International Journal of Sustainable Built Environment (2016) 5, 451–460

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Gulf Organisation for Research and Development

International Journal of Sustainable Built Environment

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Review Article

Use of traditional material in farm buildings for a sustainable rural environment☆

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Received 6 January 2016; accepted 12 May 2016

Abstract

The recent increase in the sensitivity about the concept of sustainable development is stimulating the valorisation of the locally available material for agricultural construction, both for housing purpose and for some single components. This traditional building technique has indeed interesting consequences on the rural landscape perception – since the color is similar to the countryside surroundings – as well as on the agricultural environment – this material being, at the end of its useful life, recyclable in the same context. Traditional material could be employed in other agricultural components, *e.g.* for food aging, a technique used since Roman times, involving the use of earthenware amphorae, buried in the soil and used for storing wine and oil. In the present paper, the most diffused traditional building materials currently rediscovered are analyzed, focusing on their utilization opportunities. One of the most interesting traditional construction material is the sun-dried earth brick, made of raw clay soil (so-called, "adobe"), often improved by the addition of fibers to control cracking while drying in the sun. After a general overview about the diffusion of earthen construction within agriculture, the results of experimental tests on adobe bricks reinforced with a natural fiber – Spanish Broom (*Spartium junceum L.*) – are reported.

Keywords: Rural areas; Farm building; Traditional material; Adobe brick; Spanish Broom

Contents

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☆ Presented in part as an invited lecture at the Second International Symposium on Agricultural Engineering – ISAE-2015 – held in Belgrade – Republic of Serbia (9–10 October 2015), with the original title: "*Valorization of traditional building material for the sustainable development of rural areas*".
Peer review under responsibility of The Gulf Organisation for Research and Development.

http://dx.doi.org/10.1016/j.ijsbe.2016.05.005
2212-6090/

1. Introduction

Farm buildings, designed over the centuries in order to fulfill their primary agricultural role, now constitute a widespread heritage that in some cases possesses an unreplaceable architectural value, playing a central role for the sustainability of the rural environment as well. Conceived to host biological production, the farm building constitutes indeed a unique example in the wide epistemological sector of building construction (Picuno, 2012). The birth, growth and development of living vegetal or animal organisms contained *inside* these volumes raise architectural and technical issues that are radically different if compared to those of other building sectors. Aimed at producing optimal environmental conditions for plants and animals, while at the same time protecting the hygiene and health of workers involved in the daily operations for the care of living organisms at different stages of their development, the rural building constitutes therefore a unique and unrepeatable technological model (Fuentes et al., 2010; Fuentes, 2010; Picuno et al., 2015).

The originality of what happens inside the farm building corresponds to what happens *outside*. The role that the buildings have historically played is strictly connected with the surrounding context, due to the need of the farmer to live in close contact with agricultural land and animal husbandry (Cañas et al., 2009; Hernández et al., 2004; Jeong et al., 2012; Lista et al., 2013a,b). While the organization of human beings involved in the activities of the industrial or tertiary sector allowed aggregation in urban centers, the need to live in constant contact with the agricultural production developed a synergetic function of close proximity to the extra-urban land. This aspect led to the spread in rural areas of many examples of buildings that served for farming, storage and processing of agricultural products constituting, at the same time, housing for the farmer and his family. This form of settlement has been, and still is, a unique way by which humans have populated, in harmony with the natural elements, the agricultural land, joining the primary production needed for human nutrition with the control and care of rural land. So, the activities made by the Man have often strongly influenced the agricultural environment and the visual perception of its landscape (Statuto et al., 2014a,b, 2015; Tortora et al., 2015).

The growing interest toward the role that rural areas may play for a more balanced pattern of modern life, under the currently increasing sensitivity of large segments of the European population about the concept of sustainable development of the built environment, is stimulating the valorization of the locally available material used in agriculture for the realization of constructions, both for housing purpose and for the realization of each single element within the farm. This choice, that was at the time one of the pillars at the base of the formation of rural landscape, has its roots in the tradition left by our forefathers, since they had no choice than realize farm buildings and ancillary elements using the local material. Indeed, even if traditionally based mostly on an economic reason, this has very interesting consequences on the current perception of the rural landscape – since the color of the building is similar to the surroundings (García et al., 2003) – as well on the agricultural environment – this material being, at the end of its useful life, incorporated in the same context.

1.1. Agro-food maturing and storing

Today, a technique of aging that is becoming increasingly popular, used since Roman times, involves the use of earthenware amphorae for storing wine and oil. This technique was most popular in Georgia, where large earthenware amphorae were buried and used to allow the first fermentation and then the aging of wines, both red and white. The use of earthenware pots (*Kvevri* in the local language) provides a completely natural treatment and enhances the varietal characteristics. Amphorae, usually made of clay, are produced in different sizes and subjected to different types of treatment (cooking at high temperature, coatings, *etc.*). They can be buried in the ground, half buried or not buried at all, depending on the system of temperature control installed in the cellars.

Wine contains different chemical substances that influence the sensory characteristics of the final product. Amount and type of these components can be opportunely modified by managing viticultural practices, wine-making process, aging, and type of containers and closures. Phenolic compounds are important components of wine. They not only contribute to their sensory profiles, such as color, flavor and astringency, but may also act as antioxidants, with mechanisms involving both free-radical scavenging and metal chelation. The composition and concentration of phenolic components in wine depends not only on grape variety and wine-making procedures, but also on the chemical reactions that happen during aging. A fundamental role in wine sensory profile and consumer preferences is also played by volatile compounds. The aromatic profile of wine is the result of important modifications deriving from esterification, hydrolysis, redox reactions, slow and continuous diffusion of oxygen, spontaneous clarification, and CO_2 elimination (Baiano et al., 2015). As a result of these physical and chemical changes, the volatile fraction is extremely complex, accounting for more than 1000 compounds, which belong to different chemical classes, and cover a wide range of polarities, solubility, and volatility values. Aging can be made in different containers, such as stainless steel tanks, oak barrels, clay vessels, with the aim of enhancing wine flavor. Stainless steel tanks are inert containers while wood and clay interact with wine. Aging in wood changes color, structure, phenolic profile and aroma, since it is a material that enables to make a micro-oxygenation of wine and to release phenolic and aromatic substances while adsorbing other wine components. However, in the case of white wines, the aging in oak barrels is not always advantageous since both the oxygen could oxidize the wine and the wood deriving components completely mask its sensory characteristics.

The aim of in-amphorae aging is to replicate the beneficial air exchange of wood containers, without the transferring of vanillin, tannins and toast flavors from the oak barrels to the wine. Therefore, the resulting wines are different, with a cleaner taste and more pronounced characteristics of minerality and freshness. Several French (in Corsica, southern Rhone Valley, and Beaujolais), Portuguese (in Alentejo), Croatian (in Istria), U.S. (in the Napa Valley), Slovenian (in Goriška Brda region), Austria (in the east-central Thermen region) and Italy (mostly, regions such as Friuli, Campania and Sicily) wine producers have experimented with fermentation and/or aging in amphorae.

From an economic point of view, the production of in-amphora wines is becoming increasingly attractive to producers, especially to those belonging to the 'natural wine' movement. In fact, only a few hundred thousand bottles of such wine are produced annually; they are designed for consumers willing to pay medium–high prices. The in-amphora wines have received a lot of attention from wine magazines and wine lovers but there is a lack of scientific literature about the effects of this type of aging and comparison with conventional processes (Baiano et al., 2014).

1.2. Farm building – Dry-stone construction

In many rural areas, rich in sound and easily worked limestone, dry-stone walling can be found as a vernacular and widespread form of construction. Dry-stone constructions depend on the skills of professional masons; they are built by fitting pieces of stone without or, in some cases, with a small quantity of mortar. A very large number of dry-stone edifices have been raised in the past, such as retaining walls or rural constructions in Europe, but in the early 1900s dry masonry was largely renewed because of modern techniques. Over the past few years, there has been a growing interest into dry-stone masonry, not only for the maintenance and assessment of existing heritage, but also to promote know-how and to complete new projects.

Dry stone constructions are spread all over many parts of the World. Mostly within the Mediterranean area, they were employed in agricultural areas for housing purposes as well as for the materialization, through stone walls, of the delimitation of borders between neighboring countryside estates, as in some Southern Italian regions, *e.g.* Apulia and Basilicata (Fig. 1). These extraordinary examples of spontaneous architecture still constitute a visible witness about the role that the rural constructions have historically played in connection with the surrounding environment, joining the agricultural production needed for human nutrition with the control and care of extra-urban land (Picuno, 2012).

Figure 1. Dry-stone rural buildings with stone walls for the delimitation of borders between neighboring countryside estates.

1.3. Farm building – Earthen building

Earthen construction has been one of the most largely used construction techniques in different historic ages. Man began to use earthen construction at least 5000 years ago in Mesopotamia and Turkmenistan and it has been largely used by different civilizations all around the world (Angelini et al., 2013; Baiano et al., 2014; Bestraten et al., 2011). Nowadays it is estimated that between 30% and 50% of world population lives in earthen structures, mainly in some regions of Africa, Asia and Latin America, where earthen construction techniques are still largely used for new dwellings. Even in Europe, new earthen structures are built as a niche product of construction industry, mainly to ensure comfort to occupants and architectural compatibility with historical built environments. In fact, 10% of the UNESCO World Heritage properties includes earthen structures. In Europe, the historic centers of Matera, Cordoba, Oporto, Lyon, Guimarães are some of the UNESCO sites where earthen structures are largely present (Jimenez-Delgado and Cañas-Guerrero, 2006; Parisi et al., 2015; Parra-Saldivar and Batty, 2006).

One of the most interesting element of earthen construction is the use of sun-dried earth bricks – made of raw clay soil mixed with barley or wheat straw (so-called, "*adobe*") – as a walling material (Fig. 2). The main applied raw materials are coarse sand, argillaceous earth and lime. The natural earth mixtures are often corrected by the addition of fibers, to control cracking while adobes are drying in the sun. The adobe masonry is an assemblage of adobe bricks and mud mortar. On the other hand, *pisé* or rammed earth is produced by ramming and compacting earth in a formwork (McHenry, 1989; Solís et al., 2015; www.terracruda.org).

Adobe is a construction material that presents several attractive characteristics. It is low cost, locally available, recyclable, adapted to a large variety of soils, presents good thermal and acoustic properties, and it is associated to simple constructive methods that require reduced energy consumption (Millogo et al., 2014; Parra-Saldivar and Batty, 2006; Vissilia, 2009; Zhai and Previtali, 2010). Adobe bricks are usually obtained by pressing the mixture of soil, water and fibers into a prismatic formwork, and then drying each brick through the combined action of air and sunshine. In some countries, several additives are also currently added to the soil mixture. In some cases, the mixture of adobe bricks was typically also stabilized in the past with dung and urine. Nowadays, cement is sometimes added to the mix of modern adobe bricks in order to increase strength and reduce erodibility, as it also happens by adding lime (Parisi et al., 2015).

Figure 2. Earthen rural construction realized with *adobe* bricks.

Due to the re-discovering of this traditional construction material, material scientists and civil engineers are currently largely interested in earthen construction and many scholars are working on this topic (Barbari et al., 2014a, b; Lista, 2015; Silveira et al., 2012; Vega et al., 2011). The interest in this kind of structures is motivated not only by their large spread all over the world, but also by their poor mechanical properties resulting in high structural vulnerability against natural hazards (*e.g.* earthquakes, floods). Even though many scientific works on different types of earthen materials and structures are available in the literature, detailed studies are needed to assess material properties and structural behavior, since earthen structures are strongly site-specific, depending on the techniques used for material production and on-site construction of the building (Liberatore et al., 2006; Lista et al., 2014).

To improve the mechanical strength, impermeability and the durability of locally produced adobe, in general, small amounts of hydrated lime or natural fibers are added to the soil matrix. The use of local natural fibers, especially in developing countries, is more beneficial for the population, as fibers are locally available in abundance, and their productions are of low cost and low consuming energy besides are not polluting. In the available international scientific literature, several experimental investigations have established the positive effects on the physical and mechanical properties of soil composite blocks from the addition of vegetable fibers such as: jute, sisal, straw, rice-husk, sugarcane bagasse, chopped barley straw, processed waste tea, vegetal, oil palm empty fruit bunches, lechuguilla, pineapple leaves, cassava peel, *Hibiscus cannabinus*, *Pinus roxburghii* and *Grewia optivia* (Sharma et al., 2015).

The effect of synthetic fibers on soil composites has been studied theoretically with the objective of producing specific analytical models for soil composites. The main parameters that strongly influence the physical, mechanical and the durability behavior of soil composites are: the type, tensile strength and durability of fibers, besides the fibers' length and their volume fraction in the composite mix. The type of fiber has an important influence on the impermeability of the composites depending on the percentage of the lignin in the fiber. The higher the percentage of lignin in the vegetable fiber, the higher is the impermeability. Depending on the mixture of soil, its differential shrinkage during the drying process could be high. To prevent the shrinkage cracks of the soil matrix, fibers are added. The higher the resistance of fibers with high bonds, less shrinkage cracks in the brick. The optimum volume fractions and length for most vegetable fibers have been found to be between 0.3% and 0.8% in weight with 30–80 mm length respectively (Millogo et al., 2014). Fibers tensile strength directly determines the crack resistance of fiber-reinforced soil. Even if the long-term stability of this feature was not adequately studied so far, existing buildings where fibers did not decompose in the soil validate the durability of soil composite reinforced with vegetable fibers. The fiber length determines the pull-out resistance of the embedded fiber in the soil matrix and therefore directly determines the reinforcement force, which is less than or equal to the fiber tensile strength. The amount of fiber determines the intensity of the reinforcement: for small amounts (<0.2 wt.%), the strength of the reinforcement increases with the number of fibers. However, at a higher fiber mass fraction over a certain threshold, the fibers are so numerous that they weaken the soil matrix and thus lead to a lower resistance of the reinforced soil composites.

With the aim to examine the mechanical properties of adobe bricks realized with natural material locally available in the Mediterranean area, in the present paper the results of mechanical tests on adobe bricks suitably prepared are presented. These bricks were tested with different kinds of reinforcement fibers: straw as well as one of the most interesting natural fiber diffused all over the Mediterranean basin, where it spontaneously grows, *i.e.*: Spanish Broom *(Spartium junceum L.)*.

2. Materials and methods

Since no studies regarding the use of Spanish Broom fibers for the enhancement of the mechanical properties of adobe bricks appear to be conducted so far, in the present paper experimental tests on adobe bricks reinforced with natural fibers – *i.e.*: wheat straw, considered as a reference, and Spanish Broom – as well as on the fibers of this latter, are reported (Lista et al., 2014; Lista, 2015; Sica et al., 2015). All these mechanical tests were performed at the Laboratories for Testing Materials of the SAFE School of the University of Basilicata (Potenza – Italy) by using a Galdabini PMA 10 (Galdabini S.p.A., Italy) universal testing machine.

2.1. Compression test on adobe bricks

Adobe bricks of cubic shape (150 mm edge) were produced, according to local traditional practice in Basilicata Region, by taking soil having the following composition: 49.3% clay, 36.9% silt and 13.8% sand. The Atterberg values of this mixture were: Liquid Limit LL = 38.7%, Plastic Limit PL = 21.0%, Plastic Index PI = 17.7%.

Natural fibers were added to the soil–water mixture, at a 33% volume rate (Vega et al., 2011), ensuring a distribution of fiber reinforcement within the brick volume and their stabilization, in terms of lack of shrinkage cracking. N.4 different typologies of adobe bricks were produced (Fig. 3), by adding to the soil the following reinforcing fibers:

WSr – Adobe brick reinforced with wheat straw, randomly disposed within the brick.

WSo – Adobe brick reinforced with wheat straw, disposed orthogonal to the compression load.

SBr – Adobe brick reinforced with Spanish Broom, randomly disposed within the brick.

SBo – Adobe brick reinforced with Spanish Broom, disposed orthogonal to the compression load.

For each typology, n.10 specimens were produced. After drying in at the sun, the mechanical behavior of the adobe bricks was measured by placing them between the rigid steel plates of the testing machine and testing them in terms

Figure 3. Experimental Adobe bricks reinforced with natural fibers.

Figure 4. Compression test on an Adobe brick reinforced with natural fibers.

of unconfined compression strength through displacement-controlled uniaxial tests (Fig. 4). A uniform load was applied without shock and increased continuously until failure, with the moving head of the testing machine traveling at a rate of 1 mm/min.

2.2. Tensile test on Spanish Broom

Spanish Broom (*Spartium junceum L.*), a member of the Leguminosae family, is a perennial shrub growing in hot and dry climate throughout the Mediterranean area, where it naturally occurs in hilly soils, contributing to lower erosion and risks of nutrient leaching. This plant is somewhat adapted to alkaline and salty soils. In comparison with flax and hemp, Spanish Broom grows in the most unfavorable limestone soil and once planted it can be used during a period of up to twenty years, while hemp and flax demand high quality soil each year (Cerchiara et al., 2014). The name *Spartium* is from the Greek word denoting “cordage”, in allusion to the use of the plant. The stem fibers have been used since ancient times as a hemp substitute, being used mainly for coarse fabrics and cordage. Spanish Broom cortical fibers are multiple elementary fibers (*ultimates*) arranged in bundles. The elementary fibers are bound together by lignin. A thick secondary cell wall indicates a high cellulose content. The diameter of *ultimates* varies from 5 to 10 μm while the diameter of the whole bundle is about 50 μm (Angelini et al., 2013). Spanish Broom has been considered a potential interesting source of natural, sustainable, and renewable fiber for textile and technical applications. These fibers derived from the plant branchlets (known as *vermenes*) show extraordinary tensile resistance and flexibility and are able to produce materials in combination with biodegradable and plastic matrices.

Figure 5. Tensile test on a Spanish Broom natural sprig.

Figure 6. Tensile test on a Spanish Broom rope.

Within the present experimental tests, both fibers of Spanish Broom as a natural sprig (Fig. 5), as well as pieces of twine drawn from a rope ball (Fig. 6), were examined by tensile tests.

The diameter of the rope was equal to 0.9 mm. The diameter of each natural sprig specimen, assumed circular in shape, was measured using a micrometer with a precision of 0.01 mm; these diameters were registered into an interval ranging from 3.51 to 5.33 mm. All the tested samples – each one having a free length of 200 mm – were fixed to the grips of the machine, removing the slack without stretching the sample; making certain that the specimen was well aligned and straight within the grips and in the line along the applied load to the fiber, since any misalignment could produce the transverse movement of the clamps and hence introducing errors in the measurement of elongation and contributing to the premature failure of the fiber.

3. Results and discussion

3.1. Adobe bricks

In Table 1 the results of compression tests on the four different types of adobe bricks are reported in terms of average value with the corresponding 95% confidence interval (UNI 5309-66). From these results it can be concluded that the compression strength of the adobe bricks appears to be similar to those with no natural fiber added (Lista, 2015), and in general agreement with the results reported within the scientific international literature (Parisi et al., 2015; Sharma et al., 2015; Vega et al., 2011), the addition of fibers having apparently not led to a significant increase in compressive strength of soil.

Fig. 7 reports a diagram stroke/load for one of the tested adobe bricks. It can be noticed that the behavior of this material is almost elastic in the first phase, followed by a very limited plastic phase, that quickly precedes the definitive failure of the cubic specimen.

From the results obtained through the present experimental tests it can be concluded that further analysis should be performed, aimed to the definition of optimal mixture of soil with natural fibers. The presence of fibers, together with their length, plays in fact a significant role in the compressive strength improvement of soil (Sharma et al., 2015), giving a general increase of the mechanical strength, since fibers, even due to their increased aspect ratio (length/diameter) compared to non fibrous filler, usually improve the mechanical properties of composite materials.

Moreover, in addition to possessing greater compressive strength, the adobe bricks prepared with higher percentage in straw could undergo less shrinkage. This characteristic, together with an average density usually lower than that

Table 1
Compressive strength of the different adobe bricks experimentally tested.

Adobe brick	WSr	WSo	SBr	SBo
Compressive strength [N/mm^2]	0.92 ± 0.09	1.43 ± 0.34	1.10 ± 0.08	0.97 ± 0.11

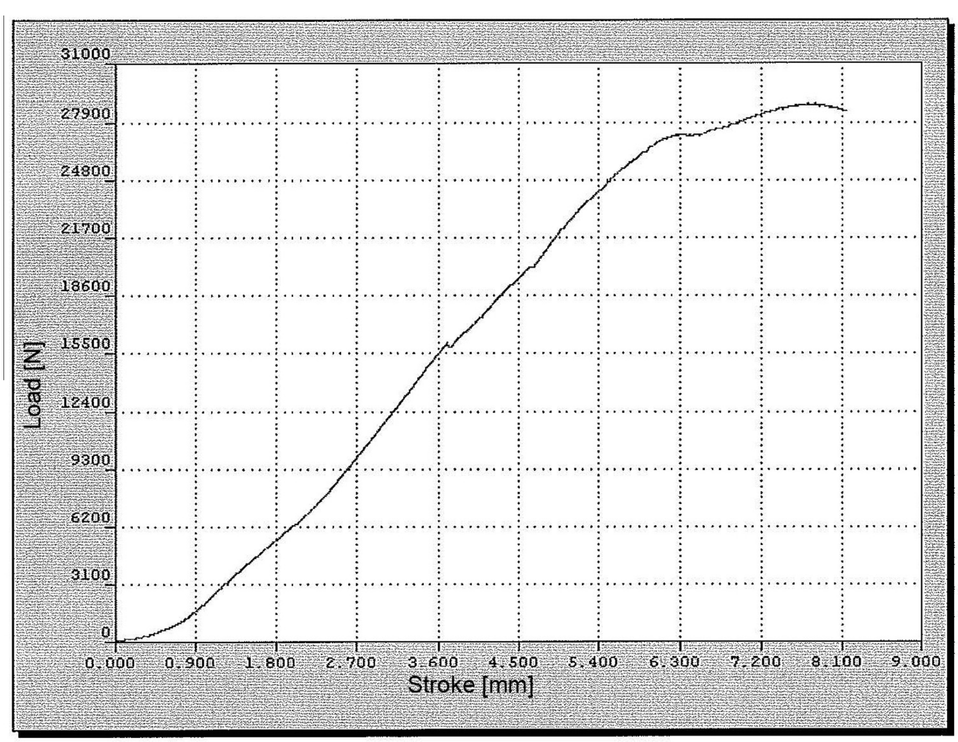

Figure 7. Stroke/load diagram for the compression test on a cubic-shape adobe brick.

of the other mix ratio, represents an advantage in its use as a construction material, as less shrinkage implies a reduced possibility of cracks appearing, and lower density results in a lighter material.

Another important aspect that was observed by some Authors (Vega et al., 2011) is that the adobe bricks demonstrate greater strength when loads are applied perpendicularly to the upper face of the brick, which coincides with the direction in which they were manually pressed during preparation. It would therefore be important to ensure that during construction, they are positioned in such a way that this is the direction in which they receive loads, which is also the same position in which they are laid out to dry once prepared.

3.2. Spanish broom fibers

In Table 2, the tensile properties of both Spanish Broom fibers tested as natural sprig and rope are reported in terms of average value with the corresponding 95% confidence interval (UNI 5309-66).

Table 2
Tensile strength of the Spanish Broom fibers experimentally tested.

Spanish broom fiber	Natural sprig	Rope
Tensile strength σ_t [N/mm^2]	41.53 ± 4.13	36.32 ± 6.37
Strain (%)	2.72 ± 0.19	2.07 ± 0.23

In Figs. 8 and 9 the diagrams elongation/load respectively for one of the tested Spanish Broom natural sprig and rope are reported.

The mechanical behavior of Spanish Broom appears very interesting, mostly because its tensile strength is considerably high, if compared with other different natural fibers.

Many other different natural fibers have, in fact, showed lower tensile strength and strain properties even if, in some cases, much higher results were obtained, as in the case of *Grewia optivia* (Sharma et al., 2015) and specially *Hibiscus cannabinus*. In this last case, from the laboratory tests, an experimental mean value of the tensile strength equal to about 1000 MPa was detected indeed (Millogo et al., 2014), with a high standard deviation depending on the natural variability of the fibers. This tensile stress is even approximately twice higher than steel, with a stiffness twice smaller, which means that this material is 4 times more deformable than steel. This deformability is favorable to reinforce Pressed Adobe Bricks (PABs), which is a material with a low stiffness.

Again in this case (Millogo et al., 2014), anyway, it was noticed that longer fibers and their high contents had a negative effect on the compressive strength of the adobe bricks, since the increase of the mechanical properties is linked to the non-propagation of cracks due to the presence of fibers in the clay matrix. The impact of these fibers on the flexural strength was positive because of the high tensile strength of the fibers and their adhesion to the clay matrix.

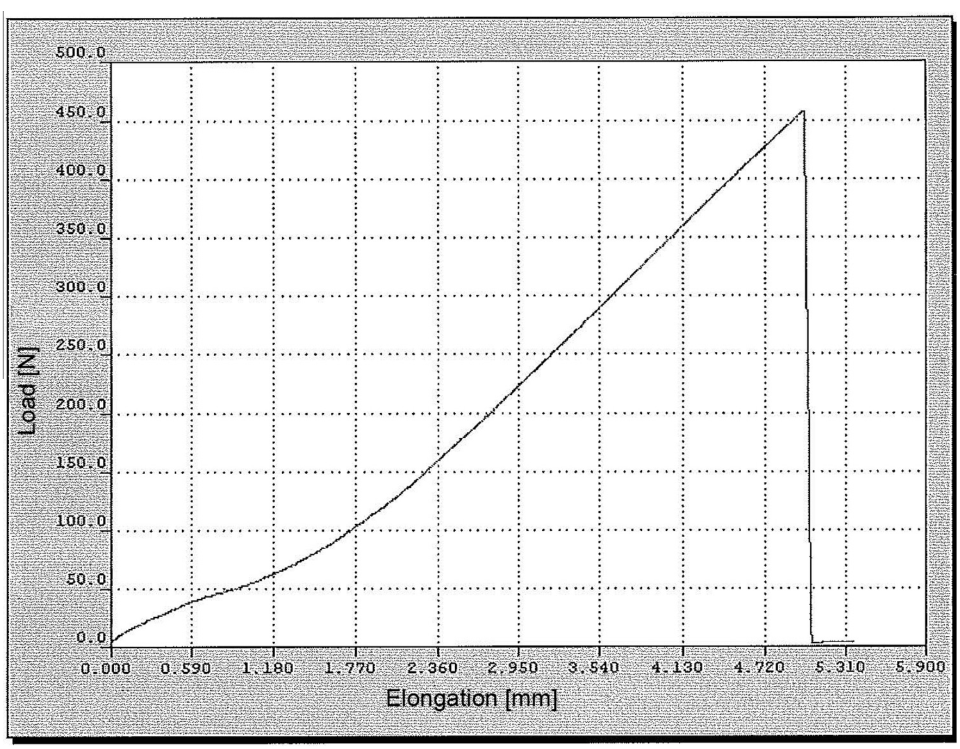

Figure 8. Elongation/load diagram for the tensile test on a Spanish Broom natural sprig.

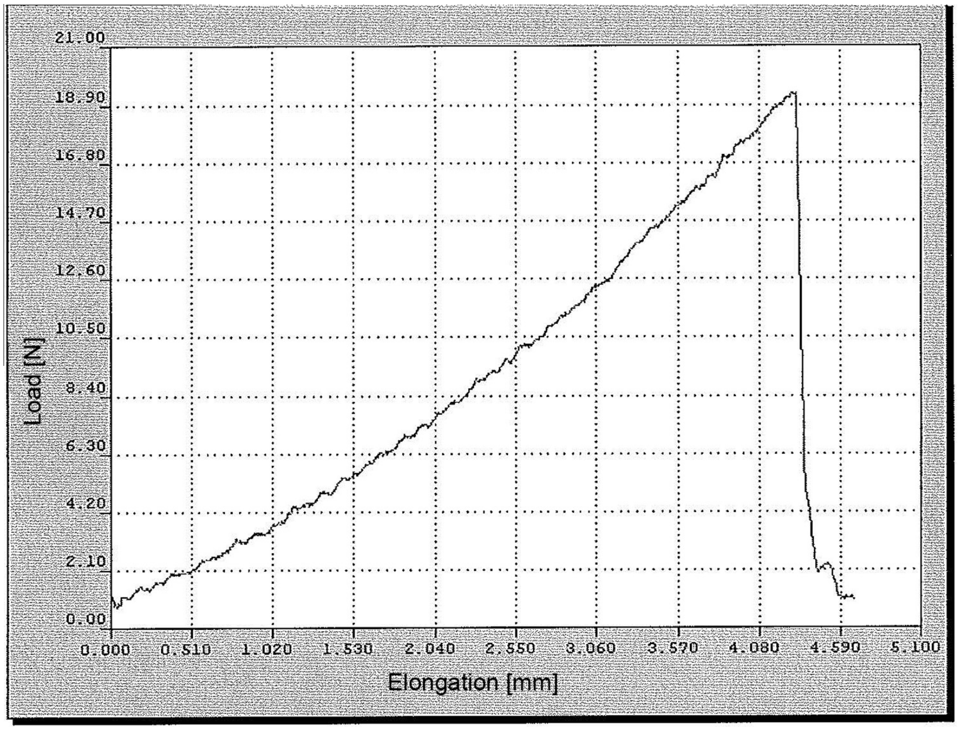

Figure 9. Elongation/load diagram for the tensile test on a Spanish Broom rope.

4. Conclusions

Farm buildings may play a central role for improving the sustainable growth of agriculture, even through new alternative ways for living the extra-urban land, as the rural tourism. The role of rural building is indeed fundamental for enabling practices aimed to reduce resources consumption, combat environmental degradation and create better living environments, preserving at the same time architectural and historical assets that constitute a living witness of the building heritage left by our forefathers, who marked the rural territories, influencing and steering the spontaneous development of nature, while leading to production that enabled to get food.

Since a suitable restoration and functional requalification of the farm building obtained through the use of traditional construction material may contribute to the sustainability of the rural environment, the use of adobe bricks would be a very interesting option, since it is a construction material that presents several attractive characteristics, being low cost, locally available, recyclable, adapted to a large variety of soils, presenting good thermal and acoustic properties, and it is associated to simple constructive methods that require reduced energy consumption. The experimental tests presented in the present paper confirm the general results available in the scientific literature about adobe material, *i.e.* it seems a good solution for non-structural application, with some possible improvements of its mechanical characteristics when, within the earthen mixture, suitable natural fibers are included.

Within these natural fibers, Spanish Broom has been revealed as an interesting option, able to improve the compression strength of the adobe bricks; other mechanical parameters would probably benefit from this reinforcement as well. Future analysis appears thence necessary, mainly focused on the role that natural fibers could perform when mixed into the earthen mixture of adobe bricks, that could be better explored through the study at microscopic level of the adhesion of the fibers to the clay matrix and the consequent effects on the general mechanical properties of the reinforced earth construction.

Acknowledgement

Many thanks to Mr. Cosimo Marano – technical staff at the SAFE School of the University of Basilicata – for his kind support in the performance of the experimental tests.

References

Angelini, L.G., Tavarini, S., Foschi, L., 2013. Spanish broom (Spartium junceum L.) as new fiber for biocomposites: the effect of crop age and microbial retting on fiber quality. In: Hindawi Publishing Corporation – Conference Papers in Materials Science. http://dx.doi.org/10.1155/2013/274359. Article ID 274359.

Baiano, A., Varva, G., De Gianni, A., Viggiani, I., Terracone, C., Del-Nobile, M.A., 2014. Influence of type of amphora on physico-chemical properties and antioxidant capacity of 'Falanghina' white wines. Food Chem. 146, 226–233.

Baiano, A., Mentana, A., Quinto, M., Centonze, D., Longobardi, F., Ventrella, A., et al., 2015. The effect of in-amphorae aging on oenological parameters, phenolic profile and volatile composition of Minutolo white wine. Food Res. Int. 74, 294–305.

Barbari, M., Monti, M., Rossi, G., Simonini, S., Sorbetti-Guerri, F., 2014a. Proposal for a simple method of structural calculation for ordinary earthen buildings in rural areas. J. Food Agric. Environ. 12 (2), 897–903.

Barbari, M., Monti, M., Rossi, G., Simonini, S., Sorbetti-Guerri, F., 2014b. Simple methods and tools to determine the mechanical strength of adobe in rural areas. J. Food Agric. Environ. 12 (2), 904–909.

Bestraten, S., Hormias, E., Altemir, A., 2011. Earthen construction in the 21st century. Informes de la Construccion 63 (523), 5–20.

Cañas, I., Ayuga, E., Ayuga, F., 2009. A contribution to the assessment of scenic quality of landscapes based on preferences expressed by the public. Land Use Policy 26, 1173–1181.

Cerchiara, T., Chidichimo, G., Rondi, G., Gallucci, M.C., Gattuso, C., Luppi, B., Bigucci, F., 2014. Chemical Composition, morphology and tensile properties of spanish broom (*Spartium junceum L.*) fibres in comparison with flax (*Linum usitatissimum L.*). Fibres Text. East. Eur. 22 (2(104)), 25–28.

Fuentes, J.M., 2010. Methodological bases for documenting and reusing vernacular farm architecture. J. Cult. Heritage 11, 119–129.

Fuentes, J.M., Gallego, E., García, A.I., Ayuga, F., 2010. New uses for old traditional farm buildings: the case of the underground wine cellars in Spain. Land Use Policy 27, 738–748.

García, L., Hernández, J., Ayuga, F., 2003. Analysis of the exterior colour of agroindustrial buildings: a computer aided approach to landscape integration. J. Environ. Manage. 69 (1), 93–104.

Hernández, J., García, L., Ayuga, F., 2004. Integration methodologies for visual impact assessment of rural buildings by geographic information systems. Biosyst. Eng. 88, 255–263.

Jeong, J.S., García-Moruno, L., Hernández-Blanco, J., 2012. Integrating buildings into a rural landscape using a multi-criteria spatial decision analysis in GIS-enabled web environment. Biosyst. Eng. 112, 82–92.

Jimenez-Delgado, M.C., Cañas-Guerrero, I., 2006. Earth building in Spain. Constr. Build. Mater. 20, 679–690.

Liberatore, D., Spera, G., Mucciarelli, M., Gallipoli, M.R., Santarsiero, D., Tancredi, C., 2006. Typological and experimental investigation on the adobe buildings of Aliano (Basilicata, Italy). In: Lourenço, P.B., Roca, P., Modena, C., Agrawal, S. (Eds.), Proceedings of the 5th international conference on structural analysis of historical constructions. 6–8 November 2006, New Delhi (India), pp. 851–858.

Lista, A., 2015. Research and development of traditional construction materials for bio-architecture techniques finalized to the valorization of rural land (in Italian: Ricerca e sviluppo di materiali costruttivi tradizionali per tecniche di bioarchitettura finalizzata alla valorizzazione del territorio rurale). University of Basilicata, Potenza, Italy (PhD Thesis).

Lista, A., Sica, C., Picuno, P., 2013a. Ancient roads in southern Italy: a hypothesis of requalification for the valorization of the rural tourism. In: III International Scientific Conference on: Development Trends in Tourism and Hotel Management, 12–13 September 2013, Kotor (Montenegro).

Lista, A., Sica, C., Picuno, P., 2013b. Ancient roads in Southern Italy: an hypothesis of requalification for the valorisation of the rural landscape. In: Proceedings of the First International Symposium on Agricultural Engineering - ISAE 2013, 4–6 October 2013, Belgrade-Zemun (Serbia), pp. VI 45–VI 53.

Lista, A., Gatto, A.G., Sica, C., Picuno, P., 2014. Mechanical characterization of constructive elements from vernacular buildings located along the “Herculia Way”. In: Proceedings of the International Conference on: EPR - European Pilgrimage Routes, 4–6 December 2014, Firenze (Italy), pp. 585–592.

McHenry, P.G., 1989. Adobe and Rammed Earth Buildings: Design and Construction. The University of Arizona Press, Tucson, Arizona, USA.

Millogo, Y., Morel, J.C., Aubert, J.E., Ghavami, K., 2014. Experimental analysis of Pressed Adobe Blocks reinforced with Hibiscus cannabinus fibers. Constr. Build. Mater. 52, 71–78.

Parisi, F., Asprone, D., Fenu, L., Prota, A., 2015. Experimental characterization of Italian composite adobe bricks reinforced with straw fibers. Compos. Struct. 122, 300–307.

Parra-Saldivar, M.L., Batty, W., 2006. Thermal behaviour of adobe constructions. Build. Environ. 41, 1892–1904.

Picuno, P., 2012. Vernacular farm buildings in landscape planning: a typological analysis in southern Italian region. J. Agric. Eng. XLIII-e20, 130–137.

Picuno, P., Stanovčić, T., Moric, I., Dimitrijević, A., Sica, C., 2015. The valorisation of vernacular farm buildings for an innovative rural tourism. In: Proceedings of the 43rd Symposium on: Actual Tasks on Agricultural Engineering – ATAE 2105, 24–27 February 2015, Opatija (Croatia), pp. 807–817, UDC 721:631.2.

Sharma, V., Vinayak, H.K., Marwaha, B.M., 2015. Enhancing sustainability of rural adobe houses of hills by addition of vernacular fiber reinforcement. Int. J. Sustainable Built Environ. 4, 348–358.

Sica, C., Lista, A., Picuno, P., 2015. Mechanical characterization of adobe bricks: ancient constructive elements for an eco-friendly building renovation. In: Proceedings of the 43rd Symposium on: Actual Tasks on Agricultural Engineering – ATAE 2015, 24–27 February 2015, Opatija, Croatia, pp. 819–827, UDC 631.2-691.

Silveira, D., Varum, H., Costa, A., Martins, T., Pereira, H., Almeida, J., 2012. Mechanical properties of adobe bricks in ancient constructions. Constr. Build. Mater. 28, 36–44.

Solís, M., Torrealva, D., Santillán, P., Montoya, G., 2015. Bending behavior analysis of geogrid reinforced adobe walls. Informes de la Construccion 67 (539), e092.

Statuto, D., Tortora, A., Picuno, P., 2014a. Spatial modeling and image processing of historical maps for rural landscape planning. In: Proceedings of the International Conference of Agricultural Engineering- EurAgEng 2014, 6–10 July 2014, Zurich, Switzerland.

Statuto, D., Gatto, A.G., Tortora, A., Picuno, P., 2014b. In: Bambi, G., Barbari, M. (Eds.), Proc. International Conference: The European Pilgrimage Routes for Promoting Sustainable and Quality Tourism in Rural Areas, 4–6 December 2014, Firenze, Italy. Firenze University Press, ISBN 978-88-6655-812-5, pp. 637–648.

Statuto, D., Cillis, G., Picuno, P., 2015. Historical cartography and GIS tools for the analysis of land use and landscape changes. In: Proceedings of the 43rd Symposium on: Actual Tasks on Agricultural Engineering – ATAE 2105, 24–27 February 2015, Opatija, Croatia, pp. 441–450, UDC 528.9-631.471.

Tortora, A., Statuto, D., Picuno, P., 2015. Rural landscape planning through spatial modelling and image processing of historical maps. Land Use Policy 46, 71–82.

UNI 5309-66, 1966. Metodi statistici per il controllo della qualità. Presentazione di una media con il corrispondente intervallo di fiducia. In: Italian – Statistical methods for quality control - Presentation of an average with the corresponding confidence interval. Unificazione Milano, pp. 1–5.

Vega, P., Juan, A., Guerra, M.I., 2011. Mechanical characterisation of traditional adobes from the north of Spain. Constr. Build. Mater. 25, 3020–3023.

Vissilia, A.M., 2009. Evaluation of a sustainable Greek vernacular settlement and its landscape: architectural typology and building physics. Build. Environ. 44, 1095–1106.

Zhai, Z., Previtali, J.M., 2010. Ancient vernacular architecture: characteristics categorization and energy performance evaluation. Energy Build. 42, 357–365.

http://www.terracruda.org/ (last access: 2 January 2016).