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REVIEW ARTICLE

# The production of environmentally friendly building materials out of recycling walnut shell waste: a brief review

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**Abstract**
Agricultural waste is one of the wastes with a significant value in producing environmentally friendly materials that can be used in the construction sector. This review paper focuses on the potential uses of walnut shell in some building materials. Walnut shell is a type of agricultural waste that can be converted from waste into usable materials by incorporating it into the manufacture of some building materials to achieve sustainability in the construction industry. Recently, walnut waste has drawn the attention of researchers to generate building-friendly materials to boost sustainability in the construction field. In this sense, the walnut shell's low specific gravity makes it a viable material, as a cheap agricultural waste product, for the development of building materials. According to a survey of the literature, walnut shells can be utilized in the production of structural elements and thermal insulating concrete, up to 30% and 50% as particles respectively.

**Keywords** Walnut shell waste · Concrete · Mortar · Brick · Composite panels · Sustainability

## 1 Introduction

All waste, including construction, agricultural, and industrial waste, contributes to environmental degradation. Researchers in the construction sector have paid much attention to using these wastes in the construction industry effectively contributing to lowering environmental pollution as well as improving the mechanical and/or physical properties of building materials. It is assessed that roughly 998 million tons of agricultural waste is created yearly around the world [1]. According to statistics from the Food and Agriculture Organization (FAO), 20–30% of fruits and vegetables are wasted during post-harvest handling [2]. Most of the agricultural waste worldwide is dumped or burned, which ignores its potential and severely impacts the environment [3, 4]. The use of fruit and vegetable waste in the construction industry to lessen environmental pollution has recently experienced a rise. Agricultural waste has been used in the construction industry in a variety of ways, including as fibers, aggregate, filler, and pozzolanic materials. Using these wastes as ash or fibers helps to improve the mechanical characteristics as a structural member and using it as a shell enhances the thermal and acoustic properties for non-structural applications. In a recent study, He et al. [5] have concluded that future concrete industries may use agro-wastes as an alternative source of sustainable and eco-efficient pozzolans. On the other hand, Jannat et al. [6] concluded that the partial substitution of nutshell wastes for some building materials (concrete, mortar, brick) can significantly increase cost-effectiveness and offer an effective solution to global waste

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management. The utilization of agricultural waste materials in all its forms in the construction industry leads to achieving economic gains. According to Jalam et al. [7], using rice husk ash and oil palm shell reduces the price of mass concrete and plaster mortar by 41% and 12%, respectively. According to Kareem et al. [8], concrete produced utilizing oil palm shells as aggregate is more cost-effective and environmentally beneficial. Oil palm shell concrete offers the potential for cost savings of up to 42% [8]. The most recent study by D'Eusanio et al. [9] highlights the potential of using peach shells as an efficient and sustainable substitute for conventional lightweight aggregates by pointing out the enhanced properties seen in lightweight concrete specimens prepared with higher roasting temperatures [9].

Raut et al. [10] reviewed that the reusing of agricultural waste products leads to the development of sustainable construction material when it s used in a proper method. Regarding the use of insulation, numerous studies have shown that natural materials function as thermally and acoustically as commercial manufactured alternatives. Agricultural byproducts utilized as thermal insulation in buildings allow for a favorable influence on $CO_2$ emissions [11]. Using agricultural waste to develop sustainable building materials was effective because the materials developed complied with established building codes. This therefore shows that agricultural waste has the potential to replace traditional building materials and achieve long-term economic, ecological, and social sustainability [12]. Solid agricultural byproducts like oil palm shell, coconut shell, periwinkle shell, date seed, and walnut can be utilized as a cost-effective, eco-friendly, and readily available substitute for artificial or manufactured materials in the production of lightweight aggregate (LWA) for concrete. This is particularly advantageous as these materials are abundantly produced in the region [8].

One of the significant agricultural wastes is walnut shell. Almost all walnut processing businesses have trouble selling and disposing of the shell [13]. Walnut shells are a nuisance to the environment because they take so long to degrade. A financial burden could result from the disposal. On the other hand, burning the shells produces a large amount of carbon dioxide, a recognized pollutant that makes global warming problems worse [14]. Additionally, the walnut shell is a product that is both environmentally friendly and safe for people and animals, has a suitable level of strength, does not decay, and essentially does not lose any of its qualities over time [15]. The walnut shell, when compared to other agricultural byproducts, possesses superior technical specifications [13]. Because of the high lignin content, it has much greater strength and decay resistance than materials like straw, husks, and sawdust [13]. On the other hand, walnut shell differs from bamboo, wood, and rice husk in that it is easier to crush and has varied particle sizes, which makes it easier to incorporate into some building materials, like concrete.

Additionally, as walnut shell is a porous material, adding it to some building materials may cause a phenomenon known as random porosity and an increase in the number of open pores, which will improve the material's ability to absorb water and its thermal conductivity coefficient [16]. In view of the aforementioned, walnut shells have recently emerged as a material that deserves consideration by academics working to produce environmentally friendly building materials, especially for thermal and sound insulating purposes.

The primary goal of this research is to examine prior studies' experimental results of some building materials including walnut shell waste (WSW). The impact of WSW as a powder and aggregate for producing sustainable building materials is investigated. Drawing findings regarding specific advantages, quantities of combinations, optimal walnut shell waste, and attempting to quantify the benefits are all part of the review.

## 2 Walnut shell characterizations

One of the most significant dried fruits in the world is the walnut [17]. Walnut fruit is mainly composed of shell, husk, skin, and core (Fig. 1, modified from).

According to the latest statistics on walnut production, it peaked at 2.31 million metric tons in 2021–2022, and it is anticipated to rise to 2.6 million metric tons in 2022–2023 (Fig. 2). China produced around 1.1 million metric tons of walnuts in 2021–2022, making it the world's largest walnut producer. With over 657.7 thousand metric tons, the USA ranked second for walnut output (Fig. 2).

Walnut shell makes up 67% of the overall weight of the natural product and they typically comprise cellulose 25–50%, hemicellulose 20–40%, and lignin 10–35% [19–22]. Table 1 shows the physical properties of walnut shells according to previous studies.

The walnut shell is characterized by a very low content of mineral components. The composition of the mineral part in terms of oxides (wt%) is as follows: CaO, 58.4; $Al_2O_3$, 6.14; $Fe_2O_3$, 5.42; $SiO_2$, 4.11; MnO, 3.11; $K_2O$, 2.4; $Na_2O$, 2.1; $SO_3$, 0.94; MgO, 0.81; ZnO, 0.14; others, 16.43 [27]. The characteristics of the nut shell as a fuel are as follows: $W^a = 7.93$; $A = 1.30$; $Y^{daf} = 77.58$; $C = 51.17$; $H = 6.37$; $N = 0.47$; $S = 0.08$; $O = 41.91$ [28]. Thermal analysis data and FTIR spectra are shown in Fig. 3. The broad peaks at 3350 $cm^{-1}$ and 2960 $cm^{-1}$ corresponded to –OH and –CH (aliphatic) bonds. The peaks at 1566 $cm^{-1}$, 1705 $cm^{-1}$, and 1100 $cm^{-1}$ corresponded to C=C stretching vibrations in the aromatic ring bands, carboxylic acid groups, and phenolic groups.

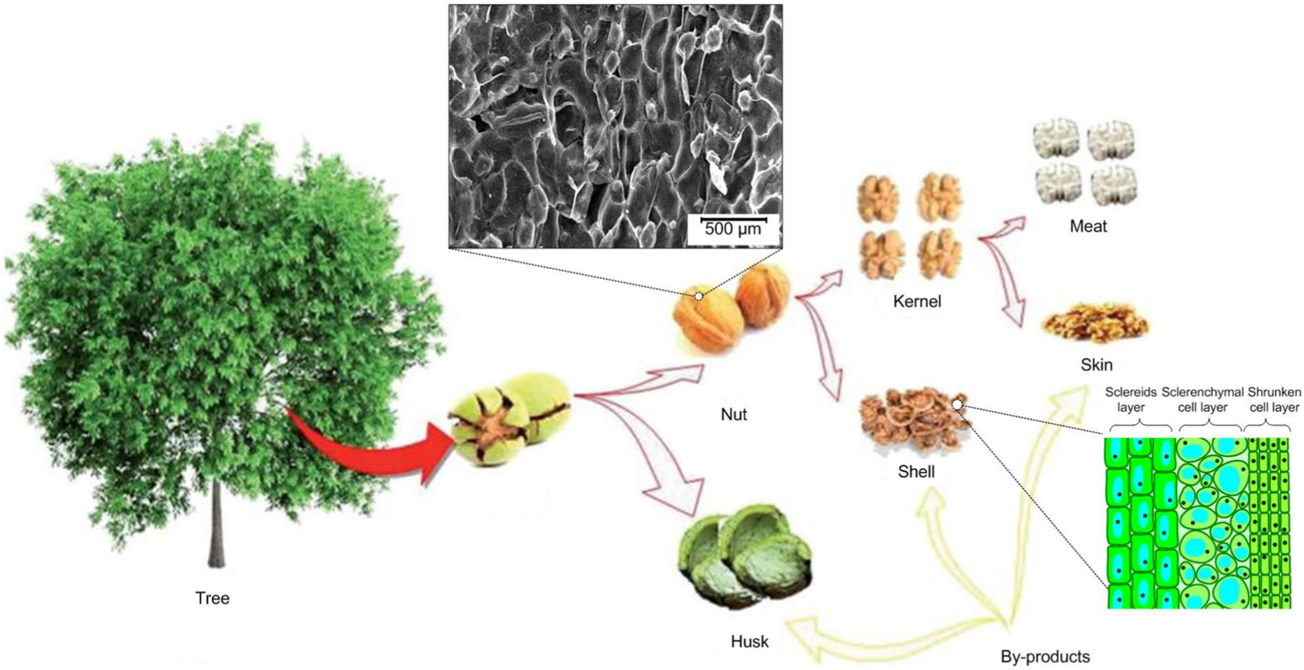



**Fig. 1** Different parts of walnut fruit and the corresponding byproducts (modified from [18]), and representation of the microstructure of a hard walnut shell according to [13]

**Fig. 2** Walnut production: **a** worldwide 2012–2022, and **b** top country production of walnuts (2021/2022) (https://www.statista.com/statistics/675967/walnut-production-worldwide/)

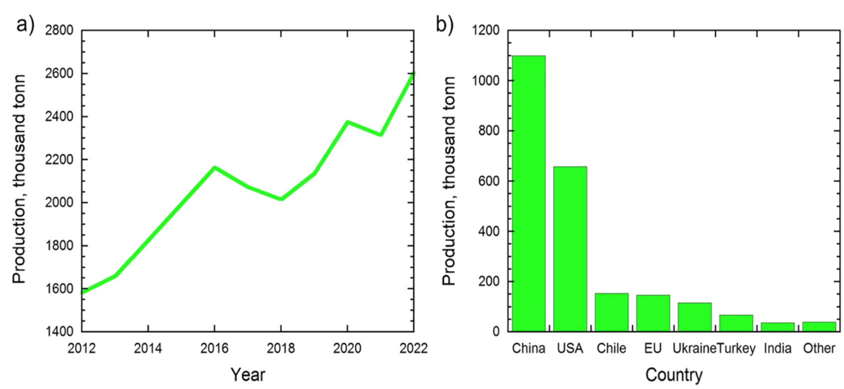
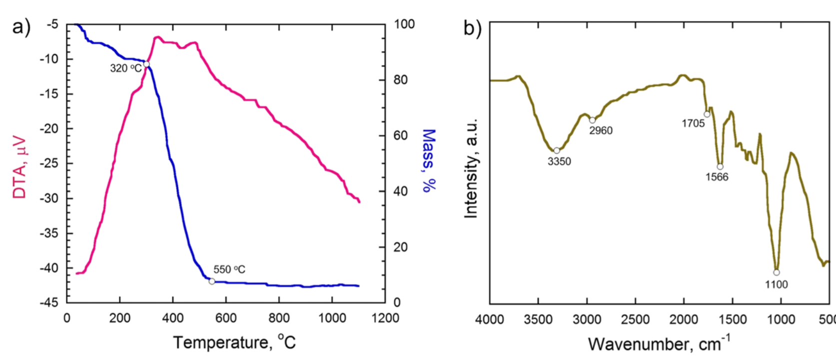



**Table 1** Some physical properties of walnut shell according to previous studies

| Density (kg/m$^3$) | Moisture content % | Conductivity (W/mK) | Color |
|---|---|---|---|
| 785.3–851.2 [23] | 6.34–10.11 [24] | 0.118–0.147 [25] | Sandy brown [26] |

**Fig. 3** TGA and DTA curves **a** [28], and FTIR spectra **b** [13] of walnut shell



The schematic representation of a hard shell's microstructure is shown in Fig. 1. Three layers make up the shell's microstructure, with the inner layer being the most porous and the outer layer being the densest [29]. It is possible to take advantage of the high porosity of the hard walnut shell by combining them with concrete for sound or thermal insulation purposes. Conversely, when walnut shells are treated with chemical treatments, the porosity increases.

Coşkun et al. [30] mention that the walnut shell (WS) when treated with HCl (HWS), $H_2SO_4$(SWS), and $H_3PO_4$(PWS) leads to create more pores in the structure. Figure 4 shows that that walnut shell treated by $H_2SO_4$ (SWS) has a much larger and deeper porous structure. It might imply that all activated WSs can be used to construct materials with high porosity to provide thermal and acoustic insulation.

Huge amounts of walnut shells are produced as agricultural byproducts and are either thrown away or burned to produce fuel [18, 31]. The disposal of walnut shells has become a significant environmental problem because it is difficult to decompose, leading to a problem as it wastes resources and pollutes the environment [14, 32, 33]. Walnut shells are one of the agricultural wastes that can be a suitable substitute for synthetic or manufactured materials for use as lightweight aggregates in concrete production due to their low cost, low density, and eco-friendliness. environment and are available in the region where they are produced in abundant quantities [12]. The high availability and several unique properties of walnut shells such as lower density, lower water absorption, higher strength, and bio-resistance characteristics have made it popular in the building construction industry [34].

Recently, researchers in the construction sector have shown great interest in the possibility of using walnut shells in the construction industry such as concrete, brick, and panels for development sustainability.

## 3 Potential of walnut shell in construction materials

### 3.1 Concrete and mortar mixes

Building design and construction must address not only structural properties but also thermal and acoustic properties [35]. Traditional organic heat insulating materials have about 80% of the market thanks to their excellent thermal insulation capabilities and reasonably inexpensive cost [36]. The lightweight of walnut shells made it a material that researchers in the construction sector are considering producing lightweight concrete for insulation purposes.

The specific gravity of walnut shells is around 1.2 to 1.4 [37], which is almost half that of natural aggregate whose specific gravity is approximately 2.6 to 2.7 [38]. In sectors of application where thermal isolation is desired, the use of large walnut shells produces better results [39].

The use of walnut shells as fine aggregate in concrete mixes has been studied by Kamal et al. [40]. The overall findings supported the replacement of fine aggregate in concrete with up to 30% of walnut shells at a water/cement ratio of 0.38, producing concrete with adequate compressive strength and lower density and water absorption than standard concrete [40].

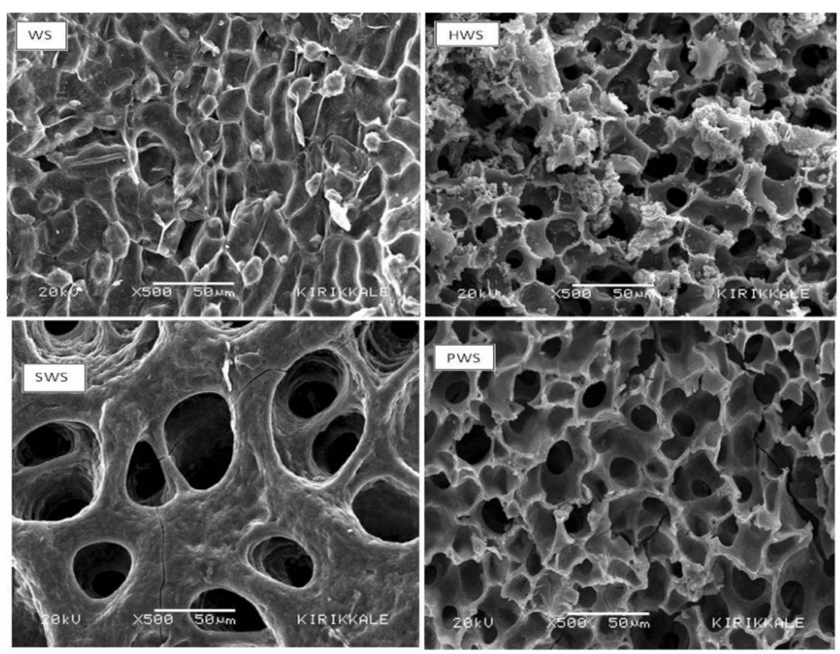



**Fig. 4** SEM image of walnut shell [30]

Abdulwahid and Abdullah [41] studied the possibility of using walnut shells (5%, 10%, 15%) as a partial replacement for sand in mortar mixes. Among the characteristics that were examined were dry density, thermal conductivity, compressive strength, and flexural strength. For treatment, the walnut shells utilized in this study were soaked in boiling water for two intervals of time: half an hour and 1 h. According to the study's findings, soaking the walnut shells in boiling water for half an hour improved the behavior of the mortar compared to the ones that were not. As a result, a mortar that is agreeable in strength, effective as a thermal insulator, and environmentally friendly is produced [41].

The study conducted by Hilal et al. [42] used walnut shells as coarse aggregate to produce lightweight self-compacting concrete. The obtained results obviously show that the optimum volume ratio of WS is 35% for getting lightweight structural SCC with appropriate fresh and hardened properties [42].

Mohammed et al. [43] had used ground walnut shells as a fine aggregate in ratios (10 to 30%) partial replacement of fine aggregate at different water-cement ratios (0.4 and 0.5). Dry density and compressive strength at 28 days of curing age were examined after exposure to an elevated temperature of 400 °C and 600 °C for 2 h. The results showed that the first series with a w/c of 0.5 produced lightweight cement mortar that is appropriate for structural requirements before and after exposure to 400 °C when the optimal GW utilization ratio was 20%. The remaining mixes, however, are appropriate for non-structural uses [43].

Kozub and Castro-Gomes [44] studied how effectively waste ground walnut shells work as an alternative to fine aggregate in the production of geopolymer mortars. The results showed that the partial replacement of sand with ground walnut shells in fly ash–based geopolymer composites allows for a significant reduction in thermal conductivity (over 50% compared to the reference sample), allowing the use of these composites as insulation materials [44].

Cheng et al. [45] studied the possibility of the development of a sustainable lightweight wet-mix shotcrete by replacing natural coarse gravel with a kind of byproduct, walnut shell. This study found wet-mix shotcrete incorporating PET fiber with the walnut shell of about 35% coarse aggregate replacement could be used for roadway support as lightweight shotcrete per the requirements of mine support. Additionally, the study demonstrated that the walnut shell's specific gravity is obviously lower than that of the natural aggregate. A walnut shell can therefore be considered a lightweight aggregate [45].

Hama and Abdulghafor [46] investigated the effects of using a walnut shell as a lightweight aggregate to partially substitute coarse aggregate on various properties and load-deflection behavior of concrete. The findings revealed that the concrete with 50% WA had a notable drop in strength of 62.57% when compared to the reference slab, and that the crack breadth at failure for the concrete with walnut coarse aggregate was bigger for the reference slab [48].

Abed et al. [47] studied the compressive strength of hardened cement-walnut shell ash composite. The results showed that the incorporation of the walnut shell ash resulted in an improvement of the compressive strength, decreasing the density and slightly increasing the water absorption. The optimum strength for the cement-ash composites is obtained at the level of 22 wt% of walnut shell ash as replaced by cement using W/C=0.42 [47].

According to Kamal et al. [48], walnut shell ash can be used as a green binder to partially replace cement. Cement paste setting times can be maintained by replacing some of the cement with walnut shell ash up to 22% by weight of cement. Additionally, the findings indicated that using agricultural waste as partial replacements in cement (such as walnut shell ash) is one way to reduce the risks brought on by incorrect waste management. It also significantly lowers the cost of construction [48].

The feasibility of reusing walnut shell wastes (WS) as fine aggregates in lightweight self-compacting mortar was discussed by Boukhelkhal et al. [49]. According to the test results, a 30% substitution ratio was determined to be the ideal volume ratio of WS for producing lightweight structural SCM with good thermal insulation and suitable fresh and hardened characteristics [49].

Beskopylny et al. [13] examined the impact of using walnut shells (5 to 30%) as a partial replacement for coarse aggregate on the strength and density of concrete in a recent study. The findings demonstrated that a walnut shell dose of 5% led to an increase in concrete's strength characteristics of up to 3.5% as well as the maximum strength-to-density ratio. Additionally, efficient partial replacement of coarse material with walnut shells reduces the need for crushed stone by up to 10% and the volume of concrete by up to 6% [13].

Regarding the microstructure study, Fig. 5 displays microstructures of samples of hardened cement paste with the control composition (a), walnut shell content of 5% (b), and 30% (c), which demonstrated the greatest and worst values of strength characteristics, respectively.

Figure 5c shows that the microstructure of hardened cement-paste samples taken from concrete with a walnut shell content of 30% has many voids and microcracks. The increased water absorption of the walnut shell when compared to the mineral aggregate is the main cause of the creation of microcracks along the area of contact between the cement gel and the organic aggregate. As a result, more coarse aggregate, solidified cement paste, and microcracks at the edges of the contact zone diminish the anchoring of the walnut shell in concrete and its strength properties [13]. The potential of recycling walnut shell wastes (WS) as fine aggregates in a lightweight self-compacting mortar (SCM)

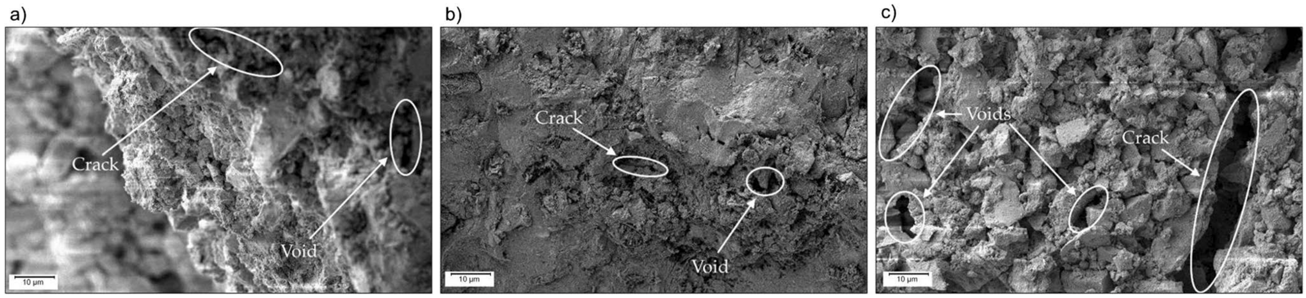



**Fig. 5** SEM image of samples of hardened cement paste **a** 0%, **b** 5%, and **c** 30% (modified from [13])

is investigated by Boukhelkhal et al. [49]. WS waste was substituted for natural sand in the experiment at different replacement ratios (0, 10, 20, 30, and 40%). The findings indicated that a volume ratio of WS of 30% substitution was ideal for obtaining lightweight structural SCM with suitable fresh and hardened characteristics [49].

### 3.2 Brick and block materials

El Hammouti et al. [50] investigated the effect of thermal insulation of mud bricks made with walnut shells (WS). The results showed that the inclusion of 20 wt% WS decreased the thermal conductivity of clay by 45.22%, resulting in an increase in thermal resistance. The numerical results showed that the use of the created composites improved residential structures' energy performance, allowing for corresponding savings of energy for heating and cooling needs (10.8% 7.94%), which motivated the suggestion to utilize WS as a new aggregate for construction [50].

On the other hand, Barnabas et al. [27] found that walnut shell addition (0 to 10 wt%) lowered the thermal conductivity of burnt clay bricks while an increase in specific heat capacity was noted at 950 °C and 1100 °C. Also, it was concluded that the study established the use of walnut shells for the development of sustainable energy-efficient bricks. WSP can be used to manufacture lightweight burned bricks, and its application can help to lower the cost of creating economical building bricks by reducing the cost of agricultural waste [27].

Jannat et al. [34] have discussed the effect of the utilization of two agro-wastes eggshell and walnut shell on some properties of unburnt clay blocks. The experiments were carried out on three series of samples in which first eggshell (10–50%) and walnut shell (5–20%) were incorporated individually and then combined (5% walnut, 10–30% eggshell) in the mixture to assess their influences on the physical and mechanical properties of the unburnt clay blocks. This study performed the following tests: density, capillary water absorption, linear shrinkage, flexural and compressive strength. The results indicated that the eggshell enhanced the strength relative to the control sample when the materials were employed individually, but the walnut shell lowered it [34].

### 3.3 Polymer and panel composites

The building, construction, and civil engineering industries use polymers and composites extensively in a variety of structures for a variety of purposes. One of the most significant types of polymeric materials for use in building and construction applications is polyurethane (PUR) [51, 52]. Due to their rich organic nature (lignin content of 50%, cellulose content of 24%, hemicellulose content of 24%) and low ash content (3.4%), walnut shells can be used for the manufacturing of high-value bio-polyols for the creation of a new class of PUR foams [53, 54].

The lignin content of walnut shell, which is around 44.54%, is mentioned by PATHAK as having potential benefits for improving thermoplastic compatibility. It also has a specific flame-retardant property that is crucial for composite used as building materials [55]. Walnut shells are inexpensive, with 1 kg of walnut shells obtained in Poland (Central Europe) costing around $0.12 in 2017. Therefore, the use of this type of filler can be justified in low-cost polymer composites [56].

In an experimental study, Salasinska et al. [56] demonstrated that the incorporation of large amounts of finely ground walnut shell (up to 50%) into thermoset polymer allows the preparation of inexpensive composites with acceptable mechanical and thermo-mechanical properties, particularly in the case of non-structural applications. In contrast, microstructure analysis indicated that the composites' increased stiffness and hardness were attributable to the reinforcing effect produced by the presence of pulverized walnut shells [56].

According to Członka et al. [57], the polyurethane (PU) composite foams that are reinforced with 1, 2, and 5 wt% of walnut shells (WS) and silanized walnut shells (SWS) have improved successfully. The best outcomes came from modifying PU foams with 1 weight percent of S WS. As an illustration, the addition of 1 wt% of S WS might improve the compressive strength of PU foams by 15%, the flexural strength by 9%, the impact strength by 6%, and the thermal insulation qualities by 0.023 W $m^{-1}K^{-1}$. It can be concluded from these advantageous effects that the use of WS and SWS as natural fillers in PU composite foams can encourage a new application path in turning agricultural waste into valuable resources for developing a new category of green materials [57].

The potential of walnut shell particles as a reinforcing agent in the thermoset matrix composite is investigated by Mittal et al. [58]. The experimental findings demonstrated that increasing the filler content of composite materials up to 35 wt% boosted their mechanical strength and modulus. A balanced mix of strength, stiffness, and toughness was demonstrated by the epoxy-based composite reinforced with 35% fine walnut particles, demonstrating its suitability as a structural material [58].

Pradhan and Satapathy [59] have studied the characterization of walnut shell powder (WSP)–filled polyester composite. It was observed that the inclusion of walnut shell powder does not improve mechanical properties but enhances the thermal properties of composites with 20 wt% of filler content. With the addition of 20 wt% of WSP, the thermal conductivity of polyester is found to have dropped by about 42% [59].

Das Lala et al. [60] examined the possibility of using walnut shell powders as a natural filler as reinforcements in the epoxy matrix. They studied the comparison between finely powdered waste rubber seed shell (RSS) and walnut shell (WNS) as reinforcements in the epoxy matrix Lapox B11 to develop composite material using the stir casting process. Both the composites with superior properties are further compared with the properties of some prominent timbers listed in standard IS 883 1994 structural timber codes based on their availability in the northeastern (NE) region of India. Both composites' characteristics are discovered to be notably superior to those of the specified timber examples. When compared to a Sundari wood specimen, RSS and WNS composite exhibit increase in tensile strength of 123% and 72%, respectively. Additionally, the compressive strength of the RSS and WNS composites is increased by 792% and 722% when compared to the Sundari wood specimen. The study investigates the possibility of a composite made of rubber seed and walnut shells as a potential replacement for traditional timber products [60]. In addition to partially alleviating the wood shortage in some walnut-rich nations like Iran, Zahedi et al. [61] note that using walnut shells in composite production may also have positive social and environmental effects.

Composite panels with a polyurethane (PU) foam core and a covering material such as gypsum, engineered wood, or some composites are used as structural elements in building construction [62]. Sound-absorbing panels with soundproofing properties can be made from walnut shell waste, which can be used in industry, transportation, construction, etc. as well as for decorative purposes in spaces such as cinemas, malls, and spas [63].

da Silva et al. [64] reported the potential of MDF modified with walnut shells to improve IAQ. MDF panels with 5, 10, and 15 wt% walnut shells incorporated were compared to a control sample with no shell. The results show that the incorporation of walnut within the MDF panels showed excellent promise for the future of MDF as a building material. This is particularly important as MDF has been identified as a problematic material due to its high formaldehyde emissions [64].

On the other hand, Akgül and Çamlibel [65] noted that walnut shell is a material that is already tough. It is superior to wood fiber when applied to the surface of MDF and increases SHA (screw-holding ability). This could be utilized to enhance the panelboards' surface qualities for usage in various applications [65].

## 4 Conclusions and future perspectives

This article explores the use of walnut shell waste in the production of building materials. It is shown that relatively few articles publish the results of using walnut shell waste in the production of ceramic bricks, where its use is seen as the most promising due to the possibility of using them as a burnable additive. The main criteria of the studied materials are density, strength, and water absorption. Frost resistance and destruction under the influence of acids and alkalis are practically not studied. There is also practically no economic assessment of the use of walnut shell waste in the production of building materials. In general, the use of walnut shell waste for producing environmentally friendly building materials has a number of potential perspectives, including:

Sustainability: the use of walnut shell waste as a raw material for building materials can help reduce the amount of waste. This can help promote sustainability and reduce the environmental impact of construction.

Cost-effectiveness: walnut shell waste is a low-cost and abundant raw material, making it an attractive option for producing building materials. This can help reduce the cost of construction and make environmentally friendly building materials more accessible.

Improved insulation: walnut shell waste has been shown to have good thermal insulation properties, making it a suitable material for use in building insulation. Walnut shells as particles can replace aggregate in the production of lightweight concrete up to 30% significantly reducing their thermal conductivity. On the other hand, using walnut shell powder up to 20% as fillers can be used for the production of thermal insulation composite polymer materials.

Structural elements: walnut shell waste can be used for the production of structural elements in civil engineering application with acceptable strength characteristics. According to previous studies, walnut shells up to 30% could be used in casting structural concrete.

Durability: walnut shell waste can be processed into a hard, durable material that is resistant to impact and wear. This makes it suitable for use in building materials that require high strength and durability.

Esthetics: walnut shell waste has a unique appearance that can add visual interest to building materials. This can help architects and builders create unique designs and stand out in a competitive market.

Overall, the use of walnut shell waste for producing environmentally friendly building materials has a number of potential perspectives that make it an attractive option for sustainable construction. However, further research and development is needed to fully realize the potential of this material.

**Author contribution** Mohanad Yaseen Abdulwahid: conceptualization; formal analysis; investigation; methodology; resources; supervision; data curation; validation; writing—original draft; writing—review and editing. Abayomi Adewale Akinwande: formal analysis, investigation, data curation. Maksim Kamarou: formal analysis, data curation. Valentin Romanovski and Imad A. Al-Qasem: formal analysis; investigation; data curation; validation; visualization; writing—original draft; writing—review and editing.

**Data availability** All data employed in support to the outcomes of the study are included in this article.

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Competing interests** The authors declare no competing interests.

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