts are diminished, and potholes are prevented.
C and I	[30]	The usage of insulated construction coverings (thermal and acoustic performance), roofing alternatives, and floor coverings are only a few of the many construction applications for *End-of-life vehicles.* The used tires can be recycled right away and used in construction for floor coverings, foundations, and to replace typical cementitious materials. In order to recycle energy, used tires can potentially be utilized as energy source. Mechanical parts and automobile chassis may be melted down and recycled to create basic metal sheets which can be used to make new cars and building materials like cladding, roofing, and flooring.
C and D	[31]	Ultra-high-performance concrete can be made with recovered filler made *from Constructions and Demolitions waste*.
C and D	[32]	Recycled *gypsum waste* is employed in manufacturing of construction bricks with better properties.
C and D	[33]	The research proved that eco-friendly *geopolymer* concrete may be produced using readily available materials like *metakaolin* and concrete mixtures
C and D	[34]	C and D wastes are alkaline activation technology-compatible because they can be employed as a binding agents and aggregates.

Research that was not published in peer-reviewed journals was disqualified. Meta-searching for "recycled materials," "construction," and "buildings" in publications from 2010 to 2022 initially yielded 85 study findings; this number was increased to 90 once more sources included in the original research outputs were uncovered. After identifying multiples of the same study, we chose those that were most relevant to the issue of recycled products. 18 publications were chosen for this analysis. The PRISMA selection process is depicted in a flowchart (Fig. 1). Thematic analyses of findings were conducted.

III. Discussion

A. Use of Recycled MSW in Construction

Worldwide, people produce over 3.5 million tons of MSW every day [35]. In 2050, based on estimations of the UN, the number of people globally would be 9.7 billion and 11.2 billion in 2100 [36].

For a long time, clay bricks were the most prevalent building material, and this enabled the creation of enormous structures. This is because they are long-lasting and have several desirable qualities, including fascinating physical-mechanical and thermal characteristics [37]. However, they are faced with limited mechanical durability. Stabilizing clay bricks makes them stronger and less likely to soak up water. This means they can compete with other common building materials used today.

To create environmentally friendly lightweight bricks, PMS and soil were used in an investigative study, the results of which were presented by [38]. Characterizing the soil types (laterite, alluvial) and PMS on a variety of levels is a key part of the manufacturing process. The proportion of PMS in the mix was determined by measuring and comparing several brick metrics to industry standards. Adding 10% PMS to the laterite soil reduced the density of the fired bricks by 24%, whereas adding the same amount to alluvial soil reduced the density by 21% at the same firing temperature of 900 °C. The addition of PMS increases porosity without causing a phase shift, as determined by X-ray diffraction, leading to a net reduction in mass. The results showed that using a 10% PMS blend with either soil type resulted in bricks that performed well at a burning temperature of 900 °C. Reference [39] discovered that using 20% degraded MSW led to a net 8% decrease in the amount of energy from outside sources that was used.

Technologists, scientists, and engineers have recently been optimistic about the potential for global valorization of eggshell waste (ESW). The use of ESW has been regarded as the most economical method for cutting down on building material costs [40]. Even though several building materials have had their physical and mechanical properties improved, recycling and reusing ESW has been shown to be good for the economy, and the environment. This is because it fully utilizes eggshells while bringing down the price of construction activities for the economic growth. Fig. 2 depicts a few construction projects that use eggshell.

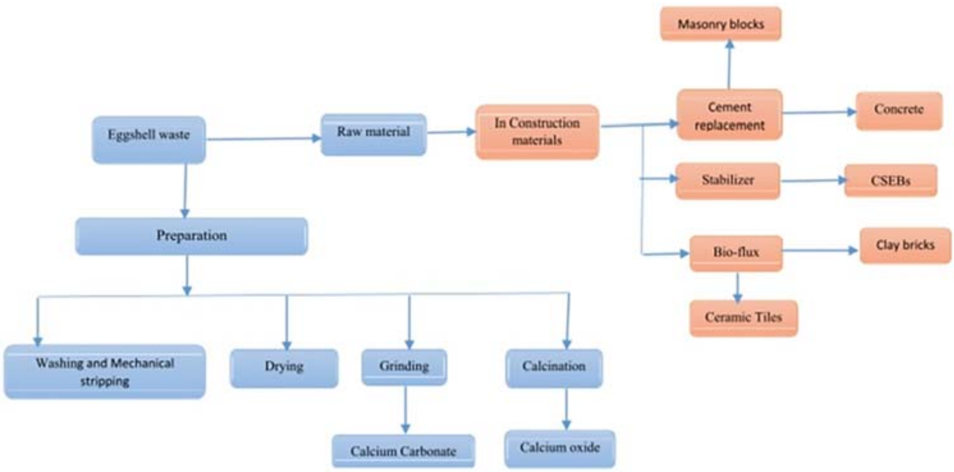

Fig. 2 Utilization of ESW and other materials in the building industry [40]

Stabilizing and strengthening clay bricks to render them highly durable and ecofriendly have been accomplished using waste marbles [41], [42], lime [43], and bone ash [44]. The incorporation of eggshell powder into the clay improved their properties significantly [45]. Following the sintering stage, and given the right precursors, the formation of the anorthite phase ($CaAl_2Si_2O_8$) is possible. The addition of eggshell powder (ESP) as a filler contributes to the vitrification process, thereby refining and altering the characteristics of clay bricks [46] at 1000 °C for a period of five hours.

Cement is not only a costly material but also a major contributor to the release of greenhouse gases during its manufacturing [47]. During cement production, about one ton of carbon dioxide is discharged [48] and about 1.6 tons of natural resources are needed.

Studies have shown that by using readily available agricultural and industrial waste in place of some of the cement, costs, waste, and carbon dioxide emissions can be reduced [49]. Some examples of such waste include sugarcane, maize cob, rice grain husk ash and millet grains husk ash. Rice husk is obtained from the food and farming industries [50], and because it is regarded as undesirable, it is typically burned in the open air [51]. The proper disposal of agricultural and industrial waste is currently a major issue. Rice husk is an example of one of these types of agricultural waste. The quantity of rice husk that is produced annually in paddy fields is around 120 million metric tons per year [52]. Burning or dumping the husk that is produced during the preparation of rice is a common practice. Rice husk is burned at a specific temperature in an environment under these conditions. RHA has a silica concentration of 85%, which is classified as non-crystalline silica, and cement might potentially be made with it as an additive [53]. Since RHA is a highly cementitious substance, it might be added to concrete as a means of reducing the latter's environmental impact [54].

An investigation on the qualities of hardening concrete was carried out utilizing 10% RHA as the hardening agent [55]. Results showed that concrete's temperature can be reduced by utilizing RHA instead of normal cement [56]. In [57], experts examined how cement modified the final product's characteristics. After a month, crush concrete that was mixed with 10% RHA had a 15.74% better mechanical property [57]. Evidence from studies shows that ashes from rice grain husks is crucial to the characteristics of cementitious materials [58]. RHA particles are smaller in size compared to OPC particles, which results in improved concrete characteristics [59]. RHA has a particle size of around 25 microns, which enables it to perform an important function as a filler in cement [60]. RHA is positioned to have a major impact on the building sector. During this controlled experiment, RHA was mixed with concrete in amounts that ranged from 0% to 20% by weight.

B. Use of C and I Waste in Construction

Every country's economy rests on the shoulders of the construction industry. Therefore, the possible use of waste products will contribute to making construction processes and practices more eco-friendly. The environmentally responsible utilization of plastic for architectural applications results in monetary advantages as well. If PW is repurposed for use in sustainable construction, it will be diverted from landfills and thereby reduce the amount of waste released into the oceans. The construction industry may benefit greatly from the use of PW, but only if the material could meet the mechanical and long-term standards. In addition to its functionality as a construction material, PW also needs to be environmentally friendly if it is to displace other materials in the construction industry. Floor and wall tiles with improved fire resistance and structural rigidity [61] have been made from recycled, non-biodegradable waste plastic bags. Waste plastic bags are not biodegradable. PW includes a wide variety of materials depending on the polymers' original purpose [62]. Fig. 3 shows a breakdown of PW by category along with rough estimates of total volume [63].

Utilization of recycled plastics in fiber bolstered concrete was investigated in [26]. The splitting tensile, fracture toughness, and beams flexing rigidity of the concrete were all improved thanks to the addition of ring-shaped PET. The analysis showed that adding plastic fibers to concrete did not change how it broke, but it did improve the beams' mechanical performance in terms of first crack force and strength.

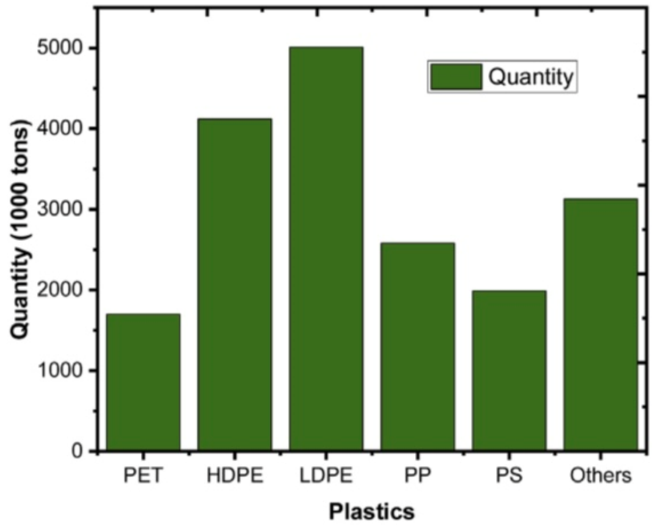

Fig. 3 Estimated volumes and descriptions of PW ([63] as cited in [64])

Many years ago, other countries began instituting practices for ELV waste recycling in the home building industry. Architect Michael Reynolds' earth-sheltered homes, for instance, feature rammed earth-tire walls that provide thermal mass and thus insulation from hot summers [64]. The temperature of the internal air was reduced by 12 °C when bits of recycled rubber tires were embedded in the outer walls of a concrete building, in comparison to a control construction [65]. Reusing tires as an insulator for concrete and a solution to lower the heating of driveway surfaces has become popular in the building industry in Malaysia. A variety of eco-home designs have been devised utilizing recycled tires to lower surface temperatures [66]. Some of the methods explored by "smart" and "cool" home designers to lower internal temperatures include aerated concrete slabs, dual-paned windows, and the "Bernoulli Effect" ceiling [67].

A developer examined the heat sink [66] in one of its pilot homes by placing it in direct sunlight on a driveway. The flooring of the parking space remained cool despite the midday sun because it was embedded with three layers of discarded tires stacked over ground beams underneath the concrete slab. Later, a Malaysian contractor by the name of Mainstay Development used similar idea to construct a new commercial area in Shah Alam, Malaysia, aptly dubbed Space U8. As heat is dissipated through the autoclaved aerated concrete bricks used in this cutting-edge building method, the interior temperature is kept at a comfortable level [68].

The increasing popularity of crumb rubber in pavement construction and maintenance can be traced back to its many beneficial properties, such as the obvious advantages of recovering and recycling used tires, the improved flexibility the rubber contributed add to the binder, and the increased protective components linked to durability. There are three main hurdles that must be managed before crumb rubber customized asphalt mixtures can be promoted for extensive application in pavements: the high initial expenses, the shortage of parties involved, and insufficient familiarity with the efficiency and intricacies of crumb rubber-based, individualized asphalt compositions [69]. When compared to traditional wall systems on unstable terrain, this form of wall structure provides improved drainage and stability [70].

C. Use of C and D in Construction

When compared to other types of industry, construction generates the most waste in Europe, accounting for 35% of all waste created, which is two to four times more than the amount of rubbish generated by the average American or European family. The recovery target for the European Union as a whole, including backfilling, has been met for 2020 [71].

Concrete, masonry and mixed aggregates are the three primary types of C and D waste aggregates [72]. Since the amounts of individual components in the mixture have the potential to have an impact on the blend's characteristics, the majority of C and D blends are made up of a variety of these categories [73]. Some mixtures can also include other materials, such as ceramics [74].

Recycled asphalt pavement (RAP) aggregate is another popular substitute material for both pavement and geotechnical projects [75]. RAP aggregate is created when crusher mixtures are combined with a bituminous binder. Employing recycled C and D waste material in building projects has many advantages [76], including reduced building costs, avoided waste disposal levy and improper disposal, decreased energy consumption, decreased pollution of greenhouse gases and other pollutants, preservation of useful forest lands, prolonged landfill life, and the new employment opportunities. Recycled materials are increasingly being used in construction projects in the United States for three main reasons: reduced trash, lower overall costs, and a lower environmental impact [77].

Reusing recycled materials near where they were reprocessed is said to reduce both the total embodied energy and the emissions from transportation [78]. A study conducted in Japan found that completely recycled residential properties might cut power use by at least 10% [79]. To make recycled aggregate more suitable for supplementary uses (such as cement), Japan is also employing cutting-edge technology [80].

According to a study by [81], switching from using natural coarse aggregates to using recycled coarse aggregates can cut carbon dioxide emissions by up to 65% and cut the use of nonrenewable energy by up to 58%. When compared to a conventional quarry product of the same quality, recycled aggregate in Australia reduces energy usage and greenhouse gas emissions by roughly 4 kg of carbon dioxide per ton [82]. Other studies have not been able to prove the positive carbon footprint of recycled C and D waste material, despite these findings [83]. Poor structural behavior is one of the causes of this, and it must be improved by adding reinforcements.

IV. Conclusion

In this paper, we looked at how recycling can be applied to the construction industry. Recycled and repurposed materials are discussed, along with the various applications they might have in building design. There are a variety of creative approaches of reusing and recycling construction materials. Recycled materials have been successfully used in numerous commercial and residential structures.

Reusing materials in construction is fraught with complications, the majority of which are monetary in nature [84]. This may be the price of the recycled materials themselves, or the time and energy spent putting them to use. Construction companies have the additional concerns of liability and risk. The availability and appropriateness of resources is a further concern, especially when it comes to recycled materials. There may also be a need to rethink and adjust how to go about the design process. While this may seem like a limitation at first, it may present a unique opportunity for creative problem solving. The lack of knowledge among contractors with the challenges and reality of using recycled materials, in addition to sustainable building in general, is one of the most significant barriers to the utilization of recyclable materials. It is necessary to convince architects, clients, and developers into using recyclable products and other building goods that are better for the environment in terms of the amount of waste produced, the amount of pollution produced, the amount of energy consumed, and other negative impacts such as the loss of habitat and species.

Applying recycled materials in construction should not be seen as an alternative activity carried out by builders, but as something in which all participants in the building industry should engage. Barriers will be reduced if there is a greater emphasis on using recycled materials and a greater dissemination of practical knowledge about their use.

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