

Article

Clay-Based Products Sustainable Development: Some Applications

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Abstract: Clay has a low environmental impact and can develop into many different products. The research presents two different case studies. In the first, the clay is the binder of raw earth doughs in order to produce clay-bricks. We investigate the effects of natural fibrous reinforcements (rice straws and basalt fibers) in four different mixtures. From the comparison with a mix without reinforcements, it is possible to affirm that the 0.40% of basalt fibers reduce the shrinkage by about 25% and increase the compressive strength by about 30%. Future studies will focus on identifying the fibrous effects on tensile strength and elastic modulus, as well as the optimal percentage of fibers. In the second study, the clay, in form of brick powder (“cocciopesto”), gives high alkaline resistance and breathability performance, as well as rendering and color to the plaster. The latter does not have artificial additives. The plaster respects the cultural instance of the original building. The research underlines how the use of a local (and traditional) material such as clay can be a promoter of sustainability in the contemporary building sector. Future studies must investigate further possible uses of clay as well as a proper regulatory framework.

Keywords: sustainable architecture; traditional materials; clay; low footprint; raw earth; brick powder; fibers stabilizer; natural mortar; basalt fiber; volcanic aggregate



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1. Introduction

The last few decades have been characterized by the progressive growth of energy demand and consequent depletion of the planet's material reserves and production of waste. In terms of energy, in 2019 there was a growth of demand of 1.3% compared to 2018 [1], which in turn stood out for the highest increase since 2010/11 [2].

In particular, the construction department absorbs about 40% of the final energy demand, a percentage that continues to grow annually (1% compared to 2018, 7% compared to 2010) [3]. These evaluations are comparable to what emerges from a European analysis [4], which underlines also the contribution to greenhouse gas emissions (equal to 36%) and to the production of waste (equal to 50%). These data lead to important reflections considering that the European building stock is inefficient for more than 75% and characterized by age (35% of the buildings are over 50 years old, 85% are over 20 years old). In Europe, the weighted annual energy renovation rate is lower than 1% (member State rates vary from 0.4% to 1.2%) [4].

To act on the built environment is numerically significant. The so-called “Renovation Wave” is considered the most effective cost–benefit strategy for achieving the Paris Agreement. In fact, it could reduce the EU's total energy consumption by 5–6% and lower CO₂ emissions by about 5%, as well as create around 160,000 new green jobs [4–6].

The current methods of assessing the quality and environmental impact of the built environment focus on energy consumption and emission of pollutants that buildings cause during their period of use. However, a building is an open system, in constant energetic, material, social and economic dialogue with the environment, not only during

its period of use. Therefore, to act on its energy performance means to systematize this dialogue analyzing it throughout its life cycle. It must include the energy costs of extraction, transformation, transport and even possible recycling or disposal after the death of the raw materials, as well as of construction, maintenance and use of the building [7]. The implementation of an LCA highlights that the use of sustainable materials reduces the building's carbon footprint index after retrofit compared to standard materials, as seen in the case studies in the Mediterranean area [8–11]. In line with the previous studies, the results demonstrate that the energy consumed by buildings is largely deriving from the production of materials, their extraction, treatment and finally their waste.

Therefore, in a sustainable supply chain perspective, in addition to the usual performances (functional, aesthetic, thermo-hygrometric), a building material must be easy to find and work with. It also should come from recycling activities and be itself recyclable, with high durability and maintainability, non-toxic and non-polluting. Such features can be found in the vernacular materials. These were natural and local resources, inherently sustainable. In fact, the vernacular communities adopted materials suitable for the territory in order to ensure their own survival. Even traditional materials, linked to the know-how of ancient guilds, have similar characteristics because of the limited means of transport and industrialization, as well as the absence of a global market. Each corporation promoted a specific local material in the use of which it was a master. Compared with industrially produced materials, which possess a very high embodied energy, the vernacular ones present low environmental impacts [12]. Lately, the interest in these materials has increased considerably because, in addition to the environmental advantages, they allow social and economic benefits since their local production has lower costs, also creating jobs [13]. However, the growth in the diffusion of these materials was not accompanied by an adequate standardization process. Therefore, the testing protocols of vernacular (and nonconventional) materials are fragmented and in their earliest stages, even among experts [14].

Among these materials, there are also clay and some of its derivatives. Clay is one of the first materials that man was able to model, whether it was to produce tools or buildings. Over the centuries, countless products and techniques have been developed. Still today it is a core element of innovations in the field of nanotechnologies. However, past techniques are also at the center of investigations that aim to understand traditional know-how. In the latter case, the panorama of results can be more articulated and fragmented. This is because there is no commonly accepted regulatory framework.

This research fits into this fragmentary panorama and presents the results of two different case studies with clay materials. In both, traditional techniques are analyzed and harmonized with the material peculiarities of the Etna area. The first research investigated the effect of basalt fibers (BFs) on the compressive strength of raw earth mixtures to produce clay bricks. In particular, we compared two types of fibrous reinforcement (rice straws and basalt fibers) through compressive tests on cubic specimens. Based on the knowledge of the authors, the use of BFs as reinforcement of raw earth has no precedent. Therefore, the study expands the list of fibrous stabilizers of raw earth mixtures. In the second study, we developed a specific plaster for a historical building subject to aggressive marine aerosol. We used the powder obtained from broken bricks and tiles, destined for landfill, as aggregate. This last aspect is relevant since the construction waste is composed mainly of bricks and concrete elements [15–17]. The aim was to limit the free lime in the dough, through the clay component. Furthermore, since it was a restoration, the new plaster had to comply with the rendering and colors of the built heritage. The novelty of the research lies in creating a plaster faithful to the original materials, but with better hydraulic performance, without the use of artificial additives.

These aspects highlight the sustainability of the cases examined, as well as the potential of combining clay with traditional techniques and local materials.

2. Spontaneous Available Solutions

2.1. Vernacular Architecture

In addition to the search for new technologies, it is necessary to look at the past and at the techniques unconsciously developed by the ancestors, in a renewed perspective. The ability to adapt to climatic condition is spontaneously present in animals: think of the hibernation of bears (reduction of metabolism), the micro-bubbles that birds trap in their feathers to isolate themselves as well as the genial nest of the compass-termites. This last case shows how the application of simple physical principles, making use of the resources that nature makes available, allows maintaining constant internal temperatures despite the important external temperature range. This attitude to construction is not unknown to man, but it eclipsed with the appearance of the standardization of the house promoted by the, i.e., International Style.

Vernacular architecture is a spontaneous, uneducated architecture, which bases its design on local needs, materials and traditions. Beyond the fascinating debate regarding the aesthetic intentionality of vernacular architectures [18], it is interesting to notice how in past centuries man, despite the absence of cultural connections, responded with the same design solutions to similar climatic stresses. However, each solution is unique and identifies the place and time in which it arises. Thus, in hot dry climates, we find massive architectures, with light colors, reduced openings, screened and permeable to air, and internal courtyards with fountains. In cold climates, we find airtight casings, with few openings except to the south in order to maximize solar gain. In rainy areas there are sloping roofs, protruding from the walls. In areas with strong winds, instead, the buildings are oriented to present a minimum area in the direction of the prevailing winds.

The type of structure and the materials used also depend on the function of the building: mobile structures will be lighter and easier to disassemble. The design response was not only morphological, but also social and economic [18–20].

The roles of the client and the designer progressively parted over time. This led to the introduction of non-local and refined materials, in order to demonstrate the client's wealth. Apart from specialized architecture (palaces and churches), users are still mostly local, and their construction is entrusted to the local corporations. Later, the possibility to generate profitable monetary returns, together with the industrialization of the building process and the theories of the modern movement, led to productions far from the individual local realities and needs. Another inevitable consequence of that has been the legitimate conquest of new technologies and the birth of higher-level professional figures. On the other hand, most of the traditional techniques and know-how passed down orally are now lost.

Today, in view of the new sustainability needs, vernacular architecture is not seen simply as a style, but rather as a document/testimony of historical technologies, from which it is still possible to learn [18–20].

2.2. Design Strategies

Contemporary designers can learn a lot from their ancestors about the different forms of sustainability (environmental, economic, social and cultural). In general, climatic factors and local emergencies should be considered resources rather than limits. The analysis of the morphology and of macro and microclimatic factors can guide the design solutions. A building, if properly designed, can capture and convey the energy obtained from the natural climatic resources of the site, through "active" (AcS) and "passive" (PsS) systems. [21] The AcS are well-known and constantly expanding (photovoltaic solar panels, thermal solar panels, wind microturbines, geothermal probes, etc.). The PsS aims to ensure internal comfort (thermal and light) in order to reduce the energy requirements of the installations. Whether it is solar gain or summer cooling, these systems influence: the orientation of the building and its shape (the ratio between the dispersing surface of the envelope and the heated volume bounded by it), the layout and the number of transparent surfaces, therefore the type of shielding, the arrangement of the openings to favor natural ventilation, even the

thermal capacity required by the envelope. In the case of new construction, these aspects can be easily implemented thanks to the ever-increasingly efficient software. In the case of building recovery, especially if it is restricted, the introduction of such systems can be more complicated but not impractical, as demonstrated by the retrofit interventions that involve both the envelope [22] and the internal lighting comfort [23]. In these cases, due to the impossibility to change the geometries, it is possible to intervene on materials. In particular, by modifying their capacities and thermal inertia also through additive strategies such as coats [22,24] or green roofs [25–27].

It is evident that the materials used are essential for the correct functioning of these systems and more generally for the perceived comfort in indoor environments. The more similar interventions are virtuous and effective, the less impactful the materials are. Furthermore, a local material (whether vernacular, traditional or new) can intrinsically satisfy economic sustainability due to its territorial availability and capacity to generate work [13,28]. In discovering (or rediscovering) unconventional materials, however, we often encounter technical and application difficulties due to the absence of standardized production and of use and certification procedures. For these reasons Giuffrida [29], while speaking of raw earth, suggested that the reduction of the environmental impact must be pursued from a supply chain perspective. That means, choosing solutions or new technologies that involve low energy consumption and low emissions in the stages of production, use, management and end of life. Moreover, the improvement of recycling and the creation of virtuous production circuits can lead to a circular economy model suited to the sustainability principles pursued [30,31].

Therefore, in the case of new or rediscovered materials, the performance approach requires verification of the reliability, stability of yield and production processes [32]. An internal protocol was therefore outlined in both pieces of research to guarantee the systematic repeatability of the approach methodology. This approach is based on the study of the past from which to draw the directions of application and development to be followed in contemporary research. For this reason, in the next paragraph, we will analyze the past uses related to clay and only later the current variations.

2.3. Clay and Brick Powder—Lesson from the Past

Studying the use and declinations of a material in the past, it is possible to outline its potential and limits. However, it is impracticable, as well as dispersive, to retrace the history of clay since its temporal and spatial extension. From the beginning of its history, in the transition from nomad to sedentary, man has learned to model silts and clays of the rivers. Thanks to the cohesion given by the clay minerals, the soils deprived of their coarser parts were mixed with water, shaped and dried. The craftsmanship of this construction process led to the development of specific construction traditions, techniques and variations, in different parts of the world determined also by the different mineralogical and granulometric composition of the soils. This makes raw earth architectures “universal and different” as suggested by Houben and Guillaud [33] and highlighted by archaeological finds as well as by architecture (vernacular and monumental).

In the use of clay, another relevant process is the burning phase. Depending on the temperatures (573–1323 K), the finished product, whether it was a brick, a tile or an amphora, took on different characteristics. Beyond the great use in the artistic field, as revealed by the archaeological findings, the crushed and finely ground terracotta was used as an aggregate in the production of mortars and plasters since ancient times [34]. The mortars thus obtained were used above all for aqueducts, thermal buildings, cisterns and terraces, due to their almost impermeable (pozzolanic) behavior and mechanical performance [35,36].

The uses and characteristics of clay products derive from their chemical and mineral nature. Clay minerals belong to the Phyllosilicates class, due to their tabular habit. As explained by Fratini [37], this geometry derives from stacked states of siliceous planes/sheets alternating with aluminous planes/sheets. The combinations of these crystalline structures,

the possible isomorphic substitutions and the possible insertion of ions and water molecules are all factors that can lead to extremely different clayey systems in chemical composition. A negative layer charge can be created by the non-equivalent isomorphous substitution of central atoms in the octahedral or tetrahedral sheets. This layer is compensated by hydrated exchangeable inorganic cations. Their high affinity to water imparts hydrophilic character which can be changed to hydrophobic by replacing them with organic cations [38]. Despite this vast chemical articulation, the structure of clays (and consequently most of its physical properties) was classified [39] according to the sequences between the fundamental units O and T.

Below 1073 K, heat treatment destroys the crystalline structure of the clay, generating amorphous pozzolanic substances such as metakaolinite [40]. This is commonly accepted as the most active mineral of the pozzolanic activity although other minerals such as illite, kaolinite and muscovite show that activity [41]. The effectiveness of the thermal activation process depends on many factors such as calcination temperature, particle size and shape, time and others [40]. In particular, the temperature can significantly affect the activation process. When too high temperature the melting of minerals and their recrystallization generate phases, which do not react with the cement hydration products. On the other hand, in the case of too low temperature, there is no pozzolanic activity due to the incomplete dehydroxylation [40]. Amorphous substances, mostly aluminosilicates, react with lime to produce calcium silicate hydrate and/or calcium aluminate hydrate at the brick–lime interface and the pores of the bricks [34,41]. The formation of these interlocking crystals improves the strength and increases the hydraulicity of lime mortars with brick powder. However, a more detailed discussion of the property and structure of clay minerals is beyond the scope of this research.

Understanding these techniques allows us to outline their possible declinations in line with current technical needs.

3. From Past to Future—How Is It Possible to Use These “New” Materials Today?

Since the 1970s, with the “oil crisis” and the growing debate stemming from the limits of growth [42], many designers have rediscovered the potential of clay-based products. In particular, clay nanocomposites have been studied extensively due to their ability to improve wellbores stability during the drilling process of unconventional reservoirs [43–48]. Moreover, the adsorption capability of natural clay can be used for the recovery of Rare Earths, key components in electronic devices [49]. This result is important since on the one hand, electric and electronic wastes are the fastest-growing ones in the world. On the other hand, Rare Earths demand increase with the spread of technologies.

It is well known that there are no ecological materials in an absolute sense, given that environmental “performance” is a function of countless variables: geographical context, (energy and material) production, application in the building, operating conditions, duration of performance over time (obsolescence). Therefore, when we talk about environmentally friendly materials, we refer to those materials that generate minimal impacts on the environment in terms of both the consumption of resources and the production of waste and pollution. To these materials it is, therefore, necessary to associate the research of the so-called “eco-efficiency”, that is the improvement of the performances with equal or lower environmental impact.

We have seen how with technological progress raw earth and brick powder (cocciopesto) have been gradually supplanted by standardized products. This places us before a reflection. On the one hand, we have witnessed a loss of the traditional know-how linked to these materials, with important repercussions in the field of protection and conservation of the built heritage. The exact formulation and use are not functional to recreate historical fake, but to understand the possible interactions–repercussions and to be able to intervene in compliance with the historical stratifications. On the other hand, it highlights the performance or production problems that have partially excluded them from the global market. Although they have not completely disappeared, appearing punctually in case of specific

needs. An emblematic example, in the case of raw earth, is provided by the post-war reconstruction of Germany. The restrictions period led to the reuse of the pisè technique (stampflehm in German) due to the wide availability, easy use and speed of installation of raw earth. [50] In that case, possible implementations of the traditional technique were studied, such as the use of clay tile in place of the classic formwork.

This example shows that the dialogue between past and present is possible. Therefore, research must concentrate both to recreate lost knowledge and improving the expected performance of both the single material and the possible techniques in the view of contemporary use of them

3.1. Clay—Raw Earth

A major critical issue of raw earth is its mechanical resistance. Depending on the use, the mixture must respond to different needs and stresses, therefore it has different percentages of clay, silt and sand. Even referring only to the adobe technique in the literature, it is possible to find an extremely wide range of compressive strengths.

According to Achenza [39], the uniaxial compressive strength of raw bricks in the dry state determined in the laboratory is between 1 and 3 MPa. The last value drops to 2 MPa in the research of De Francisci [51]. The investigation conducted by Ioannou et al. [52], reports literature values within a range between 0.6 MPa to 8.3 MPa, with a greater distribution between 0.8 and 3.5 MPa. In Korjenic [53], for unstabilized soil, the values fluctuate between 0.60 and 2.25 MPa, but it can increase up to 3 MPa in the case of compaction (manual or mechanical). Similar parameters (0.75–2.25 MPa) [54] are presented in another research on the optimization of the compressive strength of clay.

This wide range of results refers only to non-stabilized doughs. The mechanical performance obtained with stabilization depends on the type of process and stabilizer used, as well as its percentages in the mix.

Doat et al. [55] identify four different ranges according to the type of stabilizer: 5–10 MPa in case of cement, 3–8 MPa with lime, 1.5–6 with bitumen and 2–4 MPa with generic resins. Cement is one of the most investigated stabilizers. By varying the percentage, up to maximum use of 10%, the compressive strength reaches 4–5 MPa [56,57], furthermore, if combined with mechanical compaction, it can be increased by 70% [57]. By combining lime and cement, instead, there is a decrease in the resistance range from 3.5–5 MPa to 2.6–3.6 MPa [54]. Even the use of lime alone leads to an improvement compared to non-stabilized mixtures [54] thanks to the formation of hydrated calcium silicate from the reaction of lime and quartz [58].

Many examples of research experiment with the use of other local stabilizers such as coal ash and cassava peel (in which it emerged that the addition even just of the peelings can be harmful) [59], industrial waste, even potentially harmful (phosphoflex and blast furnace slag to make reach between 2.8–4.4 MPa) [60], vegetable fibers and waste from agricultural production [61]. In the case of fibrous reinforcements, the range foreseen by Doat et al. [55], between 0.5 and 2 MPa, is not totally true. Sawdust, tobacco residues and grass can reach values between 2.6 and 5.10 MPa [61]. An important contribution is that of Quagliarini who investigated mixtures reinforced with straw on two families of specimens distinguished by size [62].

Therefore, the benefit of the use of fibrous reinforcements must always be verified and not taken for granted. As mentioned, this vast and fragmented panorama of results is difficult to read. The causes are linked to the intrinsic heterogeneity of the subject, but also and above all to the absence of a globally accepted framework of testing procedures. This also emerges from the reviews by Delgado et al. [63] e Cid [64]. To this end, this study aims to create a system of data that could be a valid starting point for future researches.

3.2. Clay—Lime and Brick Powder (Cocciopesto) Mortars

Most construction and demolition waste (CDW) consist of concrete and clay-bricks [65,66]. The enormous quantities of waste produced annually represent an environmental problem,

in relation to storage and soil contamination. Therefore, many pieces of research aim to evaluate the reuse of CDW and, more specifically, clay-brick, as an environmentally and economically friendly strategy. Brick wastes can be crushed to obtain clay brick powder (CBP). The latter can be used as aggregates to produce mortars, cements and concretes [65,67]. The extraction of aggregates, in fact, is considered one of the main consumers of natural resources [67]. In Nasr et al. [67] the effects of brick dust on the physical–mechanical properties of paste, mortar and concrete are analyzed. The study shows that there are conflicting results in terms of positive and negative impacts on different characteristics. However, in general, replacing cement with CDW leads to a reduction in the compressive strength of the mixture. Abd-Elmoaty et al. [65] state that the use of recycled aggregate and dust made of clay bricks is promising in many applications where the thermal resistance, cost and environmental aspects are imperative. Their study indicates that the main obstacles to the use of CBP are the absence of proper legislation and the absence of well-recorded experiences. The results instead show that the CPB improves cement paste structure. It also reduces volumes and the number of pores. When used as an additive, and not as a substitute for cement, it results in a slight improvement in compressive strength. Zhang’s results [66] indicate that due to its high porosity, water absorption and low density, CBP has negative influences on the quality of the concrete in terms of consistency, workability, mechanics and durability properties of the final product. However, CBP has pozzolanic properties that improve the durability of concrete such as resistance to attack by sulphates and the mitigation of the alkali–silica reaction.

These considerations constitute an authoritative starting point in the elaboration of plasters with CBP. In the field of environmental restoration, an important role is played by historical buildings’ facades. In fact, they underline spaces, volumetric ratios, stylistic and decorative characteristics of each building. They determine the landscape connotation of the built environment in relation to the geographical characteristics. The chromatic structure of a historic building is a recognizable value to be safeguarded, communicating the cultural identity of a city [68].

In the past, plastered facades were frequently replaced, as they were considered a surface of sacrifice. Therefore, they were removed when they were no longer able to fulfill the function of protection and aesthetic finishing. The scientific community, in Italy initially, then in other parts of the world, has understood that the surface records the change and passage of time: it must be preserved through a critical process [69]. The ancient state of matter is unattainable [70], because of the difficulties to recover the traditional execution techniques, but it is possible to identify the mineral matrices through the study of local stone. This is possible because the historical construction materials are linked to the geological nature of the territory in which they insist. For these reasons, research on the use of *cocciopesto* as an aggregate does not aim at defining a standard plaster, valid for all applications. The chemical, mechanical and even chromatic implications are studied in the different application cases. A special mention to those researches which use clay and ceramic waste as aggregates underlining their technical and environmental advantages, as we can see in the review by Matias [71].

The history of a city is narrated through the materials used for its construction, especially in those places characterized by a strong landscape such as the volcanic one: here the use of basaltic stone and clay has motivated the experiences that are discussed in the next chapters.

4. The Experiments: Raw Earth Stabilized with Basalt Fibers

4.1. Materials and Mixes

The present study investigates the effect of basalt fiber on the compressive strength of earth blocks. A comparison between four different mixes was made in order to estimate the contribution of the fibers. The different mix designs were developed starting from a basic raw earth formula. Two different natural fibrous reinforcements were added to that formula: rice straw (RS) and basalt fibers (BFs). The different mixes are so identified: a

standard one without fibers (nTC), a mix with RS (nLC), a mix with 0.40% of BFs (nB04) and a mix with 2% of BFs (nB20). All mixes present a clay-inert volumetric ratio equal to 1:3. Basaltic sand (so-called “azolo”) was used as inert. It is easily available, and it has a well-known and ancient tradition of use in the Eastern area of Sicily, because of the presence of Mount Etna. The inerts were also divided into two groups by their size, coarse and fine, in a ratio of 2:1. The different mixes are reported in Table 1. We obtain the nLR mix by adding 0.40% of the total dry weight of rice straw to the nTC mix. The same amount of BFs was used in the nB04 mixture. The nB20 has a BFs quantity five times bigger.

Table 1. Mixes investigated: materials and quantities.

| Mix. | Component | Size [mm] | Nominal Volume | Weight [kg] | %Dry Weight | %Weight |
|-------|---------------|-----------|-------------------|-------------|-------------------|---------|
| n TC | Volcanic Sand | 0–4 | 2 | 4.75 | 54% | 47.0% |
| | Volcanic Sand | 0–3 | 1 | 2.22 | 25% | 22.0% |
| | Clayey earth | 0–2 | 1 | 1.83 | 21% | 18.0% |
| | Water | | 1 | 1.32 | - | 13.0% |
| n LR | Volcanic Sand | 0–4 | 2 | 4.75 | 54% | 46.8% |
| | Volcanic Sand | 0–3 | 1 | 2.22 | 25% | 21.9% |
| | Clayey earth | 0–2 | 1 | 1.83 | 21% | 18.0% |
| | Water | | 1 | 1.32 | - | 13.0% |
| | Rice straw | | 0.4% ¹ | 0.035 | 0.4% ¹ | 0.3% |
| n B04 | Volcanic Sand | 0–4 | 2 | 4.75 | 54% | 46.8% |
| | Volcanic Sand | 0–3 | 1 | 2.22 | 25% | 21.9% |
| | Clayey earth | 0–2 | 1 | 1.83 | 21% | 18.0% |
| | Water | | 1 | 1.32 | - | 13.0% |
| | Basalt fiber | | 0.4% ¹ | 0.035 | 0.4% ¹ | 0.3% |
| n B20 | Volcanic Sand | 0–4 | 2 | 4.75 | 54% | 46.2% |
| | Volcanic Sand | 0–3 | 1 | 2.22 | 25% | 21.6% |
| | Clayey earth | 0–2 | 1 | 1.83 | 21% | 17.7% |
| | Water | | 1 | 1.32 | - | 12.8% |
| | Basalt fiber | | 2% ¹ | 0.176 | 2% ¹ | 1.7% |

¹ Percentage evaluated on the total dry weight of the mixture.

More specifically, we used Florida’s earth, from nearby Syracuse (about 60 km away) as a clayey binder. The granulometric analysis provided by the manufacturer is in line with [72] Caponetto’s measurements, and is reported in the following tables (Table 2).

Table 2. Granulometric analysis: sieving and sedimentation.

| Sieve | Passing | Eq. Diameter | Passing | Eq. Diam. | Passing |
|--------------|---------|--------------|---------|-----------|---------|
| 16.000–4.000 | 100% | 0.06777 | 64.5% | 0.00332 | 15.7% |
| 2.000 | 99.2% | 0.05051 | 52.6% | 0.00255 | 12.7% |
| 1.000 | 96.2% | 0.03594 | 51.1% | 0.00156 | 9.1% |
| 0.500 | 92.4% | 0.02603 | 45.1% | 0.00717 | 27.4% |
| 0.250 | 83.4% | 0.01862 | 42.2% | 0.00514 | 21.8% |
| 0.125 | 76.0% | 0.01379 | 39.0% | 0.00332 | 15.7% |
| 0.075 | 72.1% | 0.01008 | 30.1% | 0.00255 | 12.7% |
| | | 0.00717 | 27.4% | 0.00156 | 9.1% |
| | | 0.00514 | 21.8% | | |

The “azolo” derives from pyroclastic rocks produced by the eruptive activity of Mount Etna. As emerged from the analysis by Belfiore et al. [73], azolo clasts present a seriate porphyritic texture with vitrophyric to hyalopilitic groundmass textures. It also exhibits phenocryst of plagioclase, augitic clinopyroxene, Ti-magnetite and olivine, in decreasing order of abundance, as well as crystalline aggregate of mafic and felsic phase. The “azolo” is widely used in the Eastern area of Sicily, especially in the production of mortars [74,75].

Its granulometry varies over a range up to 20 mm. In this study, the azolo was screened in two distinct ranges: 0 to 4 mm and 0 to 3 mm. The basaltic sand was supplied by a quarry, located in Belpasso. Its chemical characterization is reported in Table 3.

Table 3. “Azolo” chemical characterization.

| Component | Quantity |
|--------------------------------|----------|
| SiO ₂ | 45.90% |
| Al ₂ O ₃ | 20.43% |
| CaO | 10.22% |
| Fe ₂ O ₃ | 9.99% |
| MgO | 4.71% |
| Na ₂ O | 4.02% |
| TiO ₂ | 1.44% |
| K ₂ O | 1.35% |
| P ₂ O ₅ | 0.48% |
| MnO | 0.15% |

Rice straw is a by-product of rice cultivation. From a chemical point of view, it is mainly made up of cellulose, lignin, minerals and silicates. It is distinguished from other straws by the high concentration of silica, which gives high performance in terms of durability and resistance to rot and mold. Generally, the use of rice straw aims to increase thermo-hygroscopic performance. As hemp fiber, rice straw modifies the geometry of the pore network which has important repercussions on hygrothermal processes of raw earth dough, as emerges from the review by Giuffrida et al. (2019) [21]. Another advantageous aspect is the low energy cost of its production (in terms of CO₂ emissions). Rice straw, as a plant, also contributes through the photosynthesis process to absorb the CO₂ present in the atmosphere. Furthermore, since it is a production waste, it does not further impoverish the planet’s reservoirs.

Basalt fibers derive from a melt spinning process of acidic basaltic rocks, without any other additives [76]. These rocks are characterized by a Silica (SiO₂) content higher than 46%. Higher percentages further enhance mechanical fiber properties [77]. These fibers can have about 30,000 different uses according to a 2019 estimate [78]. In particular, one of the main fields of application is composites materials. In recent years, fiber-reinforced polymers (FRPs) arouse more interest due to their mechanical and chemical performance. For these reasons, the characteristics of basalt fibers are often compared with glass fibers. The latter are in fact the ones most used in the production of FRPs. Study attest that modulus and strength values of basalt fibers are between E- and S- glass fibers [77,79]. Moreover, BF has countless advantages: considerable physical and chemical stability, excellent tensile strength and good compressive strength, high flexibility, excellent strength to weight ratio, dielectric properties, high quality thermal and acoustic insulation, incombustibility and high resistance to heat and explosion. Furthermore, it is a totally natural product, not harmful to health and reusable. The materials are presented in Figure 1.

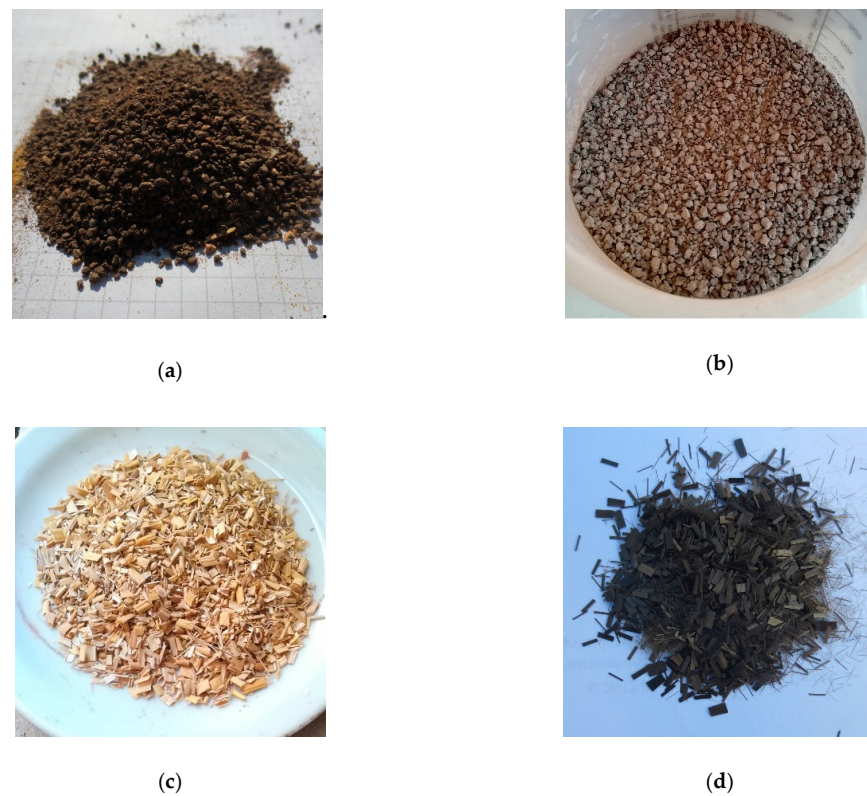


Figure 1. Materials used: (a) Florida's Earth; (b) "Azolo"; (c) Rice straw panel; (d) Basalt fibers.

4.2. Methodology

In order to consider the heterogeneous nature of mixture, to determine the size of the specimen, we respected the criterion [80] (coded for concrete) that requires the minimum size to be at least 7–10 times the size of the largest aggregate used. For each mixture, 4 cubic specimens of 100 mm side length were provided.

The production of the specimens required the first phase of experimentation in order to determine the quantity of water and the appropriate molding. The amount of water used in the production, in fact, is one of the main factors that influence the dry compressive strength and the shrinkage of earthen building materials [53–55]. In this phase, we analyzed two different amounts equal to 9% and 14% of the total dry weight. We recorded a loss of integrity of the specimens at the moment of removal of the formwork (Figure 2). To solve the problem, we tested both the formwork's preparations and the dough resting time. In fact, a time longer than 24–48 h increase the phenomenon of dough–mold adhesion.



Figure 2. Some documented cases of loss of integrity, despite the following treatments: (a) sanding; (b) water film; (c) parchment paper.

After this stage, we decided to interrupt the study of the doughs with 9% water because they are less performing mechanically and trickier to package. In addition, we developed a standard procedure for mold preparation, packaging and conditioning. The aim was to ensure both the integrity of samples and the comparability and repeatability of tests.

The molding process lasts 24 h and it is divided into 10 steps. Follows a maturation period in an open area and the measurements of the sample. The first six steps concern the preparation of the mixture; while the last four steps concern modeling and subsequent demolding. In particular, the mixing takes place in four stages: two dry and two wet. Once the two dry steps are completed, the procedure continues with those with water. In summary, we started by mixing binders and aggregates and then, as a more step, we added the fibers. Once mixed all the dry parts, we added half of the amount of water requested and we restarted to mix. Lastly, after appropriate quality control, we added the remaining part of the water and mixed it for the last time.

Two relevant phases to ensure the integrity of the specimens are the preparation of the formwork and its dismantling. The formwork is manually smoothed, cleaned with a dry cloth and it is greased with oil. To set the dismantling at 24 h from modeling avoids the creation of adhesions between the dough and the formwork. After demolding, ripening begins. The authors have set a 28-day period during which the specimens undergo periodic quality checks.

4.3. Preliminary Analysis

The specimens were left to dry for 28 days in a ventilated and suitably sheltered place. The specimens were turned upside down every 24 h for the first 5 days of maturation, to ensure exposure to the air of each face. During the ripening period, the specimens were subjected to quality controls and periodic measurements. Visual analysis and weighing of the individual specimens were performed daily (Figure 3a). The touch analysis and the evaluation of the shrinkage were performed on the 1st, 5th, 10th, 15th, 20th and 28th days (Figure 3b).



Figure 3. Measurements: (a) weight; (b) shrinkage.

Visual and touch analysis are part of a wider range of adobe production quality controls presented in the text by Achenza et al. [39]. Weight measurement is not part of the quality control procedures, unless specific density requirements. However, this is a necessary parameter for verifying the maturation according to the UNI 772:2015. The norm says that a sample must reach the condition of “constant mass” in order to be subjected to a compression test. This means that in two consecutive measurements, at 24 h, the mass losses must be within 0.2% of the total mass. For weight measurements, we used an ORMA (Italy) digital readout electronic scale with a tolerance of 0.1 g.

The length of the edges was measured with a Vernier caliper with a constant of 0.02. The transverse and longitudinal shrinkages were evaluated compared to the size of the formwork. Vertical shrinkage was assessed based on the heights measured on the first day, in order to consider possible leveling errors during the molding phase.

4.4. The Compression Test

The compression test was made at the Materials Testing Laboratory of the University of Catania, on the 28th maturation day. We use the mechanical servo-hydraulic press ADVANTEST-9 produced by ControlsGroup (Italy). The test machine has a maximum capacity of 1.00×10^5 N (Figure 4a). For the displacement evaluation, we used a linear transducer with a full scale of 10.0 mm and tolerance of 1.0×10^{-3} mm (Figure 4b).

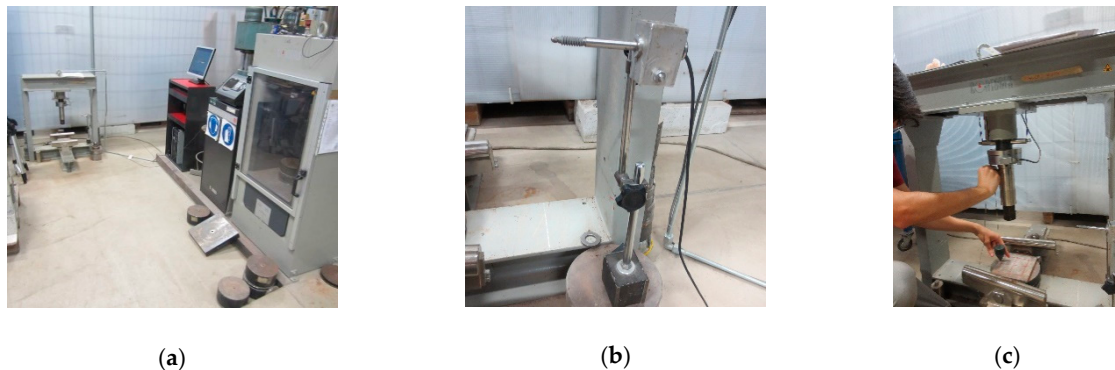


Figure 4. (a) Test machine; (b) Displacement transducer; (c) Alignment operation.

The preliminary centering operations were carried out with a plumb line every day of testing (Figure 4c). These were to ensure the alignment between the piston and the specimens, and to avoid other stresses than the uniaxial compression. Once the preliminary operations were completed, the test was set up through the program interface. The settings are reported in Table 4.

Table 4. Testing parameters.

| Parameter | Set |
|----------------------|---------------------------|
| Load speed | 100 N/s |
| Set point | 0.5 kN |
| Target | 35.0 kN |
| Peak sensitivity | 1.0 kN |
| Ramp offset | 1100 b |
| Proportional | 1.75 |
| Integrative | 0.2 |
| Max. correction- | 50,000 b |
| Max. correction + | 5000 b |
| Cross sectional area | various * mm ² |

Note: * The value varies for each specimen. Alternately it is possible set an average value and consider the correct one (for each specimen) during the post-processing data.

Once the program was set, the specimen was placed in the center of the press aligned with the compression load. After the positioning of the specimen, the transducer was fixed. This must be perfectly perpendicular to the pressing plate, otherwise, the shortenings could be overestimated, distorting the test. Additionally, the transducer was positioned as close as possible to the piston in order to be representative of the displacement of the specimen and not just of one edge. For this reason, Rovero [80] recommends using 4 translators: one for each edge of the pressing plate. The movement is recorded as a tensile displacement, because by pressing the specimen the plate moves away from the tip of the instrument decompressing it. The test continued in accordance with the instructions for the use of the hydraulic press.

4.5. Results

4.5.1. Dimensional Characterization (Shrinkage)

The diagram of the shrinkage over time shows an asymptotic behavior, characterized by a rapid and consistent variation in the first 5–10 days of maturation. The same behavior was recorded in the weight variation, as shown by the diagrams Figure 5.

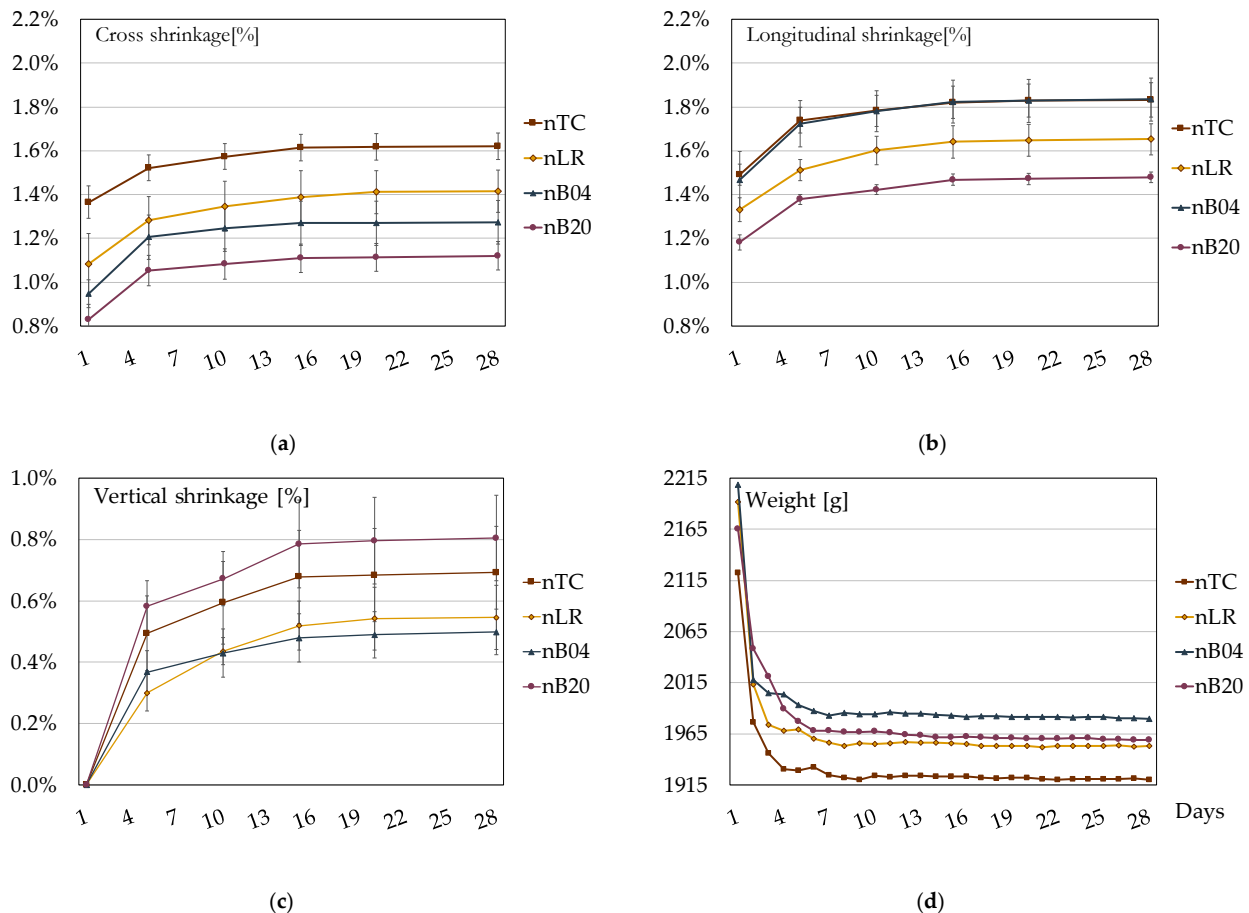


Figure 5. Variation diagram over time: (a) Cross shrinkage; (b) Longitudinal shrinkage; (c) Vertical shrinkage; (d) Weight.

The analysis of the data shows that the presence of the fibers significantly reduces shrinkage. Two anomalies also emerge: one regarding the longitudinal withdrawal of the nB04 dough, the other one concerning the vertical shortening of the nB20. These results can be explained by the loss of edge integrity or by the detachment of production burrs. The nature of the dough and the manual packaging favor small inaccuracies in the definition of the edges. In any case, the shortening values are below the acceptability threshold set at 5% by Achenza [39].

4.5.2. Compressive Strength

Table 5 shows the results of the compression tests. For each specimen, it is possible to read the maximum force applied and the compressive strength. The latter was obtained in the post-processing phase, dividing the force by the cross-section of the sample. The table also shows the average strength of the dough.

From the results, it emerges that a small percentage (0.40%) of basalt fibers (mix nB04) determines an increase in resistance of about 30% compared to samples without fibers (mix nTC). Another interesting result is that the increase in the percentage of basalt fibers (nB20) does not lead to a further increase in strength. The specimens made with rice straw (nLR), on the other hand, showed lower compressive strength values than the raw earth specimens (nTC).

Table 5. Compressive strength.

| Mix | Specimen | Max Load [kN] | Spec. Comp. Strength [MPa] | Mix. Comp. Strength [MPa] |
|-------|----------|---------------|----------------------------|---------------------------|
| n TC | n TC 1 | 22.24 | 2.28 | 1.94 ± 0.28 |
| | n TC 2 | 18.59 | 1.91 | |
| | n TC 3 | 16.84 | 1.72 | |
| | n TC 4 | 18.13 | 1.86 | |
| n LR | n LR 1 | 16.18 | 1.65 | 1.63 ± 0.07 |
| | n LR 2 | 15.63 | 1.59 | |
| | n LR 3 | 15.33 | 1.56 | |
| | n LR 4 | 16.69 | 1.71 | |
| n B04 | n B04 1 | 26.22 | 2.68 | 2.52 ± 0.20 |
| | n B04 2 | 24.09 | 2.46 | |
| | n B04 3 | 25.86 | 2.64 | |
| | n B04 4 | 22.34 | 2.28 | |
| n B20 | n B20 1 | 24.32 | 2.47 | 2.42 ± 0.06 |
| | n B20 2 | 24.14 | 2.45 | |
| | n B20 3 | 23.60 | 2.40 | |
| | n B20 4 | 23.08 | 2.35 | |

From the data, it was possible to draw the stress–strain diagrams shown in Figure 6.

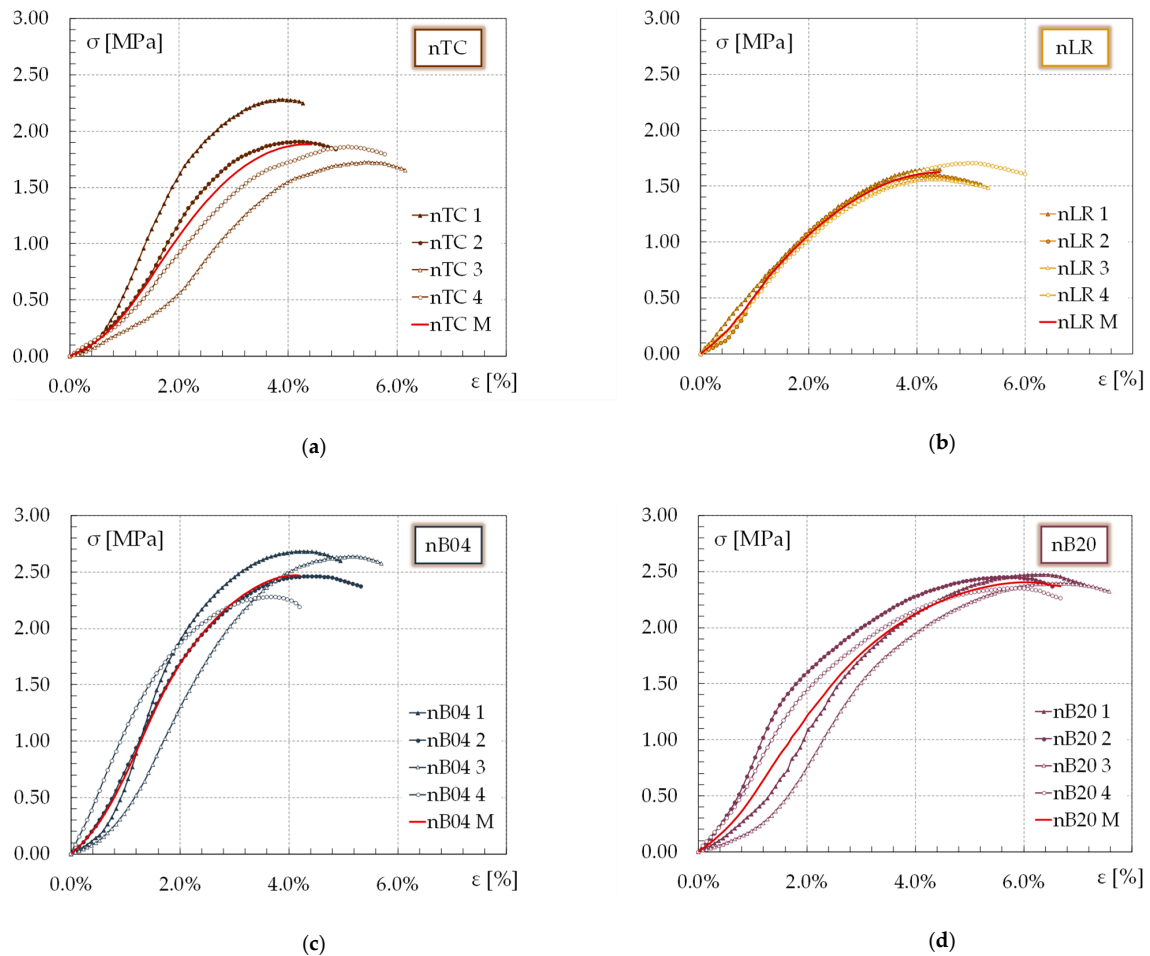


Figure 6. Stress–deformation curve of the mixes: (a) n TC; (b) n LR; (c) n B04 (d) n B20.

The tension values are represented for increasing deformation values with a constant pitch equal to 0.075%. Starting from the curves of the single specimens it was possible to outline an average stress–strain curve representative of the behavior of the specimen (in red in Figure 6). The mean curve is plotted up to the deformation corresponding to the crisis of the first specimen. The analysis of the stress–strain diagrams shown in Figure 6 also highlights a lower dispersion of the results obtained in the case of fiber-reinforced samples. In fact, the resistance values fluctuate in a range of about 0.6 MPa for the nTC mixture; 0.1 MPa for nLR; 0.4 MPa for nB04 and 0.1 MPa for nB20.

The synthetic comparison of the results is shown in Figure 7. From the histogram, it is possible to observe the direct comparison with the current regulatory acceptance limits of adobe bricks, fixed between 1.2 and 2.1 MPa [52].

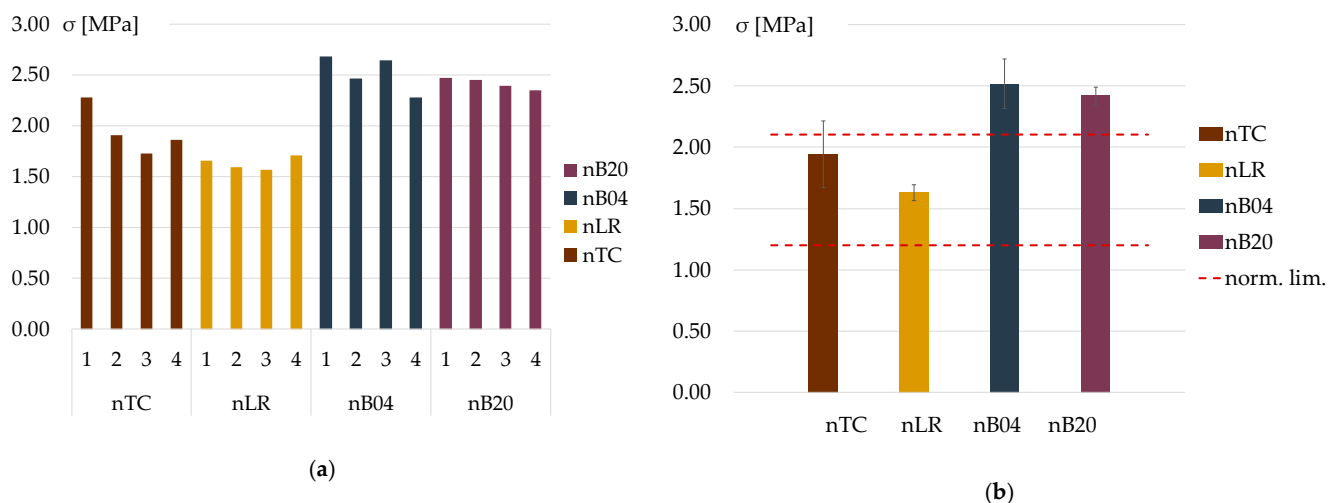


Figure 7. Histograms of the compressive strength: (a) Individual specimens; (b) Mixes average.

4.6. Discussions

The laboratory experiments described try to evaluate the contribution of straw and basalt fibers in terms of shrinkage and compressive strength. Regarding the first aspect, the results confirm literature studies: if compared to the raw earth sample, there is an improvement. Considering an average behavior in the three directions, the use of rice straw led to a reduction in shrinkage of 14.4%. The basalt fibers led to a reduction in shrinkage of just under 25% (precisely 24.7%). As a result, we can affirm that basalt fibers have the best performance, increasing proportionally these values in the range of percentages studied (0.4–2%).

Regarding the second aspect it is difficult to make a direct comparison with the data in the literature, so various due to the absence of standard procedures. However, the research's results satisfy the current legislative landscape of adobe which certifies acceptability performance of compressive strength in the range between 1.2 and 2.1 MPa.

To conclude: strict procedural control ensured the molding and conditioning. In this way, we can directly compare the samples. We can observe that basalt fibers increase the compressive strength by about 30% (precisely 29.9%) more than rice straw or simple raw earth.

5. Brick Powder for a New Suitable and Sustainable Plaster for Built Heritage

The buildings interact with the built environment through their “skin”. In the case of historic buildings, the plaster also narrates the materials used for their construction. The composition of the mortar should be carefully studied because characteristics such as quality, expected durability and ease of application derive from the mineralogical combination of the mixes and the volume ratio defined by aggregates on the binder. The mortars for fin-

ishes have also aesthetic quality, especially if their colors are not obtained by using coloring pigments but through the chromatic matrix of natural aggregates appropriately dosed.

5.1. Methodology

As underlined by Salemi, in the realization of plasters for the restoration of historical facades, the existing surfaces and their relationships with the context must be respected [81]. This approach makes it possible to preserve the historical identity of the building, maintaining its documentary/monumental value. It also avoids inconsistencies between existing and new materials.

Therefore, it is possible to define the mortar to be used to preserve the built heritage from the knowledge of the materials available in the area, the morphology and structure of the stones and aggregates. This *modus operandi* was followed in the treatment of the Scannapieco factory, a building located in the historic center of Catania (Sicily).

A relevant phase was the cognitive one. The anamnesis of the building was reconstructed, due to diachronic analysis of the construction events, recognition of the technological system and relief of decay.

The building showed significant deterioration of the cementitious plaster, which replaced the original one made of volcanic aggregate (azolo) and “ghiara”. Based on the knowledge of the Etna construction tradition, it was developed a specific mix design for a new lime plaster that reconciled the preservation of the image of the building with the need for a surface resistant to the aggression of the marine aerosol.

5.2. The Case Study

5.2.1. First Restoration

The building was the sawmill of the Scannapieco family, active in the trade and wood-working of Catania since 1876 (the year in which Vincenzo Scannapieco, the progenitor, moved from Naples to Catania) [82].

The property purchased in 1991 by the University of Catania was in a poor state of conservation, therefore in 1998 the renovation works started. The project and supervision were entrusted to prof. eng. S. Boscarino. The restoration involved the demolition of the internal walls and all the horizontal closures, as well as the extension of the basement, which was enlarged over the entire building plan. Instead of the internal load-bearing walls, a reinforced concrete skeleton structure with new continuous foundations was created.

Consequently, the original vaulted structures were replaced with horizontal floors made with steel profile (UPN 300) and concrete slabs. According to Etnean construction tradition, the original vaults were in volcanic pumice concrete and gypsum mortar. The original flat horizontal closure, made with iron profiles (I 140 mm) and filling in pumice and plaster mortar, was replaced too.

A 16 cm reinforced concrete wall was erected to consolidate the existing perimeter ones. The two walls were connected by cables and metal plates (Figure 8). The original perimeter masonry walls were made up of roughly squared basaltic ashlar and lime mortar with ghiara [75]. The latter derives from the cooking of the soil following the passage of the lava flow. It has a reddish color and is greasy to the touch. It was a very widespread aggregate in the Etna area, but today it is no longer available due to the danger of extraction operations.

The original plaster was replaced with a cementitious one mixed with water-repellent substances. Finally, a mixture of lime, cement and gravel was created to propose again something comparable to the original finishing. In 2001, the works were tested.

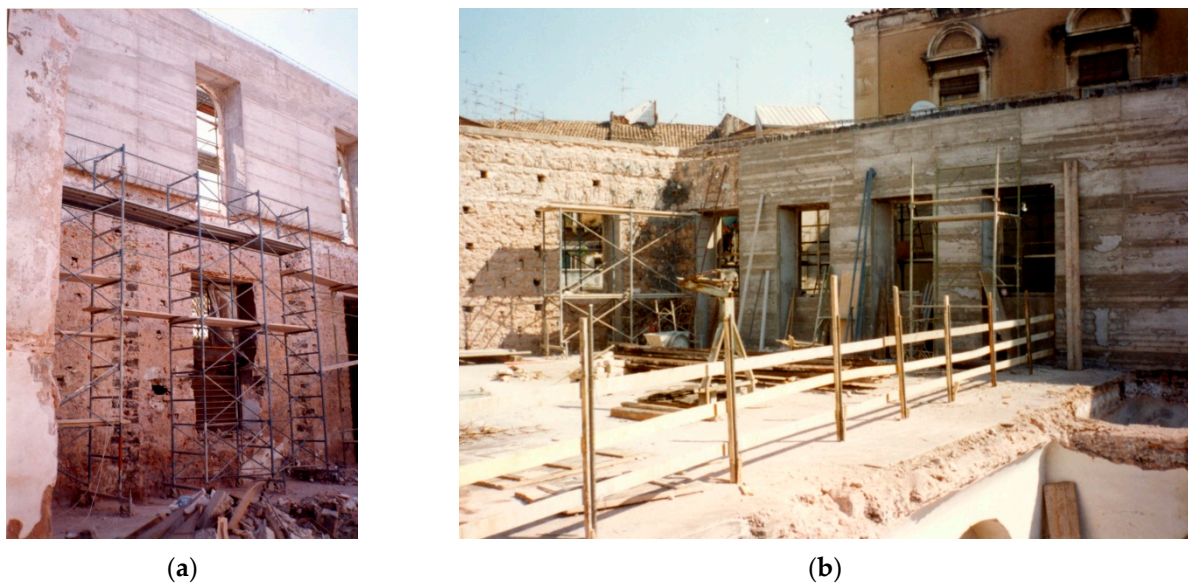


Figure 8. The 1998 refurbishment: reinforcements with a concrete septum in North West wall (a); and in North East wall (b). (Photos by Lo Faro A.)

5.2.2. The State of Fact

Today the building hosts the library, laboratories and some offices of the Department of Political and Social Sciences. With the restoration, an internal courtyard was created whose skylight illuminates the connecting and socializing spaces. The building consists of three floors connected by two staircases equipped with a lift. As it can be seen in Figure 9a, the building completely saturates the block and it is surrounded by roads. The east facade, the main one (in Figure 9b), faces a busy road that separates it from Catania's port area.



Figure 9. (a) 1974 bird's-eye views of Scannapieco Building highlighted in green; (b) the main facade.

The direct exposure to the marine environment limited the duration of the plaster. Since 2008 the plaster had abundant gaps and detachments, also due to the oxidation of consolidation plates. This had inevitable repercussions on public safety as well as on the functional and aesthetic performance of the building. The manifestation of the phenomenon also in the lower levels has brought out the widespread presence of rising damp.

The stone facade equipment consists in the basement in basaltic ashlars and the crowning in compact limestone slabs. It presented serious visible decay such as exfoliation, biological colonization, black crust and blistering. This is shown in the map of decay in Figure 10.



Figure 10. (a) Decay mapping on eastern façade; (b) Decay mapping on southern façade; (c) Legend of detected decay.

5.3. A New Plaster

5.3.1. Some Premise

The authors decided to replace totally the plaster because it was damaged and without historical value (since it was replaced in 1998). The metal plates were suitably treated against corrosion. To avoid the transmission of (thermal and mechanical) stresses between plates and plaster, we applied both an insulating sheath and a layer of silica powder.

A Sicilian company collaborated in the formulation of the new plaster. The new formula was based on experiences already conducted in the Etna area and it used just natural and local materials, mixed directly on-site [83,84]. We know that plaster in Etna's territory was always made of lime and volcanic aggregate, according to a ratio in volume 1:3. Three layers, for a final thickness of 30–40 mm, make the traditional plastered surfaces. The clay-based products (brick, tile, etc.) were widespread in Catania because of the vast deposits of clay in the neighborhood. The choice of local materials (lime, cocciopesto and volcanic aggregate) aims to meet the criteria of sustainability. These principles are in line with the indications of the restoration papers (specifically the Amsterdam Charter).

The new plaster consists of three layers (grip, body and finish) with specific characteristics. The result aims at maximum breathability in order to counteract the crystallization of salts that can come from both the marine aerosol and rising dampness.

Before applying the plaster, we prepared the substrate. The external masonry wall was brushed, washed and then appropriately wet. This last phase was crucial because if not properly executed the masonry could absorb water from the mixture.

Clearly, in addition to intervening on the plaster, the identified deterioration was punctually treated, e.g., the reconstruction of the mortar joints.

5.3.2. Design of the Plaster

The new plaster consists of three different layers. The first one ensures a stable adhesion to the support. The new mix was developed using specific volumetric ratios. It has a binder/aggregate volumetric ratio of 2:1, with a minimum thickness of 3–5 mm [82]. Traditionally the aggregates were basalt grain (azolo) and ghiara. Today it is no longer possible to extract ghiara, so we used cocciopesto instead of it. In fact, they have similar performances both chemical and chromatic [75]. Therefore, the aggregate consists of cocciopesto, azolo and limestone powder. Cocciopesto was obtained from the crushing of broken tiles and bricks sent to landfill. The aggregate thus obtained must be as pure as possible to minimize the "uncontrolled" soluble parts of residual free lime. In fact, these could boost degradation pathologies for the plaster, like salt crystallization and detachment [82]. BP is a natural hydraulic component and it ensures, according to its mineralogical characteristics, enough silicon dioxide to guarantee calcium silicates and the absence of residual free lime [82,85]. The binder is composed of Natural Hydrated Lime (NHL) 3.5 and super-ventilated calcium lime CL90. In volume (V) we used a dosage of 7 V/2 V/1 V respectively for aggregate/calcium lime/natural hydrated lime.

The main characteristic of the new plaster was evaluated according to UNI EN 1015. The particle size distribution of the mortar was determined with the dry sieving method required by the norm. The sample was taken with a shovel, in three different points of the stack and at a depth of at least 100 mm. Each sample was 0.6 kg and it was sieved once the constant mass condition was reached. In Table 6 we provide the average particle size, equal to 0.3 mm. The consistency of the fresh mortar was evaluated on two samples through the "shake table" method. In accordance with the regulations, we used a truncated cone mold with a height of 60 mm, base diameter of 100 mm and top diameter of 70 mm. The mortar was introduced into the mold in two layers, taking care to level the first in order to fill the volume at the base of the container. Once filled the mold, the dough rested for 15 s and the mold was removed. After 15 shocks we measured the diameter of the mortar on the disc. The workability time of the fresh mortar was identified with method A of UNI EN 1015-9. The test consists of measuring the time required for the mortar to reach the penetration resistance limit of 0.5 MPa. The dry bulk density of hardened mortar is defined by the ratio between the mass of the specimen after drying its volume when immersed in water in a saturated condition. The flexural strength was determined by stressing prismatic samples of 160 × 40 × 40 mm size on three points. The test was conducted according to the procedures of UNI EN 1015-11. The water absorption coefficient by capillarity was calculated by immersing for 24 h the faces of suitably dried specimens in water. The test was conducted according to the methods indicated in UNI EN1015-18.

Table 6. Main characteristics of new plaster according to EN 1015.

| Technical Characteristics | Rule | Value |
|---|------------------|----------------------------|
| Dosage of base coat (in V) | Aggregate/CL/NHL | 7 V/2 V/1 V |
| Dosage of final coat (in V) | Aggregate/CL/NHL | 8 V/2 V/1 V |
| Average particle size | UNI EN 1015/1 | 0.3 mm |
| Fresh mortar consistence | UNI EN 1015/3 | 169 mm |
| Workable life | UNI EN 1015/9 | 2–3 h at 293 K |
| Bulk dry density | UNI EN 1015/10 | 1522.97 kg/m ³ |
| Compressive strength of hardened mortar | UNI EN 1015/11 | CS.i category |
| Water absorption coefficient | UNI EN 1015/18 | >0.3 kg/m ² |
| Water vapor permeability | UNI EN 1015/19 | $\mu < 8$ |
| MOHS Hardness of aggregate mix | | 4.07 |
| Residual free lime (%) | | 0.15% |
| Average consumption (dry mix) | | 1.5 kg/m ² × mm |

The permeability to water vapor was determined under steady-state flow conditions, respecting the steps described by the UNI EN 1015-19 standard. To evaluate the hardness of the aggregate mix we used the Mohs scale. Another indicative parameter is the average consumption of material which is 1.5 kg/m² × mm for the dry components. This parameter provides essential information to the valuation of supplies and so of intervention costs. The main results obtained from the tests briefly mentioned are listed in Table 6. The resulting mixture is suitable for strongly humid environments; in fact, it presents high breathability and resistance to alkaline aggressions as well as good adhesion and elasticity.

The irregularity of the masonry wall influenced the thickness of the first layer, which had to create a planar surface. The maximum protrusion of the stones was taken as a reference. The base coat was dried considering one day for each millimeter of thickness.

The second layer had the same formulation, i.e., volumetric ratio between binder and aggregate. It was applied, after wetting the base coat, in two stages (fresh on fresh), obtaining a total thickness of about 20 mm (10 mm per application, with different finishes).

Finally, we evaluated different examples of final coating changing the quantity of cocciopesto as well as the application tools. Some samples of the finishing tests are shown in Figure 11. In the end, the choice fell on a mix with a slightly different volumetric ratio between the parts. In particular, the aggregate volumes are 8 V instead of 7 V. This result is derived by using aggregate as a natural dye. The final layer, in fact, has an identity and aesthetic purposes. As for the texture to the touch, we chose for the test to work with a trowel and finish with a sponge.

**Figure 11.** Some tests on different mix design and finishing (photo by Lo Faro A).

The replacement and creation of the plaster was a sustainable intervention, in accordance with the premises. In fact, it used local materials, not twisting the building and context, and at the same time, it avoided the creation of a fake. Beyond the perceptive aspect, the new plaster was designed to be highly breathable and resistant to alkaline aggression, therefore to the marine environment that characterizes the site.

Figure 12 shows the construction phases and the result.



(a)



(b)



(c)

Figure 12. Work phases: (a) laying the base coat; (b) laying the float coat; (c) final result, the eastern façade today.

6. Final Considerations

6.1. First Application

In the first research, the authors evaluated the effects of two fibrous reinforcements in mixtures to produce clay bricks. The fibers chosen are natural and easy to find in the eastern area of Sicily: rice straw and basalt fiber.

The tests carried out with a strict protocol have shown that, within the quantities used (0.4–2%), the use of these fibers significantly reduces the effect of shrinkage. The basalt fibers also resulted in an increase in compressive strength of about 30%.

Further investigations are necessary to express a well-founded judgment regarding the potential of basalt fibers as a stabilizer of raw earth mixtures. Studies such as the evaluation of the effects on tensile strength and elastic modulus, as well as on the optimal quantity of fiber to be used and its length, are necessary to characterize the dough. In any case, these studies require a uniform and recognized regulatory framework in order to be conducted with scientific rigor.

6.2. Second Application

The second research illustrated the application of a lime- and cocchiopesto-based mortar in a historical building of Catania (Sicily). The methodological approach, in accordance with the theories of restoration, has made it possible to outline a recipe starting from the knowledge of the mortars traditionally used in the Etna's territory.

The new mortar was designed in such a way as to respect the chromatic and material identity (as far as possible since the ghiara can no longer be extracted) of the original building. The authors considered the decay manifestations and the stresses deriving from the particularly aggressive marine aerosol. As a result, the choice of constituents was optimized to guarantee maximum alkaline resistance and breathability. This mix design did not require the use of artificial additives, but only the integration of information from the past with new knowledge related to the science of materials. The line followed in this case study critically combines "conservative" and "transformative" aspects, as suggested by Muratore [86].

Several obstacles limit the spread of the followed approach. Among these, the most important is the absence of skilled labor, the need to carry out investigations on a case-by-case basis and therefore much longer intervention times. Current practice, on the other hand, driven by economic interests, relies on pre-packaged products that are easy and quick to use. An attitude that does not pay attention to the material and chromatic identity of the territory.

Despite a greater number of attempts to obtain the targeted result, the quality of the result suggests the use of natural and local materials, which also guarantees the sustainability of the intervention. This way you can promote a circular approach to the maintenance of the built heritage as the driver of sustainable growth [82,87].

6.3. Conclusions

Although in apparently different fields, the two pieces of research investigate the potential contemporary application of traditional materials. More specifically, they focus on clay, one of the oldest and most widespread building materials.

The choice derives from the current need for sustainability. In fact, clay is a natural material, totally recyclable, non-toxic, with low incorporated energy. It is economic given the easy workability, installation speed and wide availability. Beyond its universality, in Eastern Sicily, we can record the presence of numerous quarries, supply chains and furnaces, even of secular tradition. The strengthening of local supply chains, in addition to generating induced activities, would lead to the creation of jobs, reviving the micro-economy and satisfying social sustainability.

All the materials used in the studies belong to the Etna area, so are closely related to the volcanic landscape and respond to the sustainability requirements already seen for clay.

Therefore, these studies are placed in an intermediate position between industrial, traditional and vernacular architecture. In fact, they intend to place an “indigenous” material at the center of the supply chain process (methodologically extensible on a large scale), usable in respect of the territory. The aim is not to promote two packed products ready for indiscriminate use in any condition, but a “glocal” approach to clayey resources in order to ensure high production standards in compliance with local peculiarities (material, energy and even chromatic).

The results obtained open the way to new possibilities. A lot of researches still need to be done on the clay and basalt fibers bricks (also from a thermal point of view) before reaching a usable finished product. They could reach high-quality standards, by optimizing the formulation and also integrating other mechanical stabilizers. The use of basalt fibers in a raw earth matrix is an element of absolute novelty. Considering the versatility of these two materials, characterized by many techniques, a potential panorama of numerous products opens up (perhaps involving BF in the form of bars or fabrics).

On the other hand, *cocciopesto* plasters represent a reality ready to be spread in the construction sector. They are a resource as they can enrich the aesthetics of our cities, improve the performance of buildings and reduce the load of waste on the environment. Although the study of this plaster provides universal indications to create a model, it constitutes a “unicum” as much as all the interventions that deal with the built heritage. Hence, there is a need to spread these experiences even if they must then be verified case by case. In restoration, these mortars are well known and appreciated due to their technical and environmental performance. The latter aspects could also extend the use of these products to contemporary construction. One of the main risks is that stakeholders may prefer quicker but less sustainable solutions. For this reason, it would be interesting to study and quantify the environmental impact of such an intervention and compare it with one that uses the plasters currently on the market.

However, in both cases, the role of researcher and operators result fundamental. The former is responsible for restoring the lost technical knowledge for integrating it into the current panorama. This means to create a network, even a normative one, capable of accommodating the peculiarities and performance of “old” but new materials. The operators, instead, have to be more patient and critical in their design choices which, although aimed at the efficiency of performance, must not lose sight of the principles of sustainability and local identity.

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