Eggshell and Walnut Shell in Unburnt Clay Blocks

Nusrat Jannat 1,*, Rafal Latif Al-Mufti 1 and Aseel Hussien 2

1 School of Civil Engineering & Built Environment, Liverpool John Moores University, Liverpool L3 3AF, UK; r.latifalmufti@ljmu.ac.uk
2 Department of Architectural Engineering, University of Sharjah, Sharjah 341246, United Arab Emirates; ahussien@sharjah.ac.ae
* Correspondence: n.jannat@2019.ljmu.ac.uk

Abstract: Agricultural residues/by-products have become a popular choice for the manufacturing of building materials due to their cost-effectiveness and environmental friendliness, making them a viable option for achieving sustainability in the construction sector. This study addresses the utilisation of two agro-wastes, i.e., eggshell and walnut shell, in the manufacture 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 eggshell enhanced the strength relative to the control sample when the materials were employed individually, but walnut shell lowered it. Moreover, combining the two materials in the mixer reduced the strength of the samples even further. Nevertheless, the inclusion of the waste materials decreased the density, capillary water absorption coefficient and linear shrinkage of the samples. The findings indicate that eggshell has great potential for unburnt clay block manufacture. However, walnut shell integration needs further research.

Keywords: clay blocks; eggshell; mechanical properties; physical properties; unburnt; walnut shell

1. Introduction

It is well acknowledged that the application of building materials has a substantial influence on the environment because of embodied energy and the challenges of disposal of particular materials. Hence, new approaches for the manufacture of building materials are essential. One approach for lowering the negative environmental effect of building materials and reducing the consumption of material resources is to utilise the waste materials to manufacture building materials. Agricultural industries produce a large amount of wastes and by-products that can be an important source of raw materials for different industrial sectors, including building material construction. Walnut shell is an agricultural residue/by-product that is either burnt or disposed of in landfills. According to the report, worldwide walnut production reached around 965,400 tonnes in 2019 [1] and given that the shell accounts for almost 67% of the total fruit weight, this equates to 646,818 tonnes of walnut shells per year [2,3]. Figure 1 shows the leading walnut-producing countries [4]. The hydrophobic elements (lignin, 50.3%) in walnut shells are more abundant than hygroscopic materials (cellulose (23.9%) and hemicellulose (22.4%)) [5,6]. The lower water absorption, higher strength and bio-resistance characteristics of walnut shell have made it popular in the building construction industry. Studies have been conducted using walnut shell in the production of bio-composite [7–13], particleboard [14,15], MDF panels [16,17] and as an aggregate substitute in concrete [18–22]. However, the use of walnut shells in the production of unburnt clay brick is rarely mentioned in the literature. Mirón et al. [23] used different percentages of walnut shell (5–20%) to develop compressed earth blocks in two series of experiments. One series
Another potential waste material that is available in abundance is poultry eggshell from sources such as hatcheries, food industries and domestic homes. Around 110 billion eggshells are produced globally [4] (Figure 2), with most of them ending up in landfills [26]. Such waste has a negative impact on the environment because it raises waste management costs and produces a bad smell on the site. The Environmental Protection Agency has listed eggshell waste as the 15th top food sector pollution concern [27]. The poultry eggshells are grainy in texture and constitute about 9–12% of the overall egg weight [26,28]. Eggshells are generally thought to have no economic worth, despite being high in amino acids and minerals. Calcium oxide is reported as the main component of the eggshell (94% to 98%) [29–31]. Eggshell powder can be used as a partial replacement for industrial lime due to its chemical composition, which is similar to lime [32,33]. Furthermore, the calcium content of eggshells is more absorbable than calcium from coral or limestone [34]. As a result, poultry eggshell has become a popular natural reinforcing material in the

Figure 1. Global walnut-producing countries [4].
construction industry because of these characteristics. Researchers have studied applying eggshell powder in sustainable building material production, such as masonry blocks, clay bricks, soil stabiliser, cement replacement in concrete and mortar [35]. Adogla et al. [36] used eggshell powder (0–40 wt%) in compressed earth brick production and observed that samples containing 30% eggshell powder showed better properties. In another study, Ayodele et al. [37] incorporated eggshell ash and sawdust ash (0–16 wt%) in the lateralised unburnt bricks where samples with 2–4% ash had the maximum compressive strength.

The above studies show the potentiality of employing walnut shell and eggshell in the manufacture of building materials. However, utilisation of these materials in unburnt clay brick is rarely investigated. Furthermore, no research is available on the combined effect of including walnut shell and eggshell in unburnt clay brick production. Hence, this study investigates the physical and mechanical characteristics of unburnt clay blocks using these two agro-wastes in different combinations. The effect of both individual and combined addition of walnut shell and eggshell are examined in this study.

2. Materials and Experimental Programme

2.1. Raw Materials

This investigation used Red Clay Powder (RCP) which was supplied by the Bath Potters’ Supplier, UK. Besides, two agro-wastes were considered as stabilisers: (i) Eggshell Powder (EP); particle size: 150–212 μm and (ii) Walnut Shell Grit (WSG), particle size: 1.18–2.00 mm (Figure 3). The local retailers in the UK provided the EP and WSG utilised in this investigation. All the raw materials used to make the samples were untreated. The surface morphology of the raw materials was performed using Scanning Electron Microscopy (SEM) (Figure 4). Besides, mineralogy composition was estimated by X-ray diffraction (XRD) analysis (Figure 5). Furthermore, X-ray fluorescence (XRF) spectrometry was done in order to determine the most predominant or influential oxides in the raw materials (Table 1). Next, some physical characterisations of the raw materials were conducted, which are presented in Table 2. The SEM image shows that EP has angular and irregularly shaped stone-like particles forming agglomeration (Figure 4a). On the other hand, due to the high lignin concentration, WSG has a very rigid and thick structure in the cell wall (Figure 4b) [38]. The XRD pattern reveals quartz as the primary mineralogical component.
in RCP (Figure 5c). Furthermore, haematite (Fe₂O₃) and kaolinite (Al₂Si₂O₅(OH)₄) were found in the RCP. All diffraction peaks of EP indicate the existence of calcite (CaCO₃) as the major component (Figure 5b), whereas WSG exhibits a considerable degree of amorphosity in the XRD pattern (Figure 5a).

Figure 3. Photographs of raw materials: (a) EP; (b) WSG; (c) RCP.

Figure 4. SEM images of raw materials: (a) EP; (b) WSG; (c) RCP.

Table 1. Raw materials’ physical properties.

| Materials | Plasticity Index (%) | Maximum Dry Density (kg/m³) | Optimum Moisture Content (%) | Density (kg/m³) | Specific Gravity | Porosity | Natural Moisture Content (%) | Water Absorption after 24 h under Water (%) | Colour  |
|-----------|----------------------|-----------------------------|-----------------------------|-----------------|-----------------|---------|-----------------------------|--------------------------------------------|--------|
| RCP       | 12.36 (Medium plastic) | 2320                        | 15.50                       | 1430            | 2.32            | 0.38    | 6.47                        | 27.57                                      | Red    |
| EP        | -                    | -                           | -                           | -               | -               | 0.31    | 39.42                       | 27.57                                      | White  |
| WSG       | -                    | -                           | -                           | 630             | 1.28            | 0.92    | 6.75                        | 29.90                                      | Sandy brown |
Na₂O 1.027 1.423 0.930
TiO₂ 1.411 0.096 0.098
SO₃ 0.047 0.345 0.057
BaO 0.216 0.189 0.075
ZrO₂ 0.035 0.008 0.002
MnO 0.040 - 0.002
SrO 0.011 0.042 0.001
P₂O₅ - - 0.073

Figure 5. XRD spectrograms of raw materials: (a) EP; (b) WSG; (c) RCP.
### Table 2. Raw materials’ chemical components.

| Chemical Compounds (%) | RCP | EP   | WSG  |
|------------------------|-----|------|------|
| SiO₂                   | 41.454 | 0.097 | 1.103 |
| Al₂O₃                  | 15.214 | -    | 0.536 |
| K₂O                    | 1.636  | 0.155 | 1.871 |
| MgO                    | 5.114  | 0.522 | 0.512 |
| Fe₂O₃                  | 8.104  | -    | 0.062 |
| CaO                    | 0.633  | 78.111 | 1.722 |
| Na₂O                   | 1.027  | 1.423 | 0.930 |
| TiO₂                   | 1.411  | 0.096 | 0.098 |
| SO₃                    | 0.047  | 0.345 | 0.057 |
| BaO                    | 0.216  | 0.189 | 0.075 |
| ZrO₂                   | 0.035  | 0.008 | 0.002 |
| MnO                    | 0.040  | -    | 0.002 |
| SrO                    | 0.011  | 0.042 | 0.001 |
| P₂O₅                   | -      | -    | 0.073 |

### 2.2. Sample Preparation

The mix proportions of the samples are given in Table 3. Three series of samples were prepared for the test. The first series of samples (E-10 to E-50) consisted of 10–50% EP, whereas the second series (W-5 to W-20) had 5–20% WSG. Besides, to assess the combined effect of eggshell and walnut shell the third series of samples (WE-5/10 to WE-5/30) were made using 10–30% EP with 5% WSG. Clay blocks with no additives were made for the control samples (C) in this study. The wastes materials were mixed in relation to the dry weight of the clay. The dry raw materials in the specified proportions were first poured into a mechanical mixer and thoroughly combined. After that, water was gradually added to the blend and mixed until it became uniform. Finally, the mixture was put into the prismatic mould of 16 × 4 × 4 cm and hand compacted. The samples were then cured at a laboratory room condition (23–26 °C temperature and 30–34% relative humidity) for 28 days. Three samples were examined to determine the impact of waste content on physical and mechanical characteristics.

### Table 3. Mix proportions.

| Sample ID | RCP (g) | Waste (%) | Waste (g) |
|-----------|---------|-----------|-----------|
|           |         | EP | WSG | EP | WSG |
| C         | 550     | 0  | 0   | 0  | 0   |
| E-10      | 550     | 0  | 0   | 55 | 0   |
| E-20      | 550     | 0  | 0   | 110| 0   |
| E-30      | 550     | 0  | 0   | 165| 0   |
| E-40      | 550     | 0  | 0   | 220| 0   |
| E-50      | 550     | 0  | 0   | 275| 0   |
| W-5       | 550     | 0  | 5   | 0  | 27.50|
| W-10      | 550     | 0  | 10  | 0  | 55  |
| W-15      | 550     | 0  | 15  | 0  | 82.50|
| W-20      | 550     | 0  | 20  | 0  | 110 |
| WE-5/10   | 550     | 0  | 5   | 55 | 27.50|
| WE-5/20   | 550     | 0  | 5   | 110| 27.50|
| WE-5/30   | 550     | 0  | 5   | 165| 27.50|
2.3. Sample Testing

The samples were examined for density, capillary water absorption, linear shrinkage, flexural strength and compressive strength at the end of the 28-day curing period. Additionally, the finely crushed powder of the samples was subjected to XRD tests to determine their crystal structure. The density of the samples was calculated according to the standard BS EN 771-1 [39]. The sample blocks were weighed, and their dimensions were measured using digital callipers in all three directions. The density was then determined by dividing the weight (kg) by the volume (m$^3$).

The test for determining the capillarity water absorption coefficient ($C_w$ (kg/(m$^2$ x min$^{0.5}$))) was carried out on half prismatic samples from the flexural strength test following BS EN 1015-18 (2002) [40]. According to the standard, the half prism samples were oven-dried (60 ± 5 °C, 24 h), and their weights ($M_t$ (kg)) were recorded. They were then immersed in water to a depth of 5 mm in a container. The samples were removed from the water after 10 min and weighed again ($M_f$ (kg)) (Figure 6a). Equation (1) from the standard was used to get the capillary water absorption coefficient,

$$C_w = 0.1 \times (M_t - M_f) \quad (1)$$

**Figure 6.** Test photographs: (a) Capillary water absorption; (b) flexural strength; (c) compressive strength.

In order to assess the linear shrinkage of the samples, the lengths of the samples were measured using a digital calliper before and after drying. Linear shrinkage is expressed as a percentage of the change in length compared to the original length.

The BS EN 1015-11 standard [41] specifies the flexural and compression strength test procedures. After 28 days of curing period, full prism samples (16 × 4 × 4 cm) were used for the flexural strength test. The test equipment was a Tinius Olsen H25KS, which consisted of two rollers separated by 10 cm on which the sample rested. A load was then progressively employed at a rate of 10 N/s to the top roller that was placed on top of the sample at the middle point (Figure 6b). The maximum load was recorded to calculate the flexural strength using Equation (2),

$$f = \frac{1.5FL}{bd^2} \quad (2)$$

where $f$ (MPa) is the flexural strength, $F$ (N) is the maximum load, $L$ (mm) is the space between the rollers, $b$ (mm) is the sample’s height and $d$ (mm) sample’s width.

The compressive strength test was performed on the half prism samples obtained from the flexural strength test. According to the standard, the samples were positioned centrally between two steel bearing plates of 4 × 4 cm and 0.40 MPa/s charge velocity was applied until the block fractured at which point the maximum load was recorded (Figure 6c). The compressive strength ($C$, MPa) is defined by the ratio of the axial force $F$ (N) and the cross-section area $A$ (mm$^2$).

$$C = \frac{F}{A} \quad (3)$$
3. Results and Discussions

Figure 7 presents the XRD analysis of the composites. The addition of WSG did not result in the creation of new mineral phases, as shown in Figure 7a. However, there was a pozzolanic reaction generated by calcium ions of EP with clay minerals (Figure 7b), which strengthened bonding in the clay matrix but decreased open porosity. It can be noticed that the density of samples lowered with the addition of EP and WSG (Figure 8). However, the density values of all EP incorporated samples and 5–10% WSG samples were higher than 1750 kg/m$^3$ satisfying the standard requirement [42,43] for load-bearing material. Moreover, the WE-5/10 and WE-5/20 samples met the standard with densities of 1811 and 1755 kg/m$^3$, respectively. Density decreased around 21% for 20% WSG content and 14% for 50% EP content compared to the control sample. When WSG and EP were combined in the mixture, the decrease was about 20%. The lower specific gravity of EP and WSG than the clay particle (see Table 1) resulted in a reduction in sample density. Figure 9 shows that capillary water absorption in EP samples decreased until it reached 40% content, after which it marginally increased. This can be explained by the reduction in open porosity in the samples due to the pozzolanic reaction in the mixture. On the other hand, the non-absorbent nature of WSG particles caused a reduction in capillary water absorption of the samples. Moreover, capillary water absorption further decreased in combined mix samples. Concerning the linear shrinkage, a decreasing trend was observed with the addition of both types of wastes separately and together (Figure 10). The decreases were up to 44% for 20% WSG, 30% for 50% EP and 37% for the combined mixture relative to the control sample.

Figures 11 and 12 present the mechanical strength test results. Both oven-dried and air-dried samples were tested for compressive strength. The results reveal that all the samples satisfied the standard requirements of compressive strength (1–2.80 MPa) [43–46] and flexural strength (0.25–0.50 MPa) [42,44,45]. Figure 11 shows that the mechanical strength of the EP samples improved progressively by increasing EP content from 10 to 40%, then decreased for 50% EP. The improvement in strength is attributed to the pozzolanic reaction of the minerals in RCP with calcium in EP in the mixture. When calcium oxide (CaO) in EP came into contact with water, it produced portlandite (Ca(OH)$_2$). Then, portlandite reacted with silica (SiO$_2$) in the RCP to form the cementitious compound calcium silicate hydrate (CaSiO$_3$·2H$_2$O), which enhanced the strength. On the other hand, the mechanical strength of the WSG samples declined by increasing WSG from 5 to 20%, which can be explained by the poor bond between the clay particles and WSG. Moreover, strength showed a decreasing trend when WSG was combined with EP. In this case, when clay was replaced by WSG, available silica content for reaction with portlandite reduced, and unreacted portlandite caused a negative impact on strength [47]. Oven-dried samples exhibited better strength than air-dried samples for all the mixtures. The percentages of increase/decrease in strength of different samples relative to the control sample are presented in Figure 12.
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Figure 7. XRD spectrograms of composites: (a) WSG samples; (b) EP samples; (c) WE samples.
Figure 8. Density results.

Figure 9. Capillary water absorption results.

Figure 10. Linear shrinkage results.
reacted with silica (SiO₂) in the RCP to form the cementitious compound calcium silicate (CaSiO₃⋅2H₂O), which enhanced the strength. On the other hand, the mechanical properties were affected by the presence of clay, as it replaced portlandite by WSG, available silica content for reaction with portlandite reduced, and unreacted portlandite caused a negative impact on strength [47]. Oven-dried samples exhibited lower strength than air-dried samples for all the mixtures. The percentages of increase/decrease in strength of different samples relative to the control sample are presented in Figure 12.

Figure 11. Test results of flexural strength (FS) and compressive strength (CS).

Figure 12. Comparison of flexural strength (FS) and compressive strength (CS) between the control and waste-incorporated samples.

4. Conclusions

The efficacy of incorporating eggshell and walnut shell as natural stabilisers in unburnt clay mixtures was investigated in this study. The test findings lead to the following conclusions:

- The addition of both types of agro-wastes reduced the density of the samples because of their lower specific gravity compared to the clay particles used.
- The linear shrinkage values decreased for increasing both types of wastes separately and combinedly.
- In terms of capillary water absorption, the EP sample showed a decreasing trend for increasing content from 10 to 40%. Furthermore, for WSG samples, capillary water absorption decreased for 50% EP. The improvement in strength is attributed to the pozzolanic reaction of the EP samples improved progressively by increasing EP content from 10 to 40%

The addition of WSG, which is a natural material, increased the strength of the samples. The strength of the WSG samples declined by increasing WSG from 5 to 20%, which can be explained by the poor bond between the clay particles and WSG. Moreover, the strength of the WSG samples declined by increasing WSG from 5 to 20%, which can be explained by the poor bond between the clay particles and WSG.

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absorption value slightly decreased as the percentage increased. Moreover, for the combination of EP and WSG, capillary water absorption decreased gradually.

- The mechanical strength of the EP samples increased with incorporating EP from 10 to 40%, and then the values decreased for 50% EP content. The samples with 40% EP showed peak compressive (5.68 MPa) and flexural strength (2.30 MPa). On the other hand, the addition of WSG has an adverse effect on the strength of the samples. The optimal compressive (3.83 MPa) and flexural (1.45 MPa) strength values for WSG samples were found at 5% content, which was lower than the control sample’s strength values. Besides, the strength decreased further when WSG was combined with EP. For all the samples, oven-cured samples had higher compressive strength than the laboratory environment cured samples.

It is noticed that eggshell has great potential to be used for manufacturing unburnt clay blocks. The test findings of walnut shell samples, on the other hand, revealed that while it enhanced several physical properties of the samples, it had a detrimental impact on their strength. Hence, the utilisation of walnut shell in unburnt clay materials production needs further investigation with other clay types and additives. Moreover, future research in this area can investigate the effects of different particle sizes of agro-wastes materials on the properties of unburnt clay blocks.

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**References**

1. The International Nut and Dried Fruit Council Foundation (INC). *Nuts & Dried Fruits Statistical Yearbook*; INC: Reus, Spain, 2020.
2. Martinez, M.L.; Moiraghi, L.; Agnese, M.; Guzman, C. Making and some properties of activated carbon produced from agricultural industrial residues from Argentina. *J. Argent. Chem. Soc.* 2003, 91, 103–108.
3. Jahanban-Esfahlan, A.; Amarowicz, R. Walnut (*Juglans regia* L.) shell pyrolygicous acid: Chemical constituents and functional applications. *RSC Adv.* 2018, 8, 22376–22391. [CrossRef]
4. Food and Agriculture Organisation (FAO), FAOSTAT Data. Available online: https://www.fao.org/faostat/en/#rankings/countries_by_commodity (accessed on 12 December 2021).
5. Sarsari, N.A.; Pourmousa, S.; Tajdini, A. Physical and mechanical properties of walnut shell flour-filled thermoplastic starch composites. *BioResources* 2016, 11, 6968–6983.
6. Xiao, N.; Bock, P.; Antreich, S.J.; Staedler, Y.M.; Schönenberger, J.; Gierlinger, N. From the soft to the hard: Changes in microchemistry during cell wall maturation of walnut shells. *Front. Plant Sci.* 2020, 11, 466. [CrossRef] [PubMed]
7. Ayrlims, N.; Kaymakci, A.; Ozdemir, F. Physical, mechanical, and thermal properties of polypropylene composites filled with walnut shell flour. *J. Ind. Eng. Chem.* 2013, 19, 908–914. [CrossRef]
8. Nitin, S.; Singh, V.K. Mechanical behavior of walnut reinforced composite. *J. Mater. Environ. Sci.* 2013, 4, 233–238.
9. Zahedi, M.; Pirayesh, H.; Khanjanzadeh, H.; Tabar, M.M. Organo-modified montmorillonite reinforced walnut shell/polypropylene composites. *Mater. Des.* 2013, 51, 803–809. [CrossRef]
10. Gope, P.C.; Singh, V.K.; Rao, D.K. Mode I fracture toughness of bio-fiber and bio-shell particle reinforced epoxy bio-composites. *J. Reinf. Plast. Compos.* 2015, 34, 1075–1089. [CrossRef]
11. Salasinska, K.; Barczewski, M.; Górska, R.; Kłodziński, A. Evaluation of highly filled epoxy composites modified with walnut shell waste filler. *Polym. Bull.* 2018, 75, 2511–2528. [CrossRef]
12. Orue, A.; Eceiza, A.; Arbelaitz, A. The use of alkali treated walnut shells as filler in plasticized poly (lactic acid) matrix composites. *Ind. Crops Prod.* 2020, 145, 111993. [CrossRef]
13. Hekimoğlu, G.; Sarı, A.; Kar, T.; Keleş, S.; Kaygusu, K.; Tyagi, V.; Sharma, R.; Al-Ahmed, A.; Al-Sulaiman, F.A.; Saleh, T.A. Walnut shell derived bio-carbon/methyl palmitate as novel composite phase change material with enhanced thermal energy storage properties. *J. Energy Storage* 2021, 35, 102288. [CrossRef]
14. Güru, M.; Atar, M.; Yıldırım, R. Production of polymer matrix composite particleboard from walnut shell and improvement of its requirements. Mater. Des. 2008, 29, 284–287. [CrossRef]

15. Pirayesh, H.; Khanjanzaadeh, H.; Salari, A. Effect of using walnut/almond shells on the physical, mechanical properties and formaldehyde emission of particleboard. Compos. Part B Eng. 2013, 45, 858–863. [CrossRef]

16. Khanjanzaadeh, H.; Pirayesh, H.; Sepahvand, S. Influence of walnut shell as filler on mechanical and physical properties of MDF improved by nano-SiO_{2}. J. Indian Acad. Wood Sci. 2014, 11, 15–20. [CrossRef]

17. Da Silva, C.; Stefanowski, B.; Maskell, D.; Ormondroyd, G.; Ansell, M.; Dengel, A.; Ball, R. Improvement of indoor air quality by MDF panels containing walnut shells. Build. Environ. 2017, 123, 427–436. [CrossRef]

18. Cheng, W.; Liu, G.; Chen, L. Pet Fiber Reinforced Wet-Mix Shotcrete with Walnut Shell as Replaced Aggregate. Appl. Sci. 2017, 7, 345. [CrossRef]

19. Hussain, M.S.; Ahmad, A.; Huda, S.; Asim, M. Cost optimization of concrete by replacing fine aggregate with walnut shell powder. Int. J. Civ. Eng. Technol. 2017, 8, 82–89.

20. Kamal, I.; Sherwani, A.F.; Ali, A.; Khalid, A.; Saadi, I.; Harbi, A. Walnut shell for partial replacement of fine aggregate in concrete: Modeling and optimization. J. Civ. Eng. Res. 2017, 7, 109–119.

21. Helal, N.; Ali, T.K.M.; Tayeh, B.A. Properties of environmental concrete that contains crushed walnut shell as partial replacement for aggregates. Arab. J. Geosci. 2020, 13, 812. [CrossRef]

22. Venkatesan, B.; Lijina, V.J.; Kannan, V.; Dhevasesan, P.R. Partial replacement of fine aggregate by steel slag and coarse aggregate by walnut shell in concrete. Mater. Today Proc. 2021, 37, 1761–1766. [CrossRef]

23. Mirón, S.; Wendonly, B.; Gutiérrez, R.; Salvador, R.; Orozco, M.; Eugenia, M. Alternative material for load-bearing wall with addition of walnut shell. Waste Reduction. In Proceedings of the 3rd International Congress on Sustainable Construction and Eco-Efficient Solutions, Seville, Spain, 27–29 March 2017; Universidad de Sevilla: Seville, Spain; pp. 1012–1022.

24. NMX-C-404-ONNCCE; Industria de la Construcción-Mampostería-Bloques, Tabiques o Ladrillos y Tabiconas Para Uso Estructural-Especificaciones y Métodos de Ensayo (Building Industry—Masonry—Blocks or Bricks for Structural Use—Specifications and Essay Method). Diario Oficial de la Federación: Mexico City, Mexico, 2005. (In Spanish)

25. Marte Rosario, M. Utilización de la Cáscara de Nuez Chandeler en el Yeso. Master’s Thesis, Universidad Politécnica de Madrid, Madrid, Spain, 2011.

26. Waheed, M.; Butt, M.S.; Shehzad, A.; Adzahan, N.M.; Shabbir, M.A.; Suleria, H.A.R.; Aadil, R.M. Eggshell calcium: A cheap alternative to expensive supplements. Trends Food Sci. Technol. 2019, 91, 219–230. [CrossRef]

27. Waheed, M.; Yousaf, M.; Shehzad, A.; Imam-Ur-Raheem, M.; Khan, M.K.I.; Khan, M.R.; Ahmad, N.; Aadil, R.M. Channelling eggshell waste to valuable and utilisable products: A comprehensive review. Trends Food Sci. Technol. 2020, 106, 78–90. [CrossRef]

28. Chambers, J.R.; Zaheer, K.; Abdel-Aal, E.-S.M. Chicken eggs. In Egg Innovations and Strategies for Improvements; Hester, P.Y., Ed.; Academic Press: Cambridge, MA, USA, 2017; pp. 1–9.

29. Ajala, E.O.; Eletta, O.A.A.; Ajala, M.A.; Oyeniyi, S.K. Characterization and evaluation of chicken eggshell for use as a bio-resource. Arid Zone J. Eng. Technol. Environ. 2014, 14, 26–40.

30. Shwetha, A.; Dhanaanjaya, K.S.; Ananda, S.M. Comparative study on calcium content in eggshells of different birds. Int. J. Zool. Stud. 2018, 3, 31–33.

31. Philippe, F.X.; Mahmoudi, Y.; Cinq-Mars, D.; Lefrançois, M.; Moula, N.; Palacios, J.; Pelletier, F.; Godbout, S. Comparison of egg production, quality and composition in three production systems for laying hens. Livest. Sci. 2020, 232, 103917. [CrossRef]

32. Ferraz, E.; Gamelas, J.A.F.; Coroado, J.; Monteiro, C.; Rocha, F. Eggshell waste to produce building lime: Calcium oxide reactivity, industrial, environmental and economic implications. Mater. Struct. 2018, 51, 115. [CrossRef]

33. Saldanha, R.B.; da Rocha, C.G.; Caicedo, A.M.L.; Consoli, N.C. Technical and environmental performance of eggshell lime for soil stabilization. Constr. Build. Mater. 2021, 298, 123648. [CrossRef]

34. King’Ori, A.M. A review of the uses of poultry eggshells and shell membranes. Int. J. Poult. Sci. 2011, 10, 908–912. [CrossRef]

35. Sathiparan, N. Utilization prospects of eggshell powder in sustainable construction material—A review. Constr. Build. Mater. 2021, 293, 123465. [CrossRef]

36. Adogla, F.; Yalley, P.P.K.; Argoh, M. Improving compressed laterite bricks using powdered eggshells. Int. J. Eng. Sci. (IJES) 2016, 5, 65–70.

37. Ayodele, A.L.; Oketope, O.M.; Olatunji, O.S. Effect of sawdust ash and eggshell ash on selected engineering properties of lateritized bricks for low-cost housing. Niger. J. Technol. 2019, 38, 278–282. [CrossRef]

38. Han, H.; Wang, S.; Rakita, M.; Wang, Y.; Han, Q.; Xu, Q. Effect of ultrasound-assisted extraction of phenolic compounds on the characteristics of walnut shells. Food Nutr. Sci. 2018, 9, 1034–1045. [CrossRef]

39. BS EN 771-1: Specification for Masonry Units. Part 1: Clay Masonry Units. British Standards Institution: London, UK, 2003.

40. BS EN 1015-18: Methods of Test for Mortar for Masonry. Part 18: Determination of Water Absorption Coefficient due to Capillary Action of Hardened Mortar. British Standards Institution: London, UK, 2002.

41. BS EN 1015-11; Methods of Test for Mortar for Masonry. Part 11: Determination of Flexural and Compressive Strength of Hardened Mortar. British Standards Institution: London, UK, 2019.

42. IS 1725; Specification for Soil Based Blocks Used in General Building Construction. Bureau of Indian Standards: New Delhi, India, 1982.

43. SLS 1382; Specification for Compressed Stabilized Earth Blocks. Sri Lanka Standards Institution: Colombo, Sri Lanka, 2009.
44. CID-GCBNMBC-91-1; New Mexico Adobe and Rammed Earth Building Code. General Construction Bureau, Regulation & Licensing Department: Santa Fe, NM, USA, 1991.

45. NZS 4298; Materials and Workmanship of Earth Buildings. Standards New Zealand: Wellington, New Zealand, 1998.

46. TS EN 771-1; Specification for Masonry Units—Part 1: Clay Masonry Units. Turkish Standards Institution: Ankara, Turkey, 2005. (In Turkish)

47. Ngayakamo, B.H.; Bello, A.; Onwualu, A.P. Development of eco-friendly fired clay bricks incorporated with granite and eggshell wastes. Environ. Chall. 2020, 1, 100006. [CrossRef]