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Recovery and Restructuring of Fine and Coarse Soil Fractions as Earthen Construction Materials

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Abstract: Excessive consumption of natural resources to meet the growing demands of building and infrastructure projects has put enormous stress on these resources. On the other hand, a significant quantity of soil is excavated for development activities across the globe and is usually treated as waste material. This study explores the potential of excavated soils in the Brittany region of France for its reuse as earthen construction materials. Characterization of soil recovered from building sites was carried out to classify the soils and observe their suitability for earthen construction materials. These characteristics include mainly Atterberg limits, granulometry, organic matter and optimum moisture content. Soil samples were separated into fine and coarse particles through wet sieving. The percentage of fines (particles smaller than 0.063 mm) in studied soil samples range from 28% to 65%. The methylene blue value (MBV) for Lorient, Bruz and Polama soils is 1, 1.2 and 1.2 g/100 g, and French classification (Guide de terrassements des remblais et des couches de forme; GTR) of soil samples is A1, B5 and A1, respectively. The washing of soils with lower fine content helps to recover excellent-quality sand and gravel, which are a useful and precious resource. However, residual fine particles are a waste material. In this study, three soil formulations were used for manufacturing earth blocks. These formulations include raw soil, fines and restructured soil. In restructured soil, a fine fraction of soil smaller than 0.063 mm was mixed with 15% recycled sand. Restructuring of soil fine particles helps to improve soil matrix composition and suitability for earth bricks. Compressed-earth blocks of 4 × 4 × 16 cm were manufactured at a laboratory scale for flexural strength testing by using optimum molding moisture content and compaction through Proctor normal energy. Compressive strength tests were performed on cubic blocks of size 4 × 4 × 4 cm. Mechanical testing of bricks showed that bricks with raw soil had higher resistance with a maximum of 3.4 MPa for Lorient soil. Removal of coarse particles from soil decreased the strength of bricks considerably. Restructuring of fines with recycled sand improves their granular skeleton and increases the compressive strength and durability of bricks.

Keywords: excavated soils; soil characterization; recycling; waste management

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1. Introduction

Soil is excavated for the development of infrastructure and for the construction of buildings. Excavated soil is one of the major waste materials in the European Union. In France, the building sector is the biggest waste producer, and nearly 150 Mt of soil is excavated from construction sites [1,2]. Excavated soil, whether inert or polluted, is classified as waste after its excavation from the site [3]. Excavated soil waste is further classified into inert waste, non-hazardous waste and hazardous waste [4]. The presence of heavy metals and organic impurities such as hydrocarbons due to industrial activities pollutes the soil. The presence of contaminants in soil complicates soil storage and reuse and needs prior treatment. Inert soil waste is usually dumped in landfills. Landfill storage of soil is costly as the landfill sites are usually outside urban areas, and the cost of transportation increases with distance. In addition, landfill dumping of soil waste has environmental concerns. The French government and the European Union have fixed the objective to recycle 70% of the waste of public works [5].

Soil is a heterogeneous material with significant variations in its characteristics, which significantly influences its recovery choices for different applications. For recycling of excavated soils, analysis of their environmental, physico-chemical, mineralogical, microstructural and hydromechanical characteristics is essential [6], as it helps to know the mechanical behavior of soil, water absorption and its swelling and shrinkage potential [7]. Based on soil characteristics, excavated soils can be used in agronomy, landscaping, earth construction, roads and for backfill [8]. Annually, 47 million tons of soil is excavated from 200 km along the Grand Paris Express. Nearly 70% of excavated soil is recycled, in which 80% of recycled soil is used in the backfill of quarries and landscaping, while only 2% of soil is recycled in ecological building materials including earth bricks [6].

Excavated soils are composed of clay, silt, sand and gravel. The top layer of soil is nutrient-rich and contains higher organic matter, which is suitable for agronomy and landscaping. For soil reuse as earthen construction materials, the top layer of soil is usually discarded. Higher organic matter in soils is undesirable for earthen construction and road applications due to limitations of the load-bearing capacity of soil. The treatment of soil with lime and hydraulic binders decreases the organic matter of soils and makes them suitable for earthen construction materials and roads. Lime addition stabilizes the soil, increases its pH and contributes to decomposition of organic matter [9]. The addition of lime controls the humidity, and it reacts with clay by forming calcium silicate hydrates and calcium aluminate. The lime surrounds the clay sheets, while the mineral particles (sand and aggregate) are free. The addition of lime decreases the plasticity of clayey soils, decreases its swell and shrink potential with variation in moisture content and increases its compressive and shear strength with compaction [10]. In the case of hydraulic binders such as cement, the reaction takes place between the mineral's particles. For roads and backfill applications, the addition of binders helps to increase the compressive strength of materials to 1 to 4 MPa, which is the strength recommended by French authorities for roads and backfill applications to ensure sufficient load-bearing capacity [9].

The mineral component of soil is suitable for earthen construction materials [11]. Earth bricks are the oldest construction material that is still common in developing countries. Higher carbon emissions from modern building materials and excessive resource consumption have encouraged us to look for sustainable building materials like earth blocks, which can be manufactured with minimum use of energy, and at the end of life of the structure, the earth material is reversible [12]. Different types of earthen construction include cob, adobe, compressed-earth blocks and rammed-earth blocks, etc. The type of earth construction depends on the characteristics of locally available materials and soil texture. GTR classification of soil based on methylene blue value (MBV) and granulometry helps to understand the sensitivity of soil to water. The percentage of clay in compressed-earth blocks can reach up to 50%. The MBV value of 3 g/100 g is the limit for the non-reactive clays. Therefore, it should be considerably lower than this value. For rammed-earth blocks and compressed-earth blocks, sandy soils are usually preferred, in which clay and silt varies between 30 and 50% [13]. Earth blocks are compressed to achieve maximum densification and resistance. Cob and adobe techniques are adopted for clayey soils and with higher moisture content. The mechanical behavior and durability of earth blocks can be improved by stabilization with different binders such as lime, cement and gypsum, etc. However, the carbon footprint of cement is higher, and the reversibility of the soil to nature after addition of cement and lime is not possible [14].

Another interesting approach for the recycling of excavated soil is its separation into fine and coarse particles through wet processing. The wet treatment of excavated soils helps to separate them into different constituents such as fine clay and silt particles, sand and gravel. The water used to separate the different soil fractions is recycled and reused for soil treatment, which makes it a sustainable process. The quality of recycled sand and gravel obtained through washing is good as fines are removed by washing, and this material can be used for concrete and infrastructure applications [15]. Production of high-quality aggregate through wet processing helps to recover the maximum amount of excavated soil waste into fine and coarse aggregate. Although excavated soils are used for earth-based materials, the use of the fine fraction in earthen construction is limited. The separation of excavated soils by wet treatment is relatively new, and there are only a few working installations across Europe. In addition, restructuring of fine soil with recycled sand for earthen construction is relatively unexplored. This research gap can be overcome by investigating the fine fraction reuse as earthen construction by modifying the composition of soils by adding recycled coarse sand particles to improve the soil matrix.

Recycling excavated soil waste is a promising strategy to reduce the stress on natural resources and mitigate the environmental impacts associated with excessive use of natural resources. The objective of this study is the recovery of the fine fraction of excavated soils as earthen construction materials in the Brittany region of France. This research investigates the characteristics of excavated soils in the Brittany region for their separation through wet treatment and examines the different soil fractions' reuse as earthen construction materials. Soil samples will be separated into coarse and wet fractions through wet sieving. The fine fraction of soil is the waste material obtained through washing soils for the recovery of soil in sand and aggregate. This research investigates the reuse of the fine fraction in earthen construction by improving the soil matrix with the addition of recycled sand, which is a byproduct of a construction and demolition waste recovery plant. Three soil formulations, namely raw soil, fine soil and restructured soil, were investigated for their use in compressed-earth blocks. For this purpose, three soil samples from Brittany, France, were studied and reused for compressed-earth blocks.

2. Materials and Methods

2.1. Excavated Soils

The Brittany region of France produces nearly 2.8 million tons of excavated soils annually [16]. Excavated soil samples used in this study were collected from three earthwork sites in the city of Rennes in France and were named Lorient, Bruz and Polama. The selected soil samples are the most common and representative of the soils in the region. Figure 1 shows the excavated soils used in this study.

Figure 1. Brittany soil samples: Lorient (**a**), Polama (**b**) and Bruz (**c**).

The excavated soils are reused in backfill, roads and agronomy. However, their reuse is limited due to the heterogenous nature of soil. In the case of the Grand Paris Express Tunnel construction, only two percent of excavated soil was reused as earthen construction materials, while the rest was dumped or recycled in low-value-added applications such as backfilling of quarries [6].

Granulometry of soil plays an important role for the reuse of soils. Granulometry of soil was determined using wet sieving. The initial moisture content of soil samples was determined by oven-drying the samples following the French standard [17]. The liquidity and plasticity limits of soil samples were determined using the Casagrande test and by a 10 cm long thread of soil, respectively [18]. Organic matter of soil is crucial for its reuse as an earthen construction material. Higher organic matter leads to soil degradation. Organic matter of soils was determined by burning soil samples at a temperature of 550 °C in an oven following the French standard [19]. The methylene blue value of the soil samples was determined to observe the soil classification and behavior of clay minerals on soil interaction with water [20]. Solid particles of soil are an important parameter as it helps to know the soil porosity, densification and strength. The solid particle density of soil samples was determined with a helium pycnometer [21]. The dry density and optimum moisture content of the soil was determined by using the Proctor test [22].

2.2. Fine Particles

Excavated soil waste can be recovered in the form of recycled aggregate and sand through wet processing, which is an efficient method to separate soil into a fine fraction of size below 0.063 mm and a coarser fraction of size greater than 0.063 mm. Figure 2 shows the schematic diagram of the excavated soil separation process into fines, sand and gravel through wet processing.

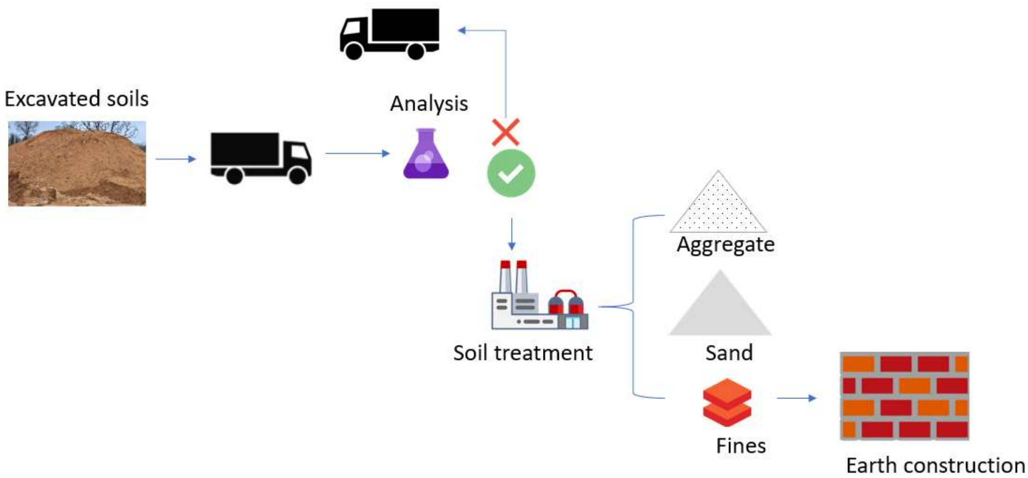

Figure 2. Wet processing of excavated soils.

Figure 2 shows the soil separation into aggregate, sand and fines. For wet treatment of excavated soils, a percentage of fines smaller than 0.063 mm is critical. Wet processing of soils is economical if the percentage of fines is lower than 30%. In the case of higher fine content, the recovery of sand and aggregate is undesirable [23]. Sand and gravel obtained through washing of excavated soils have good quality, and this material can be used for concrete and infrastructure applications. However, the fine fraction of soil is considered to be waste. The fine fraction residue of soil obtained through wet processing of excavated soils can be restructured to be used in earth-based materials, which helps to transform this waste into a valuable resource. In the present study, the excavated soils' fine fraction was separated through wet sieving by using a sieve of 0.063 mm to obtain the same size fraction coming from industrial plants. Figure 3 shows the process of soil separation into fine and coarse particles.

Figure 3. Raw soil (**a**), mixing soil with water (**b**), wet sieving of soil (**c**) and fine particles of soil (**d**).

The fine fraction of soil has a higher plasticity and is susceptible to shrinkage and swelling as this material has an MBV higher than 2 g/100 g. According to the GTR classification, soil sensibility to water increases with increasing MBV, and a value of 2 g/100 g is highly water-sensitive [24]. It is possible to modify the composition of fine soils by adding hydraulic binders or sand to increase the strength and durability of earth blocks. This study considers recycled sand as an additive.

2.3. Recycled Sand

The granulometry of the soil matrix for earth blocks has a significant role in increasing their dry density and mechanical strength [25]. To optimize the granular structure of fine particles, the restructuring of fine soil was performed by adding 15% recycled sand. The addition of recycled sand to restructure fines helps to improve the soil composition, mechanical behavior and its suitability for earth construction. Recycled sand of size 0 mm to 4 mm was mixed with the fine fraction of soil to improve the grain size distribution of the fine fraction of soil and improve its strength. Methylene blue tests show that 15% recycled sand is enough to decrease the methylene blue value of the soil mixture and the soil's sensitivity to water. Recycled sand used in this study was sourced from the processing of construction and demolition waste in Rennes, France. The characteristics of recycled sand were determined in order to use this material for earth bricks. The granulometry of the recycled sand was determined according to the French standard [26]. The amount of sulfate in sand sample was determined with a gravimetric method according to the French standard [27]. The presence of different minerals in the soil was determined through an X-ray diffraction (XRD) test using a D8-Advance Bruker-AXS diffractometer apparatus supported with DIFFRAC EVA v4.2 (©Bruker AXS) software through a protocol developed by Unilasalle laboratory [28].

2.4. Sample Preparation

Earth bricks were manufactured with three different formulations, which are (1) raw soil, i.e., soil excavated from an earthwork site and passed through a 2 mm sieve, (2) fine fraction of excavated soils with a size below 0.063 mm obtained by wet sieving of raw soil and (3) restructured fine soil with the addition of 15 wt.% recycled sand of size 0 mm to 4 mm in the fine fraction of soil. The soil mixture was homogeneously mixed at optimum moisture content determined through the Proctor test to achieve maximum densification with an electric mixer. Optimum soil moisture content is crucial for the maximum densification of the soil, which has a significant role in the mechanical behavior of earth blocks [29]. Three prismatic earth blocks of size 4 × 4 × 16 cm were manufactured following the French standard for mortar [30] for each formulation by compacting the soil mixture in two layers. Brick samples were compacted with dynamic compaction by applying Proctor normal energy through falling mass to achieve maximum densification, which is essential to obtain maximum strength [31]. The bricks were dried in an oven at 40 °C for 3 to 4 days. Most of the studies in the literature recommend brick drying at a temperature below 60 °C [32]. Once the mass of bricks was stabilized, the dry density and linear shrinkage of the bricks were measured. Samples of the earth blocks manufactured are shown in Figure 4.

Figure 4. Samples of prismatic earth blocks.

2.5. Testing of Earth Blocks

The density and linear shrinkage of the earth blocks was measured to observe their variation with different formulations according to the French standard [33]. A three-point bending test was performed on the earth bricks to determine their flexural strength following the ASTM standard [34] with the help of a Shimadzu AGS-X model machine. A 50 kN sensor was applied with displacement rate of 0.5 mm/min in accordance with the French standard [35]. After the flexural strength test, two halves of each earth block were cut into two cubic blocks of 4 cm each with the help of an electric saw for the compressive strength test. The size of the cubes is in accordance with the French standard for mortar [30]. The influence of the shape of the sample on strength variation is usually smaller than 5% for cubic or cylindrical samples of different size but with the same shape [36].

3. Results and Discussion

3.1. Soil Characteristics

The granulometry of soils plays a critical role in soil selection for its reuse as earthen construction materials [33,37]. Soil was separated into coarse and fine fractions (smaller than 63 µm) via wet sieving. Table 1 shows the granulometry of the investigated soil samples through wet sieving.

Table 1. Grain size distribution.

Size (mm)	31.5	20	16	12.5	8	4	2	<63 µm
Polama (%)	100	100	100	99.9	99.5	98.6	97.6	65.9
Bruz (%)	100	100	98.9	98.2	97.7	96.4	93.7	28.2
Lorient (%)	100	100	100	100	100	98.3	95	40.3

Note: 31.5 mm means the soil passing through the 31.5 mm sieve and so on.

Table 1 shows that the fine fraction (smaller than 0.063 mm) exhibits significant variation. The percentage of fines is very high in Polama soil and considerably lower in Bruz soil. In Bruz soil, the percentage of fines is below 30%. Therefore, it is economically viable to process this soil by wet processing to separate it into sand and aggregates. The percentage of fines is intermediate in Lorient soil, which is representative of soils in the region of Brittany.

A higher percentage of fines in soil makes it unsuitable for road and backfill materials. In the case of earth bricks, a higher percentage of fines in soil leads to complications including linear shrinkage, crack development and durability issues [12]. Therefore, an intermediate quantity of fines and sand particles is essential for manufacturing earth blocks to achieve maximum strength and improved durability. The physico-chemical characteristics of the excavated soils are summarized in Table 2.

Table 2. Physico-chemical characteristics of the soils.

Soil	ρ_s (g/cm^3)	OM (%)	LL (%)	PL (%)	Wopt (%)	MBV (g/100 g)	GTR	Coarse P. (%)	Fines (%)
Lorient	2.68	5	28.7	18.3	18	1.0	A1	59.7	40.3
Bruz	2.71	4	26.4	17.4	12	1.2	B5	71.8	28.2
Polama	2.72	4	36.2	22.1	17	1.2	A1	34.1	65.9

Note: Wopt = optimum moisture content; LL = liquidity limit; MBV = methylene blue value; ρ_s = particle density; OM = organic matter; GTR = GTR classification; Coarse P. = coarse particles. PL = plasticity limit.

Table 2 shows that the French classification (Guide de terrassements des remblais et des couches de forme; GTR) of the studied soils is A1 and B5. Most of the old earthen building structures in France have a similar composition. The GTR classification for old buildings in France is usually A1 and B5. Soil with the A1 classification has shrinkage and swelling problems upon interaction with water, while in the B5 zone, soils are usually less susceptible to water [24]. The bethylene blue value of the studied soils is below 1.5 g/100 g in Table 2, which indicates the soils are sandy, silty and water-sensitive [24]. For soil with only fine particles smaller than 0.063 mm, the MBV value of the soil samples is higher than 2 g/100 g, which makes them highly sensitive to water. The addition of 15% recycled sand decreases the MBV value to below 1.5 g/100 g, which is the acceptable limit as most of the rammed-earth buildings in France have a methylene blue value under 1.5 g/100 g [38].

3.2. Characteristics of Recycled Sand

The physico-chemical characteristics of recycled sand were determined through laboratory tests. Grading of soil has significant influence on the strength and workability of the mixture. The grading curve of recycled sand is shown in Figure 5.

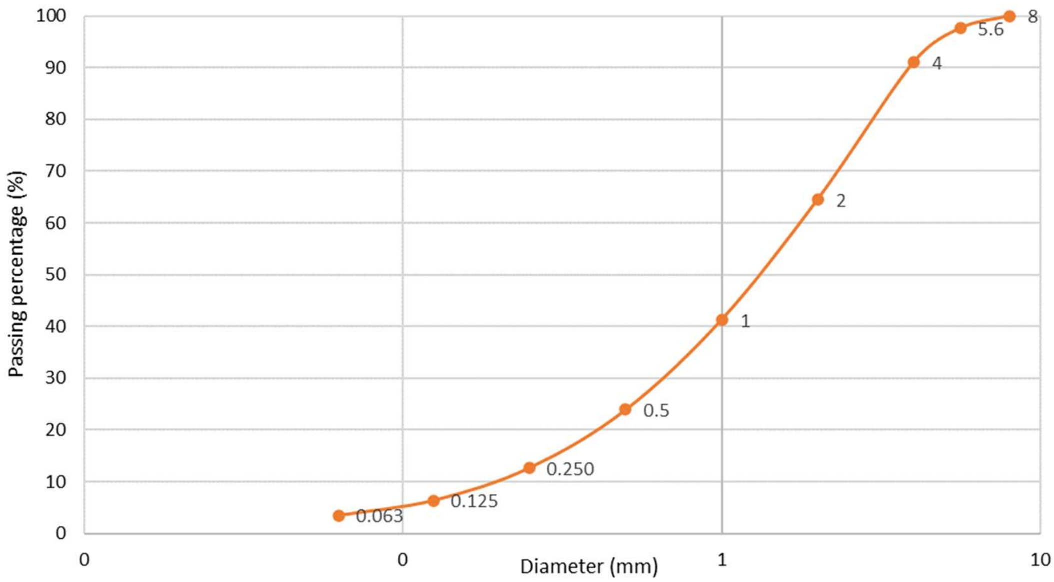

Figure 5. Granulometry of recycled sand.

The grading curve in Figure 5 shows that fine particles of sand make up 3.5%, while all the sand particles pass through the 8 mm sieve. The minerology of the recycled sand was determined by XRD analysis. Figure 6 shows the important minerals in the recycled sand sample.

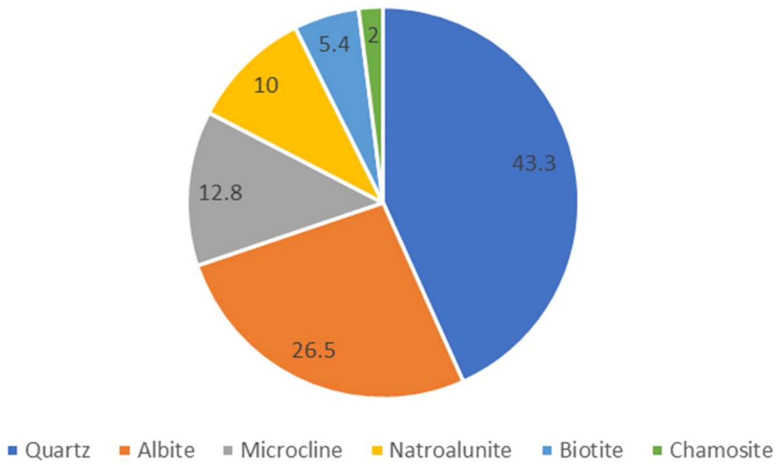

Figure 6. Minerology of recycled sand.

Figure 6 shows that quartz, albite, microcline, microcline and natroalunite are the dominant minerals in recycled sand. Higher quartz and feldspar content contributes to the strength and structural integrity of earth-based materials and decreases the shrinkage of these materials. The physico-chemical characteristics of recycled sand are summarized in Table 3.

Table 3. Characteristics of recycled sand.

Sample	Wi (%)	Fines (%)	<5.6 mm (%)	GTR	MBV (g/100 g)	Wopt. (%)	OPN Density (g/cm^3)	SS (%)
Sand	6.4	3.5	97.6	D1	0.1	8.6	1.9	0.5

Note: Wi = initial moisture content; fines = percentage of fine fraction of sand smaller than 0.063 mm; GTR = GTR classification; MBV = methylene blue value; Wopt. = optimum moisture content; OPN density = optimal Proctor normal density; SS = soluble sulfate.

Table 3 shows that recycled sand has a low initial moisture content, which is important for soil reuse in earth-based materials. The region of Brittany has higher rains, due to which soils have a higher moisture content, and it is difficult to decrease it. The lower water content of sand helps to balance the moisture content of the mixture. The MBV value of recycled sand is also very low due to the lower percentage of fine particles, and the GTR classification of recycled sand is D1 [24]. The higher sulfate content of 0.5% in recycled sand results from gypsum plaster in construction and demolition waste. A higher sulfate content in concrete and road materials leads to swelling issues due to associated reactions of cement with sulfate [39]. The optimum moisture content of recycled sand is 8.6%, which is within the typical range of optimum moisture content for common sands.

3.3. Characteristics of Compressed-Earth Blocks

3.3.1. Dry Density (ρ)

The dry density of earth bricks was determined using the dry mass and volume of compressed-earth blocks. The density values of earth blocks manufactured with different formulations are summarized in Table 4.

Table 4. Dry density (kg/m^3) of compressed-earth blocks.

Soil	Raw Soil	Fine Soil	Restructured Soil
Bruz	1698	1697	1657
Lorient	1874	1654	1746
Polama	1781	1162	1638

Table 4 shows that the dry density of compressed-earth bricks varies between 1654 kg/m^3 and 1874 kg/m^3, which is within the common density range of compressed-earth bricks. The density of earth bricks is highest for raw soils due to higher percentage of coarser particles when compared with fines and restructured soil. Lorient soil has the highest density, and Bruz soil has the lowest. The density of soil decreases with increasing clay content. The dry density of compressed-earth blocks varies significantly, and it usually varies from 1500 kg/m^3 to 2000 kg/m^3 [40]. The density of bricks decreases for the earth blocks manufactured only with fines. However, restructuring of fines with recycled sand increases the density of the earth bricks. The mechanical strength of earth bricks is strongly influenced by their dry density, and the strength of earth bricks increases with increasing density [36].

3.3.2. Linear Shrinkage (LS)

Linear shrinkage of compressed-earth blocks was measured to observe the shrinkage in earth bricks with different formulations. Table 5 shows the linear shrinkage in different earth brick samples.

Table 5. Linear shrinkage (%) in earth bricks.

Soil	Raw Soil	Fine Soil	Restructured Soil
Bruz	2.1	4.7	3.5
Lorient	2.5	3.8	2.9
Polama	1.9	3.8	1.3

The linear shrinkage of earth bricks with raw soil varies between 1.9 and 2.5%. The linear shrinkage is highest for fine soils, and its value reaches 4.7% for Bruz soil, which is considerably higher than the recommended shrinkage in French standards [33]. A higher clay content in fines leads to higher shrinkage and makes this material unsuitable for earthen construction. In the case of restructured soils, linear shrinkage in bricks decreases, and its value is in between raw and fine soil.

3.3.3. Flexural and Compressive Strength

The flexural strength of bricks was determined with a three-point bending test on prismatic specimens, followed by compressive strength tests on cubic specimens of 4 × 4 × 4 cm. The compressive and flexural strength of the earth bricks is shown in Figure 7.

Figure 7 shows that the compressive strength of Bruz soil is low, while for Lorient soil, its value is highest in raw form. The compressive strength for raw and fine Polama soils is similar. Lorient bricks have the highest compressive strength in raw form. The flexural strength of earth bricks varies between 0.3 and 0.8 MPa. Low strength in bricks made with fine soils compared to the restructured soil is due to absence of coarse particles in the soil skeleton. Clay acts as a binding agent; however, the presence of sand and gravel is essential to achieve good strength and avoid deformation [41]. Flexural strength variation from raw soil to fine and restructured soil is random. It is highest for Polama soil and lowest for Bruz soil. Recommended flexural strength varies in different norms and is usually between 0.25 and 1 MPa [33,42].

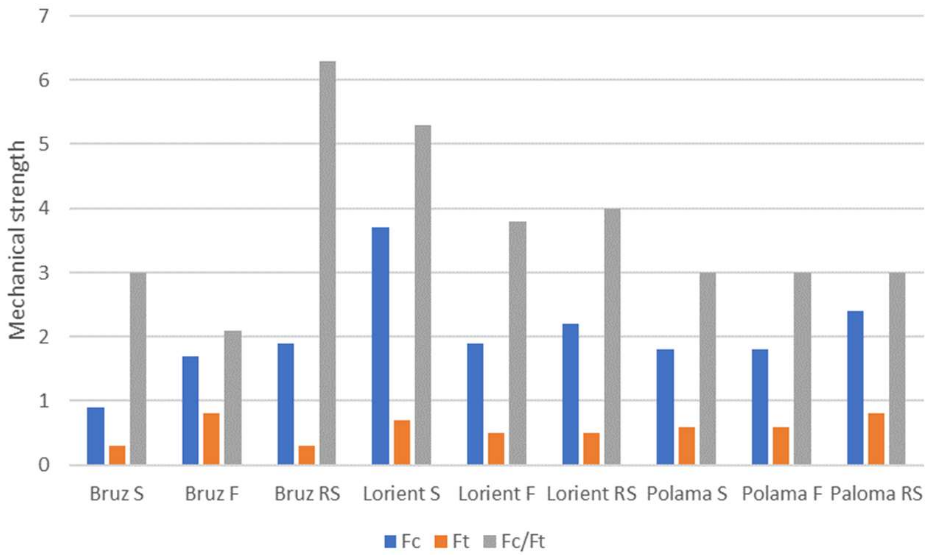

Figure 7. Flexural and compressive strength (MPa) of earth blocks. Note: S = raw soil; F = fine soil; RS = restructured soil; Fc = compressive strength; Ft = flexural strength.

Compressive strength for raw soil varies from 0.9 MPa to 3.7 MPa. In the case of fine soil, compressive strength varies between 1.7 and 1.9 MPa. Soil composition in the case of fines is less suitable for earth bricks as the soil matrix lacks sand and gravel. Restructuring of fine soil increases its compressive strength, and it varies from 1.9 to 2 MPa. The compressive strength of earth blocks recommended in international standards and the literature varies between 1 and 2.5 MPa for structural and nonstructural applications [33,36,42]. The compressive strength is highest for Lorient soil. The reddish color of Lorient soil shows the lower kaolinite content. In Brittany soils, kaolinite is commonly found in most of the soils. Kaolinite-rich soils have lower strength as their specific area is small [36]. Fine soils have lower strength, and they have durability issues due to higher clay content. The addition of recycled sand increases the mechanical strength of earth blocks and improves soil behavior. The restructured soils are within the suitable zone in GTR with lower susceptibility to water, shrinkage and swelling.

4. Conclusions

In this study, the physico-chemical characteristics of excavated soils such as granulometry, Atterberg limits, organic matter and optimum moisture content were determined to evaluate their potential for reuse in compressed-earth blocks. The percentage of fine particles in Lorient, Bruz and Polama soils is around 40%, 28% and 65%, respectively. Lower percentage of fines in Bruz soil (less than 30%) makes it suitable for wet processing to separate coarse and fine particles by washing. Due to higher percentage of fine particles, Polama soil is undesirable for wet processing. The investigated soils have low organic matter, which is around 4 to 5%. Bruz soil has a higher sand content, while Polama and Lorient soil have higher fine (smaller than 0.063 mm) content. The characteristics of recycled sand were also investigated, showing that it has a lower percentage of fine particles. Quartz, albite and microcline are the dominant minerals in recycled sand.

Earth bricks were manufactured with three types of material, namely raw earth, fine soils and restructured soil with the addition of 15% recycled sand. Earth bricks with raw soil samples have the highest dry density and the lowest shrinkage. Lorient soil has the highest compressive strength due to its suitable granulometric structure as this soil has nearly equal amounts of fine and coarse particles. The strength and density of fines is lowest while linear shrinkage is highest in these bricks. The absence of sand in the soil matrix decreases the soil strength and its density and increases the shrinkage. Restructuring of fines with the addition of recycled sand improves the strength and density and decreases the shrinkage of earth bricks. Lorient soil in raw form has the highest compressive strength of 3.7 MPa. Restructured Lorient and Polama soils have strengths higher than 2 MPa, which meets the strength requirement for earth bricks. Lorient and restructured Lorient and Polama bricks have higher dry density and higher mechanical strength and are less susceptible to shrinkage and swelling according to French norms [24]. This study demonstrates that Brittany soils in raw form can serve as a potential resource to produce earthen construction blocks. The fine fraction obtained from washing the excavated soils shows higher shrinkage, which is undesirable for their reuse in earth-based materials. The strength of bricks with a higher percentage of fine particles is also considerably lower. Restructuring of fine particles shows considerable improvement in terms of strength and shrinkage, thus presenting a promising strategy to improve the granular skeleton of soils and their suitability for earthen construction materials. Furthermore, the durability of these materials should be tested to observe their long-term performance.

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