minerals

MDPI

Article

Recovery of Demolished House Rocks from Construction and Demolition Waste with Water Jigs

Artur Bressanelli Teixeira *, Hassan Barkat, Carlos Hoffmann Sampaio and Josep Oliva Moncunill

Departament d'Enginyeria Minera, Industrial i TIC, Escola Politècnica Superior d'Enginyeria de Manresa, Universitat Politècnica de Catalunya, Avenue. Bases de Manresa 61-63, 08242 Manresa, Spain; hassanbarkat456@gmail.com (H.B.); carlos.hoffmann@upc.edu (C.H.S.); josep.oliva@upc.edu (J.O.M.)

* Correspondence: artur.bressanelli@upc.edu

Abstract: The European Union (EU) is responsible for generating quantities ranging from 310 to almost 700 million tons of construction and demolition waste (CDW) per year. Consisting of over 70% inert material (concrete, ceramics, plaster, bricks, and rocks), CDW can be recycled for various uses, and studies on the concentration of the materials of interest are necessary to improve the management of this material and reduce waste. In CDW recycling plants in Spain, there is a significant presence of limestone from old houses (a common material used in civil construction before new construction materials and technologies emerged) that were demolished and mixed with CDW that can be recovered for use as aggregates in concretes with process density concentration processes such as water jigging. The jigging process is based on the difference in density between materials, allowing the concentration of the densest material at the bottom of the jig. Concrete, conventional construction bricks, and rocks from old houses were taken separately and then were crushed and mixed based on binary and ternary tests, and each test was performed in this study by applying the jigging separation method. The physical characterization tests of these materials was carried out to observe the jigging performance in the concentration of rocks as well as the aggregates present in concrete. Binary tests (with two different materials) and ternary tests (with three different materials) were carried out to analyze the concentration of particles with a density greater than 2.55 g/cm^3. The efficiency of jigging in the concentration of these materials was proven, and products were generated with more than 70% recovery of this material, with a concentration comprised of more than 95% rocks and concrete.

Keywords: rocks from demolition; CDW; recycling; gravity concentration; water jig

Citation: Teixeira, A.B.; Barkat, H.; Sampaio, C.H.; Moncunill, J.O. Recovery of Demolished House Rocks from Construction and Demolition Waste with Water Jigs. *Minerals* **2024**, *14*, 39. https://doi.org/10.3390/min14010039

Academic Editor: Longhua Xu

Received: 28 November 2023
Revised: 19 December 2023
Accepted: 26 December 2023
Published: 29 December 2023

1. Introduction

Large amounts of construction and demolition waste (CDW) are produced worldwide each year. In the European Union (EU), quantities that vary from 310 to almost 700 million tons, accounting for a range from 0.63 to 1.42 tons per capita annually [1]. All the statistics point towards the huge generation of CDW, with increasing demand and illegal dumping [2,3]. CDW represents in Europe nowadays about 37% of all solid wastes generated on the continent [4], and a complicating factor in the management of CDW is the generation of the waste, which occurs in a diffuse and non-concentrated way. The construction sector is responsible for approximately 6 billion tons of CO_2 emissions [5]. Furthermore, the demand for raw materials as aggregate for concrete is around 2.7 billion tons/year in EU countries [6]. Moreover, at the end of the construction chain, the construction of new buildings, building demolition, and the maintenance of existing structures generate a lot of waste. Taking CDW management into consideration, in 2008, Spain published the Royal Decree 105 [7], which regulates the production and management of CDW to reduce the volume of material generated and the consequences of their disposal in inappropriate locations.

Figure 1 demonstrates the main wastes generated in the EU according to economic activities and households. In the EU, construction contributed 37.5% (% share of total waste) of the total in 2020. It was followed by mining and quarrying (23.4%), waste and water services (10.8%), manufacturing (10.7%), and households (9.4%); the remaining 8.2% was waste generated from other economic activities, mainly services (4.4%) and energy (2.3%) [8].

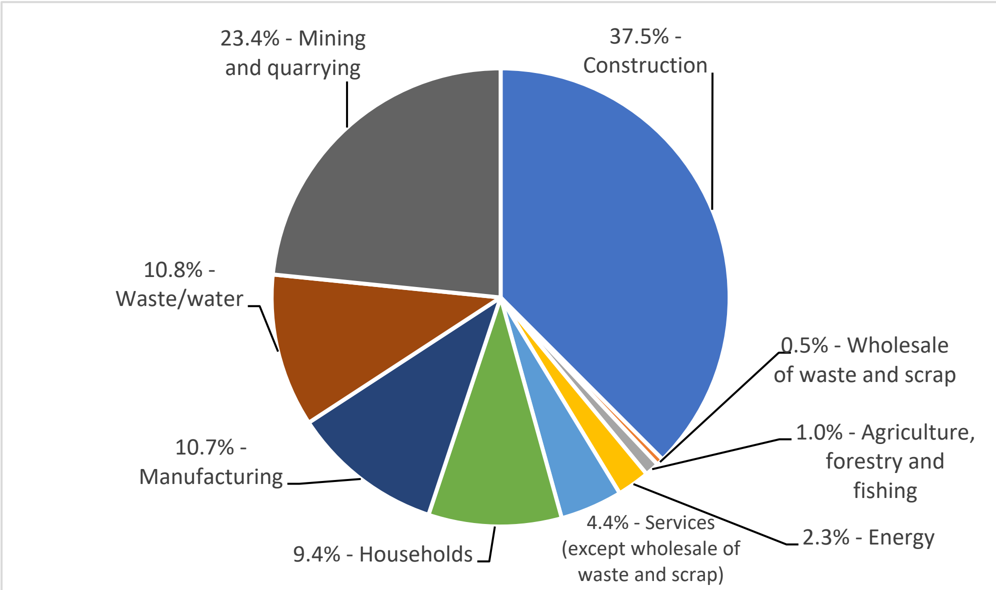

Figure 1. Waste generation by economic activities and households [8].

CDW is composed of many materials, such as concrete, tiles, ceramics, plastic, wood, glass, bituminous mixtures, metals, and even soil [9]. CDW can be used in many different applications to reduce material landfilling and to recuperate the economic value from the inert constituents that are present in most CDWs. Reis et al. [9] reviewed the current applications of the material recovered from CDW, such as sand production, use in pavements and roads, direct reuse in concrete mix as recycled aggregates (RA), fabrication of new concrete blocks, production of cement, and as adsorbents to treat polluted water. Other authors [10,11] also mentioned that the presence of contaminants limits the application of RA in new concrete since they negatively influence the fundamental properties of the aggregates, such as size distribution, shape index, bulk density, and water absorption.

One way to improve the quality of the CDW is the classification and concentration by type of material, which can be carried out by different types of equipment that use density as a separation factor, such as water- or air-based processes. Several authors have studied cases of CDW recycling plants [12–15]. As a form of initial classification, these plants usually crush the CDW and remove particulates such as plastics, paper, and wood as well as metal parts (ferrous and non-ferrous) by methods such as sieving, use of magnetic mats, or manual removal in the case of materials of larger sizes. The "inert CDW" material contains bricks, tiles, plaster, concrete, mortar, and coarse aggregate [11,16,17]. Figure 2 shows that around 76% of CDWs is composed of solidified and inert materials.

A specific case regarding Spain's CDW is the presence of rocks from old demolished houses (usually made of limestones) that are then sent to landfilling as a CDW. Their chemical composition can grade as high as 95% $CaCO_3$. The use of limestone as aggregate reduces the drying shrinkage, strength, and modulus of elasticity of the concrete formulated [18]. In addition, this material is used as aggregate in countries such as the United States of America and Japan.

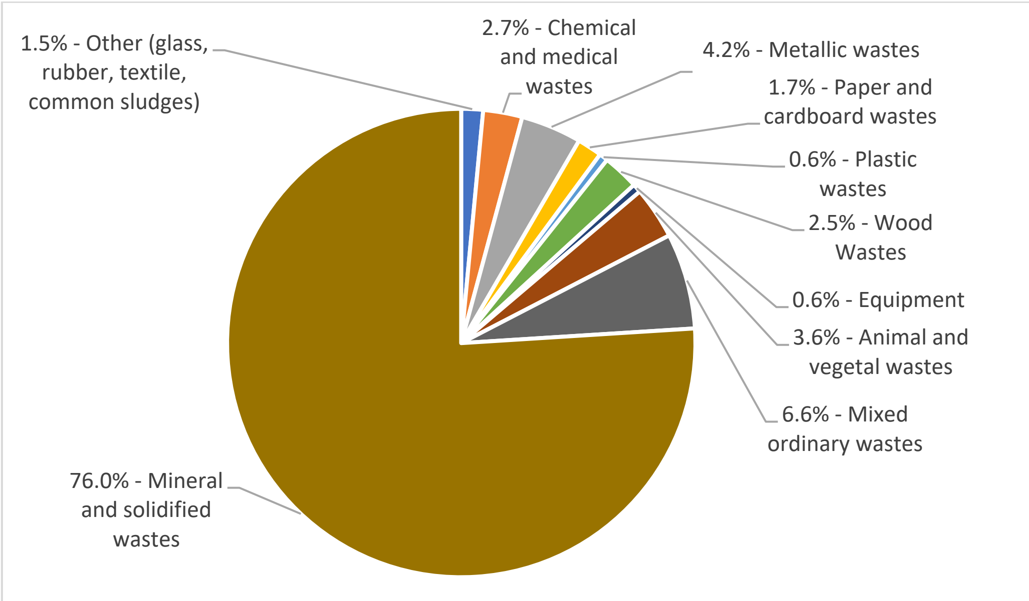

Figure 2. Constituent parts of CDW generated by waste category [4].

Research by Sampaio et al. [19,20] was carried out to define a route to recycle CDW using the jigging process and to prove the possibility of recovering this interesting material (RA) from the CDW as well as its reuse in new concrete mixtures. The production of RA using the jig process involves crushing the material, sizing it in a range from −20 mm to +5 mm, and then concentrating the RA with the jigging process and removing the contaminants from the material. The jigging products are suitable to be reinserted on the market and reused as recycled aggregates.

Jigging consists of a density separation process characterized by the repeated pulsation of a bed of particles through a fluid medium (air or water). The expected result is bed stratification into different densities, increasing from the top to the base of the bed [19,20]. F.W. Mayer [21,22] proposed a theory to explain the stratification in the jigging process called "Jigging Potential Energy Theory", which can be illustrated by considering a simple binary mixture and two ideal states of the particle bed. This theory proposes that there is a difference in gravitational potential energy between the fully mixed and stratified states concerning the densities and that the potential energy difference is truly responsible for stratification in jigging.

Another way that the separation inside the jig can be observed is by the concentration criteria (CC) proposed by Taggart [23]. CC is the relationship between the densities of two particles that have different densities and need to be separated. If the process uses water, it is necessary to discount the buoyancy force, as given by Equation (1):

$$\mathrm{CC} = \frac{rd - rf}{rl - rf} \tag{1}$$

where rd and rl are the densities of the dense and the light constituents, and rf is the density of the fluid. The higher the value of CC, the easier the density-based separation (such as jigging) of dense and light particles in a fluid.

If the CC is a large number, the density difference between the particles is large. Thus, there will be a greater decrease in the potential energy, facilitating stratification. Particles with closer densities will be more difficult to stratify than particles with greater density differences [24].

With bricks and concrete being the majority of the materials in CDW, this paper presents the recovery of the rocks from old houses when they are mixed with CDW materials in order to be reused as RA. The jigging experiment used bricks, concrete, and limestone rocks from old demolished houses. Specific and bulk density were measured as the form factor, size distribution, and densimetric distribution of the used materials. The study proved the possibility of recovering more than 75% of the limestone rocks with a density larger than 2.55 g/cm^3, which was comprised by less than 5% of contaminants.

2. Materials and Methods

2.1. Samples Preparation

The samples were prepared to represent the materials typically found in inert CDW in Spain according to their constituents, performance, and physical, chemical, and mineralogical characteristics. Concrete, bricks, and rocks from old houses were used to emulate the materials present in Spain's CDWs. The bricks used were commercial ceramic blocks without structural or refractory functions. The concrete was made according to the Structural Concrete Instruction–EHE/08 [25], and the rocks from old houses were collected in a recycling plant located in Spain; none of the materials had mortar attached. Figure 3 shows the materials' appearance before and after testing preparation. The materials were crushed in a jaw crusher (Wedag Española, S.A) with a top size aperture of 20 mm and then classified with screens to generate a material of 20 × 5 mm (size range from 20 to 5 mm).

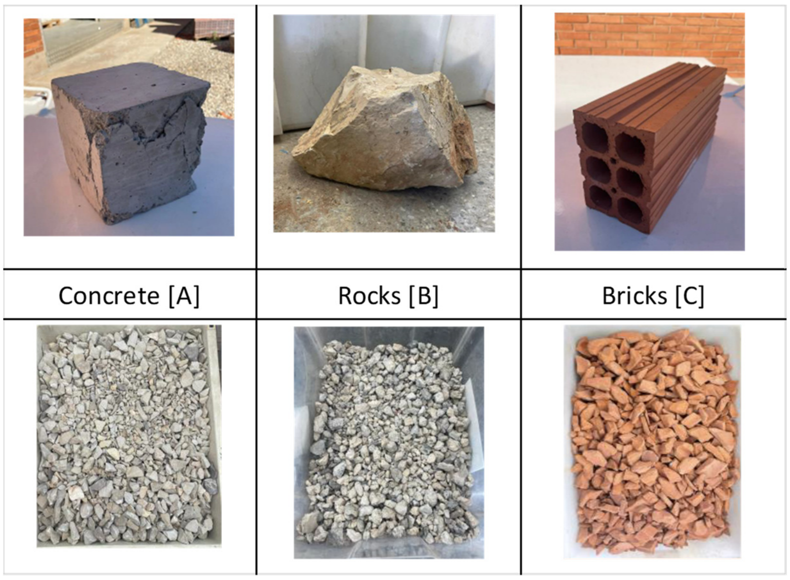

Figure 3. (**A**) Concrete before and after the preparation, (**B**) rocks from old houses before and after the preparation, and (**C**) bricks before and after the preparation.

2.2. Materials Characterization

2.2.1. Bulk Density Test

The bulk density was determined as established in the standards EN ISO 17892 2: 2014 [26]. The method consists of determining the volume and mass of the empty standard container; then, the container is filled until it is full, and the mass of the container plus its contents is determined. Bulk density is given by the weight of the material divided by the volume of the container. Equation (2) determines the bulk density of the materials as follows:

$$D = M/V \quad (2)$$

where

D = bulk density (g/L);

M = weight of each homogenous material (concrete, brick, and rock) in the full container (g);

V = container volume (L).

2.2.2. Specific Density Test

The specific density of the material was obtained through the methodology developed and presented by Leite [27]. Equation (3) determines the specific mass of the material as follows:

$$\gamma = C/(B - A + C) \tag{3}$$

where

γ = specific mass of the recycled aggregate (kg/dm³ or g/cm³);
A = sample mass + container + water + glass plate (g);
B = mass of the container + water + glass plate (g);
C = mass of the oven-dried sample (g).

2.2.3. Form Factor

The form factor test was carried out by the standard EN 933-4:2008 [28]. According to the standard, 200 aggregates must be selected that are proportional to the mass fractions of the ranges 9.5 × 12.7 mm and 12.7 × 19.5 mm constant in each sample. The selected grains are measured in their largest longitudinal portion and their smallest thickness with a caliper. Thus, the shape index of the sample is the sample mean of each grain.

The shape index of the sample was used to determine the geometrical characteristics of aggregates, as it affects the bulk density test due to packing arrangement, thus making the shape index of the sample important.

2.2.4. Sink and Flow Tests

Sink and flow tests were carried out with a solution of sodium polytungstate that can reach 2.85 g/cm^3 density in a water solution. The tests were carried out with a polytungstate solution with the following densities: 2.4 g/cm^3, 2.5 g/cm^3, 2.55 g/cm^3, 2.6 g/cm^3, 2.65 g/cm^3, 2.7 g/cm^3, 2.75 g/cm^3, and 2.8 g/cm^3. The density of the solution was measured with a manual Anton Paar Density Meter (DMA 35).

2.2.5. Granulometric Distribution Test

The particle size distribution of the material was determined by sieving the samples and analyzing the material retained on the 20 mm,12 mm, 8 mm, and 5 mm sieves as well as the fraction known as fine aggregates with sizes under 5 mm.

2.3. Jigging Equipment

The tests were carried out in a pilot water jig designed for laboratory tests (Figure 4). The water is pumped by the piston (d) and driven by the motor (e) through the water duct (b) to the jig chamber (a), which is enlarged, demonstrating the observation window and the bed height range that exists in the equipment. In the jig chamber, the water comes into contact with the material, providing expansion and compaction of the particle bed and the consequent stratification of the material inside the chamber. The material is collected manually from the top of the chamber according to the height that is defined in each test. The details on hydraulic jig operation and the forces that affect the stratification phenomenon can be found in the literature [24]. After jig efficiency analysis tests, the jigging parameters were fixed with a frequency of 35 pulses per minute, amplitude of 14 cm, and 3 min duration.

2.4. Jig Tests Procedure

Two different jigging tests were carried out during the work. The first was a binary mixture where rocks from old houses were mixed with bricks. A second test was carried out with a ternary mixture mixing concrete, rocks from old houses, and bricks to observe the behavior of the material stratification. The use of bricks and concrete was necessary, as they are the most common materials found in CDW. After each test, the particles were separated by hand according to their position in the stratification layer. Table 1 presents the values of weight, bulk volume, and the height of the bed formed by each material inside the jig chamber.

Figure 4. Image of the jig equipment used in the experiments: (**A**) jig chamber (enlarged), (**B**) water passage duct, (**C**) electric panel, (**D**) pump chamber, and (**E**) motor.

Table 1. Parameters of materials inside the jig chamber.

Binary Test			
Material	**Weight (g)**	**Bulk Volume**	**Bed Height (cm)**
Rocks	11.520	50%	8
Bricks	8.120	50%	8
Ternary Test			
Rocks	11.520	33%	8
Concrete	9.770	33%	8
Bricks	8.120	33%	8

2.4.1. Binary Test

Figure 5 demonstrates the flowchart of the binary separation. The first jig stage (1 in the figure) was made with two batches of jigging compound with rocks from old houses and bricks (Feed Material 1-FM1), with 50% of the bulk volume originating from each one, to observe the replicability of the process and generate material for the second jigging stage. Each batch generated two different materials: a light material–LM1 (2 in the figure), representing 50% of the internal volume of the first-stage jig chamber, and a dense material–DM1 (3 in the figure), also representing 50% of the internal volume of the jig chamber. Subsequently, both DM1s obtained in the initial batches were mixed and inserted into the second-stage jig chamber to analyze the complete processing route. The second jigging stage (4 in the figure) generated a light product–LP1 and a denser product (DP1).

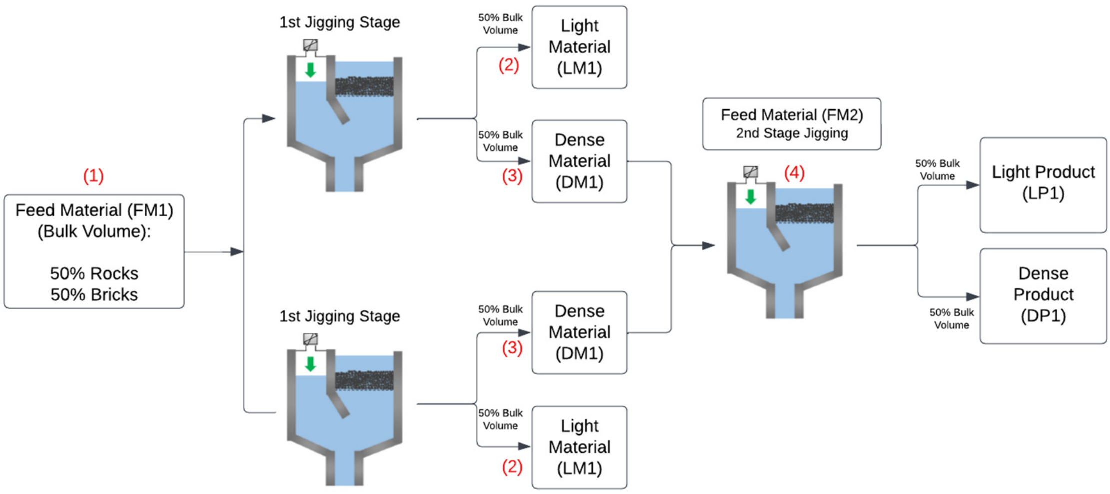

Figure 5. The flowchart of the two-stage jigging process made to concentrate the binary mixture of rocks and bricks.

2.4.2. Ternary Test

Figure 6 demonstrates the flowchart of the ternary jigging process. The batch test was carried out with rocks from old houses, concrete, and bricks, with 33% of the bulk volume originating from each one, respectively. The test generated three different materials: one light product–LP2, representing 33% of the internal volume of the jig chamber; a middling product-MP2 representing 33% of the internal volume; and a denser product-DP2 representing the last 33% of the internal volume that jig chamber.

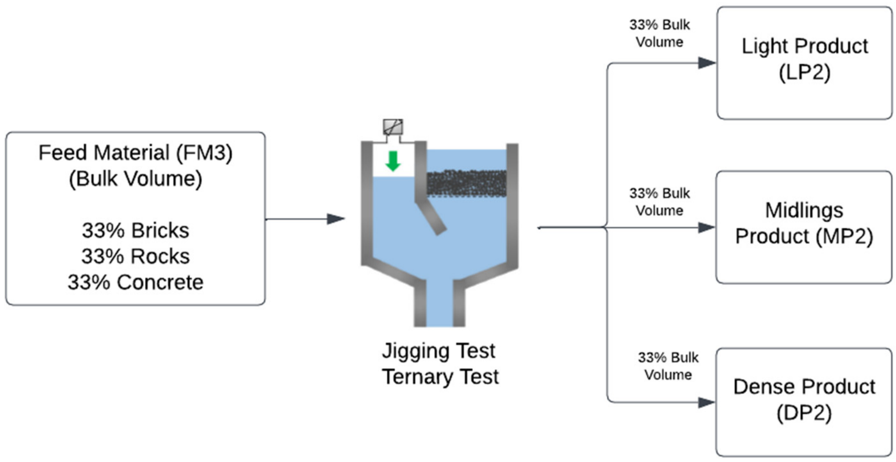

Figure 6. The flowchart of the jigging process made to concentrate the ternary mixture of rocks, concrete, and bricks.

3. Results and Discussion

3.1. Specific Density, Bulk Density, and Form Factor

Table 2 shows the values obtained for the specific density, bulk density, and form factor of the materials used in the paper. The bulk density of the materials is sometimes related to the shape factor of the materials due to the packing capacity of the material. The higher the shape factor of the material, the lower the bulk density will be normally, as the material allows the formation of voids when the sample is packed. The opposite also occurs: When the form factor is smaller, the bulk density will usually be greater, as the material has the possibility of filling the spaces, leaving fewer voids and consequently generating greater packing and bulk density value. Concrete has a shape factor of 2.19, bricks have a shape factor of 3.49, and rocks have a shape factor of 2.63.

Table 2. Values obtained for the bulk density, specific density, and shape factor and the concentration criteria of the materials used during the tests.

Materials/Parameters	Specific Density (g/cm^3)	Bulk Density (g/cm^3)	Form Factor
Concrete	2.61	1.37	2.19
Bricks	2.56	1.03	3.49
Rocks-Old Houses	2.64	1.47	2.63

3.2. Concentration Criteria (CC)

Table 3 shows the concentration criteria values for bulk density and specific density. Observing the specific density values, according to the jigging theory demonstrated by Taggart [23], as the materials have values very close to the specific density and consequently the concentration criteria (CC), theoretically, the particles should not be stratified in jigs. Observing the CC values obtained from the bulk densities, an increase in CC value is observed, which is the main factor in the stratification and process efficiency. This phenomenon was explained by Mayer [21,22], where the author demonstrated that the bulk density values are responsible for the stratification of the jigging process.

Table 3. Values obtained for concentration criteria (CC), in a binary analysis, of the materials used during the tests.

Concentration Criteria (CC)-Specific Density	Concentration Criteria (CC)-Specific Density	Concentration Criteria (CC)-Specific Density	Concentration Criteria (CC)-Bulk Density	Concentration Criteria (CC)-Bulk Density	Concentration Criteria (CC)-Bulk Density
Concrete/Bricks	Rocks/Bricks	Concrete/Rocks	Concrete/Bricks	Rocks/Bricks	Concrete/Rocks
1.03	1.05	1.02	12.33	15.67	1.27

The higher the value of CC, the wider the size range feasible to be fed into a jig, and the easier is the separation by density. It also indicates that the density of the fluid medium is also a determining factor influencing separation since the value of CC increases as fluid density gets close to the density of the light constituent [27].

3.3. Densimetric Distribution

Sink-and-float tests were carried out in the following densities: 2.4 g/cm^3, 2.5 g/cm^3, 2.55 g/cm^3, 2.6 g/cm^3, 2.65 g/cm^3, 2.7 g/cm^3, 2.75 g/cm^3, and 2.8 g/cm^3. Figure 7 shows the mass obtained from each material (rocks and concretes) in different density ranges. The rocks from old houses, as they are basically formed by limestone, do not have a very relevant densimetric variation due to their basic composition being more than 95% $CaCO_3$ [18]. More than 80% of the material is within the densimetric range of 2.5–2.6 g/cm^3, as are the values obtained for the specific density of the material.

Concrete has a much more relevant densimetric variation, ranging from 2.4 to 2.8 g/cm^3 due to the segregation of materials that exist in the composition of concrete. The concrete formulation is usually comprised of three parts coarse aggregates (high-density particles), two parts fine aggregates (sand), and one part cement.

The part of the concrete that has a density below 2.55 g/cm^3 is basically cement paste with fine aggregates or coarse aggregates with cement paste adhered. The particles with densities over 2.55 g/cm^3 are the liberated (total or partially) coarse aggregates. This liberation phenomenon is possible due to the difference in resistance between the coarse aggregates and the cement paste during crushing. The fracture tends to occur close to the interface that exists between the coarse aggregate and the cement paste.

The bricks were not subjected to the sink-float test, as they do not have a considerable densimetric variation; thus, their density was defined in the density test.

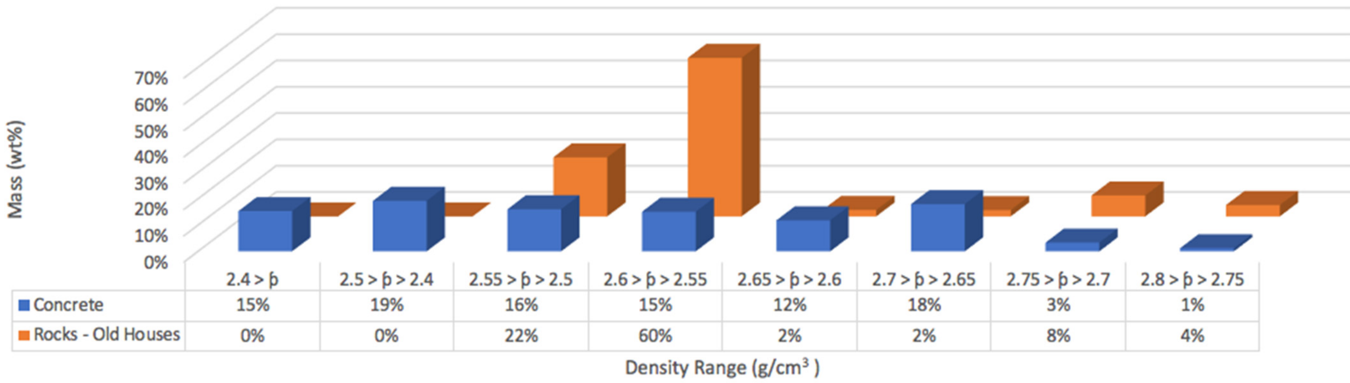

Figure 7. Densimetric distribution graphics from concrete and rocks from old houses.

3.4. Granulometric Distribution

The particle granulometric distribution of the material was determined by sieving the samples and analyzing the material on the 5 mm, 8 mm, 12 mm, and 20 mm sieves as well as the fine aggregates. The granulometric distribution of the material with a 5 × 20 mm range is given in Figure 8. After comminution, 33% of the concrete, 22% of the bricks, and 23% of the rocks remained in the 0 × 5 mm range, being classified as fine aggregates and separated for future studies.

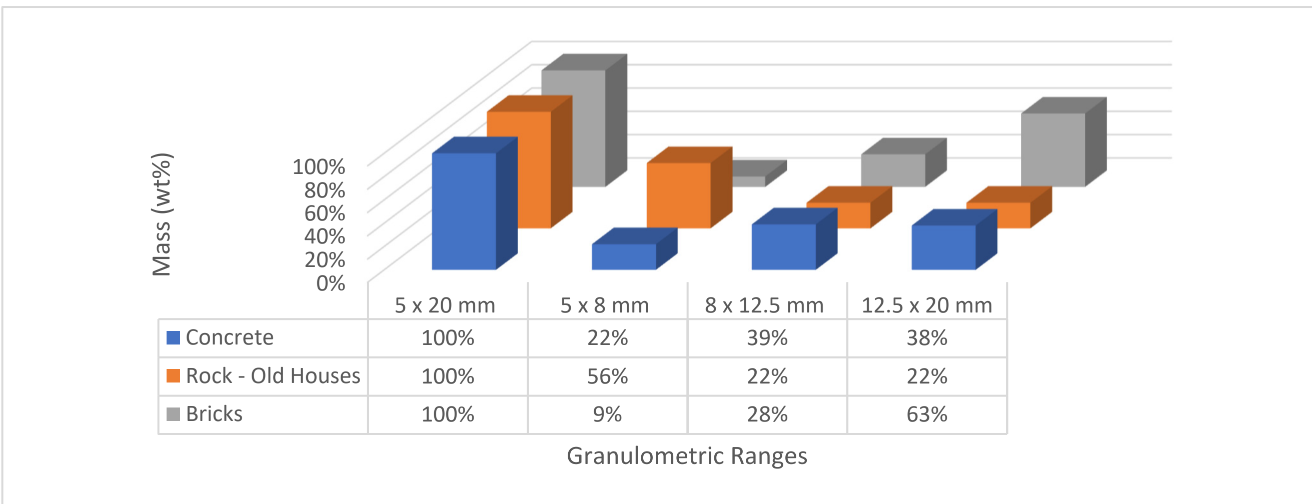

Figure 8. Granulometric distribution of the rocks, concrete, and bricks with 5 × 20 mm range.

During the comminution process, the bricks tended to fracture into larger fractions (12.5 × 20 mm) due to their original shape and low resistance. Bricks tended to form lamellar particles, with thinner width measurements and more elongated sizes. Of the bricks, 9% was 5 × 8 mm, 28% was 8 × 12.5 mm, and 63% was 12.5 × 20 mm in size. The rocks, due to their more homogeneous composition ($CaCO_3$), tended to fracture into smaller fractions, generating a material of which 56% was 5 × 8 mm, 22% was 8 × 12.5 mm, and 22% was 12.5 × 20 mm in size. The concrete, depending on its composition, showed randomly distributed fractures and composition of the granulometric portions. Concrete is composed of coarse aggregates (high-strength particles), fine aggregates (material mixed with cement), and cement (low-resistance material). While crushing, the concrete tended to fracture in the interstitial zones, thus forming particles that only had liberated coarse aggregates, middlings that were coarse particles with cement paste adhered, and liberated cement paste. Of the concrete, 22% was 5 × 8 mm, 39% was 8 × 12.5 mm, and 38% was 12.5 × 20 mm in size.

3.5. Jigging Tests

3.5.1. Binary Test

The first jigging test was carried out with a 16 cm bed height and with a Feed material-FM1 (defined in Figure 5) with a mass comprised of 11.520 g of rocks (58% by the total mass) and 8.120 g of bricks (42% by the total mass), representing 50% in bulk volume from each material, where 6.360 g of this material has a density greater than 2.55 g/cm^3 (32% by the total mass) measured with the sink-float test. After jigging, the materials were manually removed from the equipment in two different layers, with the Light Material–LM1 comprising the upper 8 cm of the chamber (50% bulk volume) and the Dense Material–DM1 comprising the last 8 cm of the chamber (50% bulk volume). With the densest material being located at the bottom of the jig, the material removed from each layer was separated manually to quantify its compositions. Figure 9 shows the flowchart with the values obtained for each material, the values of the content by mass (rocks, bricks, and material with density >2.55 g/cm^3), and the values according to the feed material (FM1).

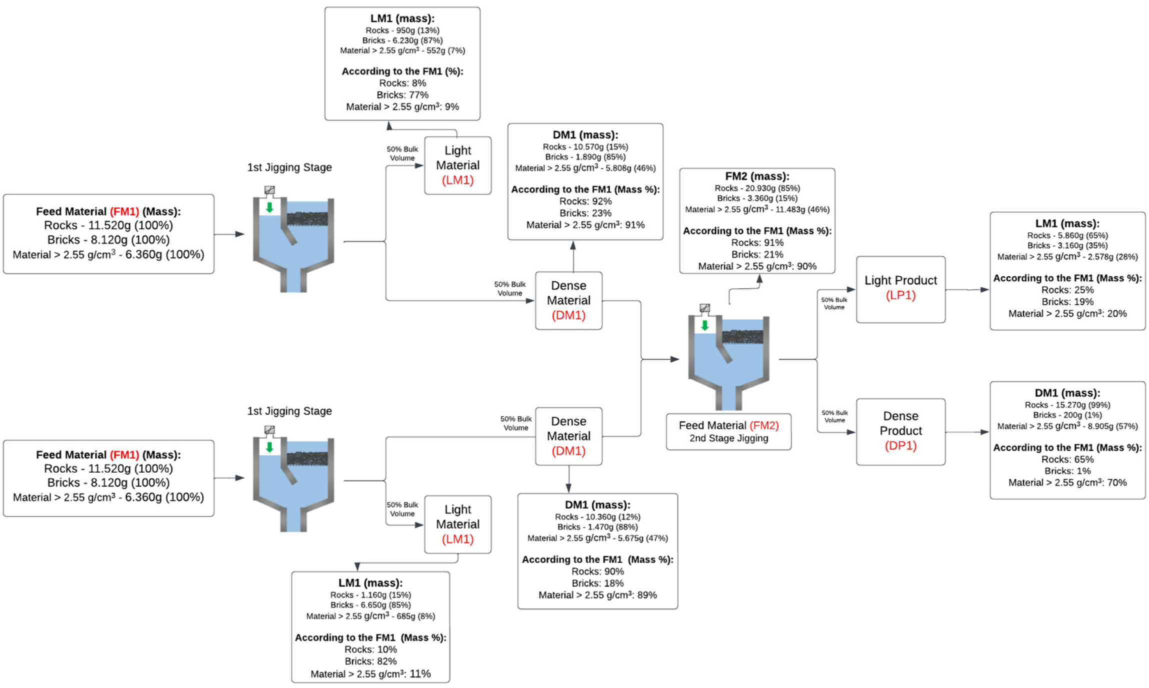

Figure 9. The flowchart of the jig tests and mass balance of the binary test.

The first stage of jigging (two batch tests) generated two types of materials (LM1 and DM1). The light material (LM1) in both tests presented very similar characteristics. The same occurred with the dense material (DM1). The results demonstrated the possibility of replicating the experiment. The LM1s were comprised of 85% bricks and 15% rocks by mass. The DM1s were comprised of 85% rocks and 15% bricks by mass. The tests were carried out in duplicate in order to generate a volume that would allow the second jigging stage. The two LM1 products were discarded, and the DM1 material (in both tests) was the feed material-FM2 (second stage of jigging). The second feed material (FM2) presented a mass of 24.290 g, with 20.930 g of rocks, 3.360 g of bricks, and 11.483 g of the materials having a density over 2.55 g/cm^3. These materials represent a recovery of 91% of the rocks and 21% of the bricks presented in the feed material (FM1).

In the second jigging stage, the feed material (FM2) was processed, generating two different products: the light product–LP1 and the dense product–DP1 (defined in Figure 9). LP1, known as the least-dense portion of the material, represented 50% of the bulk volume of the second feed material (FM2) and was composed of 5.860 g of rocks and 3.160 g of bricks, of which 2.578 g was material with a density greater than 2.55 g/cm^3. These materials represent the recovery of 25% of the rocks, 19% of the bricks, and 20% of the material with a density over 2.55 g/cm^3 from the feed material (FM1). The DP1 material represented 50% of the bulk volume of the second feed material (FM2), and it was composed of 15.270 g of rocks and 200 g of bricks, of which 8.905 g was material with a density above 2.55 g/cm^3. These materials represent the overall recovery of 65% of the rocks, 1% of the bricks, and 70% of the material with a density over 2.55 g/cm^3 from the feed material (FM1). DP1 has a high degree of purity due to the low presence of (<3%) bricks, which could be reused as RA.

3.5.2. Ternary Test

The jigging process was carried out with the feed material-FM3 (Figure 10) on a 24 cm bed height with a mass of 11.520 g of rocks (39% by mass), 8.120 g of bricks (28% by mass), and 9.770 g of concrete (33% by mass), representing 33% of the bulk volume of each material. The feed material (FM3) presented 9.017 g of material with a density greater than 2.55 g/cm^3 (31% by mass). Figure 10 demonstrates the flowchart with the values obtained for each product.

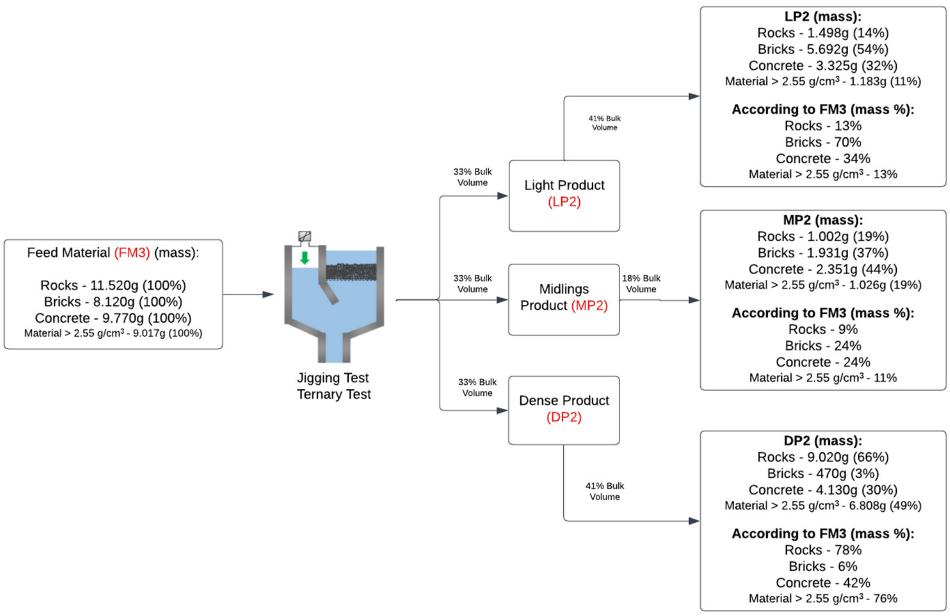

Figure 10. The flowchart of the jig tests and mass balance of the ternary test.

The light product-LP2 occupied the top 10 cm of the jig chamber, representing 41% of the bulk volume of the batch. LP2 had a greater quantity of bricks, with 70% of the bricks from the feed material (FM3) composing 54% of the mass of the sample removed. The lower bulk density and higher form factor of the bricks, as shown in Tables 2 and 3 (brick/rocks and brick/concrete), led to a higher CC value, allowing a good separation. Concrete represented 32% of the mass obtained in LP2 and a recovery of 34% of the concrete presented in the FM3. This material usually represents the portion of concrete formed basically by cement paste with a lower density. Rocks represented 14% of the mass obtained from the LP2 and a recovery of 13% of the rocks in FM3, which is normally formed by the rocks particles since they suffer a greater influence from gravimetric forces in the jig chamber and are unable to fall to the denser layer. The LP2 presented a small content of material with a density greater than 2.55 g/cm^3 with 11% by the mass of the product, representing a recovery of 13% of the total amount inserted in FM3.

The middling product-MP2 occupied the central 4 cm of the batch, representing 18% of the bulk volume of the test. Overall, 37% of the material was composed of bricks by mass, representing a recovery of 24% of the bricks inserted in feed material (FM3). Concrete represented 44% of the mass obtained in MP2 and a recovery of 34% of the concrete present in the FM3. This material normally represents the portion of concrete formed by coarse aggregates adhered to cement paste, which modifies the density of the particle and does not allow it to percolate into the dense layer of the jig. Rocks represented 19% of the mass obtained from the LP2 and a recovery of 13% of the rocks in FM3. This material (MP2) could be submitted to an impact mill to liberate part of the coarse aggregates and, subsequently, be recirculated in the jig feed to increase the coarse aggregate liberation.

In the densest layer, the dense product-DP2 material represented 41% of the bulk density of the feed material (FM3). Overall, 30% of the DP2 was composed by concrete, representing a recovery of 42% of the concrete inserted into the FM3. This part of the concrete was basically composed of totally liberated aggregates and aggregates with the presence of cement paste, which is the denser part of the concrete, as shown in Figure 7 (densimetric distribution). The mass of DP2 was 66% rock, which represents a recovery of 78% of the material inserted in FM3, and 3% of the DP2 was made up of bricks, representing a recovery of 6% of the material inserted in FM3, thus showing the generation of a material with a low impurity content. Moreover, 50% of DP2 had a density greater than 2.55 g/cm^3, representing more than 75% of the denser material present in FM3.

4. Conclusions

The main conclusions of this paper are the following:

- The rocks from old houses do not have a very relevant density variation due to their basic composition, and more than 80% of the material was within the density range of 2.5–2.6 g/cm^3. On the other hand, concrete had a much more relevant density variation, ranging from 2.4 to 2.8 g/cm^3;
- For all materials studied (rocks, bricks, and concretes) and crushed in a top size of 20 mm, most of the mass was in the size range of coarse aggregates (5×20 mm);
- During the comminution process, bricks tended to fracture into larger fractions and lamellar shapes due to their original shape and low resistance. The rocks, due to their more homogeneous composition, tended to fracture into smaller fractions, and concrete, depending on its composition, had random size distribution of fractures and the composition;
- It is possible to concentrate old rocks from demolished houses with water jigs, with high mass recoveries (over 65%) and low impurities based on the binary tests conducted;
- The tests proved the efficiency of jigging in the process of concentrating rocks as well as liberating the portion of concrete with a density above 2.55 g/cm^3, generating final products with low impurity contents. This concentrate presents enough purity to be used as recycled aggregate;
- The bulk density is the main factor responsible for the segregation mechanism inside of the jig.

Author Contributions: Conceptualization, A.B.T. and H.B.; methodology, C.H.S. and J.O.M.; software, A.B.T.; validation, A.B.T., H.B., C.H.S. and J.O.M.; formal analysis, C.H.S.; investigation, A.B.T. and H.B.; resources, C.H.S. and J.O.M.; data curation, A.B.T.; writing—original draft preparation, A.B.T.; writing—review and editing, C.H.S. and J.O.M.; visualization, H.B.; supervision, C.H.S. and J.O.M.; project administration A.B.T. and C.H.S.; funding acquisition, C.H.S. and J.O.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Agència De Suport A La Competitivitat De L'empresa Catalana, Acc1ó, grant number: ACE034/21/000093.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors would like to thank the Agència de Suport a la Competitivitat de L'empresa Catalana for the funding received as well as the company ROMÀ Infraestructures i Serveis for the samples provided.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. European Commission. 2011. Available online: http://ec.europa.eu/environment/waste/pdf/2011_CDW_Report.pdf (accessed on 5 November 2023).
2. Wong, C.L.; Mo, K.H.; Yap, S.P.; Alengaram, U.J.; Ling, T.C. Potential use of brick waste as alternate concrete-making materials: A review. *J. Clean. Prod.* **2018**, *195*, 226–239. [CrossRef]
3. European Environment Agency. *EU as a Recycling Society—Present Recycling Levels of Municipal Waste and Construction & Demolition Waste in the EU*; European Environment Agency: Copenhagen, Denmark, 2009.
4. Eurostat. Waste Statistics in Europe. Available online: http://epp.eurostat.ec.europa.eu/ (accessed on 5 November 2023).
5. Huang, L.; Krigsvoll, G.; Johansen, F.; Liu, Y.; Zhang, X. Carbon emission of global construction sector, Renew. *Sustain. Energy Rev.* **2018**, *81*, 1906–1916. [CrossRef]
6. European Aggregates Association. *A Sustainable Industry for a Sustainable Europe—Annual Review 2017–2018*; European Aggregates Association: Brussels, Belgium, 2018.
7. Royal Decree 105/2008. Production and Management of Construction and Demolition Waste. Available online: https://www.boe.es/buscar/pdf/2008/BOE-A-2008-2486-consolidado.pdf (accessed on 7 November 2023).
8. Eurostat. Statistics Explained. 2023. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Main_Page (accessed on 7 November 2023).
9. Reis, G.S.; Quattrone, M.; Ambrós, W.M.; Cazacliu, B.G.; Sampaio, C.H. Current Applications of Recycled Aggregates from Construction and Demolition: A Review. *Materials* **2021**, *14*, 1700. [CrossRef] [PubMed]
10. Galderisi, A.; Iezzi, G.; Bianchini, G.; Paris, E.; Brito, E. Petrography of construction and demolition waste (CDW) from Abruzzo region (Central Italy). *Waste Manag.* **2022**, *137*, 61–71. [CrossRef] [PubMed]
11. Galderisi, A.; Bravo, M.; Iezzi, G.; Cruciani, G.; Paris, E.; Brito, J.d. Physico-Mechanical Performances of Mortars Prepared with Sorted Earthquake Rubble: The Role of CDW Type and Contained Crystalline Phases. *Materials* **2023**, *16*, 2855. [CrossRef] [PubMed]
12. Nunes, K.R.A.; Mahler, C.F.; Valle, R.; Neves, C. Evaluation of investments in recycling centers for construction and demolition wastes in Brazilian municipalities. *Waste Manag.* **2007**, *27*, 1531–1540. [CrossRef] [PubMed]
13. Neto, R.O.; Gastineau, P.; Cazacliu, B.G.; Guen, L.L.; Paranhos, R.S.; Petter, C.O. An economic analysis of the processing technologies in CDW recycling platforms. *Waste Manag.* **2017**, *60*, 277–289. [CrossRef]
14. Cazacliu, B.; Sampaio, C.H.; Petter, C.O.; Miltzarek, G.L.; Guen, L.L.; Paranhos, R.S.; Huchet, F.; Kirchheim, A.P. The potential of using air jigging to sort recycled aggregates. *J. Clean. Prod.* **2014**, *66*, 46–53. [CrossRef]
15. Coelho, A.; De Brito, J. Economic viability analysis of a construction and demolition waste recycling plant in Portugal—Part I: Location, materials, technology, and economic analysis. *J. Clean. Prod.* **2013**, *39*, 338–352. [CrossRef]
16. Wu, Z.; Yu, A.T.W.; Shen, L.; Liu, G. Quantifying construction and demolition waste: An analytical review. *Waste Manag.* **2014**, *34*, 1683–1692. [CrossRef] [PubMed]
17. Hua, K.; Chen, Y.; Naz, F.; Zeng, C.; Cao, S. Separation studies of concrete and brick from construction and demolition waste. *Waste Manag.* **2019**, *85*, 396–404. [CrossRef] [PubMed]
18. Carlos, A.; Masumi, I.; Hiroaki, M.; Maki, M.; Takahisa, O. The effects of limestone aggregate on concrete properties. *Constr. Build. Mater.* **2010**, *24*, 2363–2368.
19. Sampaio, H.C.; Ambrós, W.M.; Cazacliu, B.G.; Oliva Moncunill, J.; Veras, M.M.; Miltzarek, G.L.; Silva, L.F.O.; Kuerten, A.S.; Liendo, M.A. Construction and Demolition Waste Recycling through Conventional Jig, Air Jig, and Sensor-Based Sorting: A Comparison. *Minerals* **2021**, *11*, 904. [CrossRef]
20. Gschwenter, V.L.S.; Tubino, R.M.C.; Ambrós, W.M.; Miltzarek, G.L.; Sampaio, C.H.; Moncunill, J.O.; Cazacliu, B.G.; Dal Molin, D.C.C. Production of High-Quality Coarse Recycled Aggregates through a Two-Stage Jigging Process. *Minerals* **2022**, *12*, 532. [CrossRef]
21. Mayer, F. A new theory concerning the mechanism of settling with its consequences for the rational shape of the diagram of the washing stroke and development of the corresponding regulator of a non-plunger jig. In Proceedings of the 1st First International Coal Preparation Conference, Paper A7, Paris, France, June 1950; pp. 316–322.
22. Mayer, F. Fundamentals of a potential theory of the jigging process. In Proceedings of the 7th International Mineral Processing Congress, New York, NY, USA, 20–24 September 1964; pp. 75–86.
23. Taggart, A.F. *Handbook of Mineral Dressing*; Wiley: Hoboken, NJ, USA, 1945; Volume 1.
24. Ambrós, W.M. Jigging: A Review of Fundamentals and Future Directions. *Minerals* **2020**, *10*, 998. [CrossRef]
25. Royal Decrete 1247/2008; (EHE-08): Structural Concrete Instruction. Available online: https://www.mitma.gob.es/recursos_mfom/1820100.pdf (accessed on 12 November 2023).
26. *UNE-EN ISO 17892-2*; Geotechnical Investigation and Testing—Laboratory Testing of Soil—Part 2: Determination of Bulk Density. Asociación Española de Normalización: Madrid, Spain, 2014.

27. Leite, M. *Evaluation of the Mechanical Properties of Concrete Made with Recycled Aggregates from Construction and Demolition Waste*; Federal University of Rio Grande do Sul Porto Alegre: Porto Alegre, Brazil, 2001. Available online: http://hdl.handle.net/10183/21839 (accessed on 10 November 2023).
28. *EN 933-4:2008*; Tests for Geometrical Properties of Aggregates. Part 4: Determination of Particle Shape—Shape Index. British Standards Institution: London, UK, 2009.