Protecting earthen heritage using a green strategy: a study about natural water repellents

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Abstract

Using earth as a construction material is an ancient technique that can be found around the world in monumental and vernacular architecture. Earthen heritage is also associated with maintenance techniques employing natural and local products still being used in some countries. Having those methods as a background, this paper proposes to adopt a green conservation strategy and a scientific approach, learning from traditional procedures to apply on earthen heritage. In the present research, three natural products – arabic gum, linseed oil and beeswax – were studied in terms of efficiency with adobe specimens, by means of non-destructive tests (colorimetry and water absorption). The obtained data shows promising results regarding the use of natural products as an alternative for earthen heritage protection.

Keywords

Earthen heritage, Conservation, Natural products, Water repellents.

Introduction

Earthen construction is a versatile technique still used nowadays, not only for social housing, but also for monumental structures. According to UNESCO, 19% of the World Heritage is partially or completely built with earth (Schroeder, 2016). Moreover, earthen buildings can present different techniques, showing a wide variety of solutions that mankind used to adapt to geographical location, weather conditions and local materials available (Houben & Hubert, 1989). Figure 1 illustrates three of the most common earthen techniques used for construction: adobe, rammed earth and wattle and daub (Correia, 2006; Mileto, Vegas, Cristini, & García, 2011).

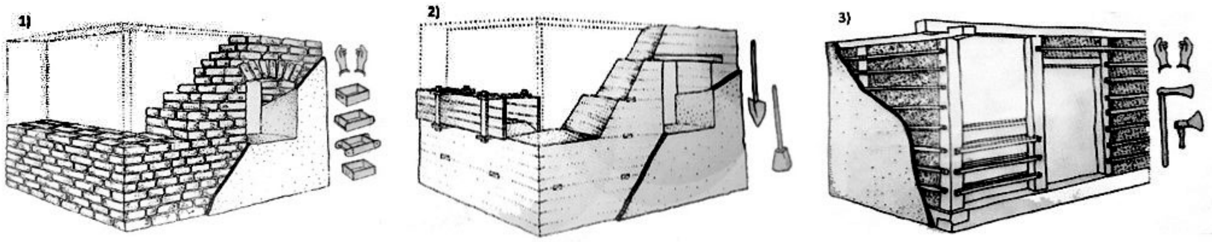


Figure 1 – Illustrative drawings of three of the most common earthen construction techniques. 1) adobe; 2) rammed earth; 3) wattle and daub (source: Mileto et al., 2011).

This adaptability of earth to different methods of construction is due to the constitution of soil, which, in equilibrium with all its elements, can produce a stable and mouldable material. One of the most important components in soil structure is clay, since clay particles in contact with water work as a binder, acquiring plasticity and cohesion properties. After being dried the material becomes stiff and resistant; however if water is added again, this state is reversible (González, 2006). This exchangeable characteristic of clay, although with all its advantages regarding workability, represents also one of the most vulnerable aspects from a conservation point-of-view. Consequently, the interaction between water and earthen materials is one of the most common causes for material degradation (Aguilar et al., 2016; Elert, Sebastián, Valverde, & Rodriguez-Navarro, 2008).

Since earthen construction is a millenary practice, populations learned how to preserve their own buildings and monuments, most of the times using local and natural products (Ribeiro, Oliveira, & Lourenço, 2019). By observing nature and trying different recipes, our ancestors understood some properties added by plants, fruits, or animal products and how to apply them as a protective layer in their constructions (Fontaine & Romain Anger, 2009). Nowadays, in some countries, the same recipes are still used and passed through generations, constituting not only an important intangible asset but also a fundamental source of knowledge. Traditions and know-how of populations concerning preservation of heritage (vernacular or monumental) is essential when dealing with this type of constructions and empirical knowledge plays an important role that should not be neglected.

Having this idea as a background – that learning from our ancestors’ traditions one may discover solutions for contemporary problems – this paper aims to study some of those natural products used for protecting constructions from the humidity and rain. Furthermore, using natural and local products, a green strategy may be adopted contributing for a more sustainable future. The way historical cities and their heritage is preserved needs a change in its paradigm in order to follow the environmental changes that Earth is facing (Appendino, 2017). The target for energy reduction stablished by the European Technical Committee is for 20% until 2020, meaning an urgent decrease in gas emission and consumption of world resources (Loli & Bertolin, 2018). Conservators are daily exposed to toxic synthetic products that not only represent a risk for their health, but also contribute for increasing the greenhouse effect due to the factors previously exposed. New green solutions and strategies are needed so future generations can learn from our heritage.

Hydrophobic treatments in earthen heritage

A common practice as a preventive measure for conservation of heritage-built façades is to use a water repellent external coating. When these constructions are exposed to rain, protecting their surfaces against liquid water may reduce the degree of deterioration due to exposure to normal environmental conditions (Siegesmund & Snethlage, 2014). Hydrophobic products work as a barrier between surface and water (in liquid state), making rain to run down instead of wetting the protected material. An important characteristic of a water repellent product is that it should not seal the material porous matrix, allowing the diffusion of water vapor. This way, liquid water cannot penetrate in the surface, but vapor water can be dispersed. To prevent the normal hydrophilic properties of a porous material, a water repellent acts as a layer that decrease the solid-liquid attraction forces, preventing a drop to spread over the surface and compelling it to form a spherical shape (Domaslowski, 2003). Therefore, an ideal hydrophobic treatment should be compatible, reversible, invisible (should not change colour or appearance of the original surface), and impermeable to liquid water, but permeable to water vapor diffusion. However, such a product, that combines all these important characteristics, is almost impossible to find (Aires-Barros, 2001). That is why it is crucial a detailed and careful evaluation of the state of conservation of an earthen building, identifying not only all degradation phenomena, but also the causes for existing pathologies.

As previously referred to, water is one of the main causes for earthen material degradation (see Figure 2). Capillary action affects mainly the base of the building, while rain causes more damage in the façade and top of walls. Infiltrations and impact of rainwater against the surface are the main causes for material degradation, affecting not only the external part, but also compromising the physical stability of the structure (Mileto & Vegas, 2017). Due to clay chemical composition and crystallography structure, it bonds with water and consequently it acquires a plastic behaviour (Das, 2011). This changing process of clay when in contact with water is observed by several phenomena that occurs in an earthen construction, such as: expansion of clay particles; changing to a plastic state (becoming deformable); and possible material loss or erosion (Mileto & Vegas, 2017). Therefore, creating preventive measurements to avoid water damage in earthen heritage is an urgent matter that requires more efficient solutions.

Figure 2 – Examples of earthen buildings with deterioration phenomena caused by exposure to rain: (a) poor roofing system and the lack of a protection layer induced an infiltration problem with appearance of cracks (Cuzco, Peru, credits: author); (b) intense rain caused the detachment of an unprotect earthen mortar render (Yazd, Iran, credits: author).

In the last years, relevant research about earthen heritage preservation has been developed and established (Correia & Walliman, 2014). Nevertheless, when dealing with such complex material as earth, a holistic approach is necessary to reach better answers on how to preserve it. Unfortunately, empirical knowledge and scientific research not always work together, and solutions to protect earthen historical buildings from water damage vary according to the ideas of who is in charge (Correia, 2016). Building a new structure on top of the existing site or surrounding it is usually an architectural approach; stabilising earth by mixing with hydrophobic products, creating a new material is a common method studied by engineering and material science community; applying commercial water repellent products on earthen heritage surface is a practice frequently developed by conservators (see Table 1). So, which approach is correct, or more appropriate? There is no direct reply to this question since each case should be analysed carefully and individually, and most important it should always be created a multidisciplinary team to achieve the best solution.

Table 1 – Examples of water repellent products tested.

Year	Water repellent		Test method	Reference
2007	Lime and metakaolin	(natural)	Additive: mixture with compressed earth blocks	(Eires & Jalali, 2007)
2010	Starch, linseed oil, and glycerol	(natural)	Additive: mixture with compressed earth blocks	(Eires, Camões, & Jalali, 2010)
2012	San Pedro Cactus	(natural)	Mixture in the earth to produce adobe blocks	(Checa & Cristini, 2012)
2012	Siloxane	(synthetic)	Surface coating: case study in rammed earth walls	(Martínez, Aynat, & Marcos, 2012)
2016	Chitosan	(natural)	Coating and admixture on adobe samples	(Aguilar et al., 2016)
2017	Carrageenan	(natural)	Additive: incorporate in the mixture for adobe production	(Nakamatsu et al., 2017)

However, sometimes the answer can be in the simplest solution. An interesting exercise is to look to what our ancestors used to do to preserve their buildings and monuments. By observing the nature, and understanding what type of materials were surrounding them, they developed recipes that were able to protect their constructions from water damage (Fontaine & Romain Anger, 2009). But there is an important aspect that needs to be highlighted: these protective methods require maintenance. Nowadays, a solid preventive conservation plan is often neglected giving room to extensive restoration interventions, instead of small and less intrusive works planned for a certain period of time. This is based in the erroneous idea that this way is less costly. Adopting a more sustainable perspective regarding conservation interventions is a necessary path. Natural and local products may be a solution if one looks back to history and know how to use it in modern times.

Experimental work

In order to evaluate the efficacy and drawbacks of using natural water repellents on adobe bricks, three products were selected and tested. The selection of these products was based on literature review (Vissac, Bourgès, Gandreau, Anger, & Fontaine, 2017) and availability in the Portuguese context. For experimental analysis, two main parameters were tested: colorimetry (by calculating ΔE*) and water absorption either by contact sponge method (Ribeiro, Oliveira, & Bracci, 2020) or microdrop absorption time, both non-destructive methods.

Materials and Methods

Adobe blocks (30cm x 15cm x 7cm) brought from Montemor-o-Novo (Alentejo region, South of Portugal) were cut into cubes of approximately 7cm side. Specimens were characterized in terms of density and porosity. Density was calculated by the ratio of mass per volume. Porosity was calculated with the ratio of voids volume to total volume (Das, 2011).

A set of geotechnical, mineralogical, and chemical analyses was performed to characterize the adobe specimens in terms of: particle size distribution (*LNEC E196* 1966); density (*NP-83* 1965); Atterberg limits - Liquid limit (LL), Plastic limit (PL), and Plasticity index (IP) (*NP-143* 1969); X-ray diffraction (XRD); and energy dispersive X-ray fluorescence (EDXRF). The resume of these results is reported in Table 2.

XRD analysis were carried out using a Philips PW-1830 diffractometer with a Cu Kα radiation. The operational conditions were 40 kV, 50 mA, a step size of 0.02° 2θ in the 3-90° 2θ range, and a step time of 2.50 seconds. The samples were dried and grounded before testing. For EDXRF, three samples from each soil were analysed using an ArtTAX X-ray spectrometer (Bruker), equipped with a Xflash (Si (Li)) detector, with 170 eV resolution, and operating with a molybdenum X-ray source. Through the average of three independent spots, elemental composition was acquired, using a tube voltage of 40 kV, a current intensity of 600 μA, and a live time of 180 s.

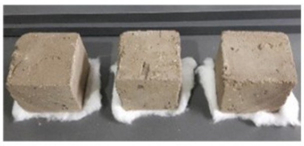
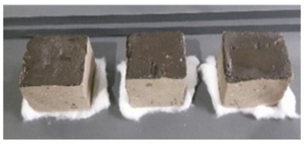
Table 2 – Adobe specimens' characterization.

	Density (g/cm^3)	Porosity (%)	Particle size distribution	Bulk density (g/cm^3)	Atterberg limits	XRD	XRF
Adobe specimens	1.96	0.82	0% Gravel 58% Sand 15% Silt 27% Clay	2.63	LL 29% PL 18% IP 11%	Quartz, albite, pargasite	Al, Si, K, Ca, Cr, Mn, Fe, Cu, Zn, Ba, Pb

Regarding the water repellent products, the selection was based on literature review, having as a main objective exploring the use of natural coatings. Arabic gum is extracted from acacia trees and is used mainly in Africa as a protection and for fix the surface of earthen constructions (Correia, Guerrero, & Crosby, 2016; Vissac et al., 2017). Since it can be dissolved in cold water, the preparation is easy, fast and low-cost. Linseed oil has been used since 15th century for paintings and as a protection layer in earthen plasters or surfaces, especially in Europe. This oil is obtained through grounding of the seeds and has impermeabilization properties since, as any other oil, it does not mix with water (Vissac et al., 2017). Beeswax is a natural wax produced by bees and it was commonly used as a water repellent in European earthen constructions (Correia et al., 2016).

All these three products were applied directly on top of the adobe specimens' surface, on two layers – one horizontal and one vertical – to guarantee complete coating, using a soft brush. Arabic gum was dissolved in cold water with a proportion of 1:4, linseed oil was applied without any solvent, and beeswax was prepared in a 5% turpentine solution (Table 3). All products were applied in five specimens each in a controlled laboratory environment of 20˚C and 60% relative humidity. Even though the products dried after 48 hours, all specimens were kept in the same conditions (20˚C and 60% relative humidity) for 15 days for stabilization purposes before and after application of the products.

Table 3 – Example of some adobe specimens before, during and after the application of three natural water repellents.

Product	Before application	Application	After dried
Arabic gum 			
Linseed oil 			
Beeswax 			

Contact sponge method was performed following Italian Standard (UNI 11432:2011). Preliminary tests to define the contact time between the sponge and the sample were done, setting it to 60 seconds. Colorimetric parameters were accessed in a quantitative way using the coordinates L*, a*, and b* (CIE, 1976) and the standard procedures (UNI EN 15886:2010). The equipment used was a Datacolor Spectraflash SF600® Plus CT, under D65 illuminant, measuring 9 spots for each specimen. To obtain the colour variation between reference specimens and the ones with product applied, **ΔE*** was calculated according to eq. (1):

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

For microdrop absorption time (RILEM 25PEM:1980) a pipette approximately 1cm away from the specimen was used, and a set of 9 drops of distilled water (≈4 μl) were placed over the surface of each specimen. The time taken by each drop to be completely absorbed or evaporated was measured and compared with a reference surface (non-polished glass). All tests were carried out under controlled laboratory conditions, at 20˚C and 60% relative humidity.

Results and Discussion

In order to evaluate the efficacy of the applied natural products in terms of hydrophobic parameters, two sets of tests were performed: contact sponge and microdrop absorption time.

In the contact sponge test, it is possible to observe a decrease on water absorption after application of the products. Reference adobe specimens (without any water repellent) show an average value of water absorption of 3.80E-04 g/cm^2.sec while specimens with arabic gum exhibit a decrease of water absorption of 87% and linseed oil, as well as beeswax, showed a decrease of 93% (Figure 3). This means that all three natural products work as water repellent since there is a significant reduction on water absorption by the adobe surface. As previously mentioned, a surface shows non-wettability property when solid-liquid attraction forces are reduced, and this parameter can be measured, in this case, by the reduction of water absorption.

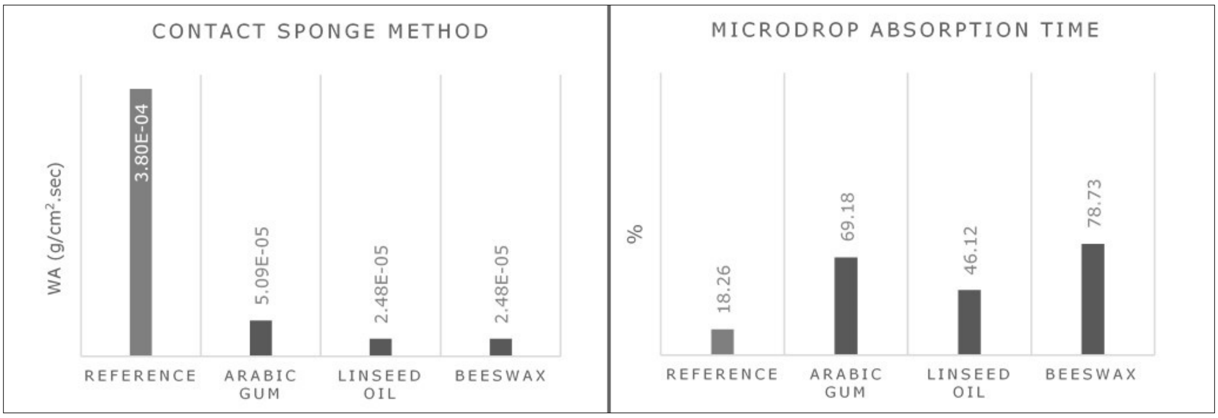


Figure 3 – Contact sponge and microdrop absorption time test results on adobe reference specimens and specimens with natural repellent coatings.

To confirm these results, another test was performed also related with water absorption: microdrop absorption time. Values equal or superior to 100% indicate that the water repellent product is completely hydrophobic. Looking at Figure 3, it is possible to observe an increase in the time that microdrops of water take to be absorbed by the specimen surface when a product is applied. Although the tested natural water repellents did not reach 100%, meaning that they are not totally hydrophobic, there is a significant increase in the absorption time when compared with the reference samples. Also, during the test, it was possible to notice that while in a non-treated surface all drops of water spread and started to be absorbed immediately, in the specimens with water repellents, all drops formed a spherical shape (Table 4). In the adobe reference specimens, microdrops take an average of 5 minutes to be absorbed, while in specimens with a layer of arabic gum, microdrops stay in the surface for an average of 20 minutes, with linseed oil 14 minutes, and with beeswax 23 minutes.

Although these products are not 100% hydrophobic, they exhibit a strong water repellence factor proved by a drastic decrease on water absorption, and by the spherical shape that drops of water adopt when in contact with the protected earthen surface, see also Table 4.

Table 4 – Top and perspective view of microdrops in contact with adobe specimens without treatment (reference) and with a layer of natural water repellent (arabic gum, linseed oil, and beeswax).

	Reference	Arabic gum	Linseed oil	Beeswax
Top view				
Prespective view				

Regarding colour measurements, **ΔE* was a**ssessed for all specimens with applied natural water repellents. Values show that all products changed the original colour (linseed oil and beeswax with a ΔE* of 7.6 and 8.2, respectively), being arabic gum the one with less variation (with a ΔE* of 2.1) (Table 5). Looking specifically for the results of each coordinate, it is possible to conclude that linseed oil and beeswax have higher variations in terms of L* values, which, being negative, indicate a darkening of the surface.

Table 5 – Values of variation for each coordinate (regarding reference specimens).

	ΔL*	Δa*	Δb*	ΔE*
Arabic gum	0.6	1.4	1.4	**2.1**
Linseed oil	-6.8	3.4	-0.6	**7.6**
Beeswax	-7.0	2.6	-3.4	**8.2**

Conclusion

In order to face current challenges regarding environmental actions to earthen heritage, the paradigm of conservation methods and ethics needs to be reviewed. The continuous use of products that represent potential danger for its users and that may be unsuitable for earthen heritage, as well as with great impact in terms of resources consumption is an urgent matter to be addressed. Protection through regular maintenance is an ancient practice that has been lost over modern times, however valuable lessons can be learned from it. Using natural and local products for conservation treatments may be seen as a non-proofed or even inefficient method, since more research is needed in this area. The present paper aimed to study the possibility of applying a natural oil, wax and gum as a protective layer against water for external earthen heritage surfaces, achieving promising results.

In terms of water absorption, all three products showed a significant reduction of this parameter, acting as a barrier against absorption by liquid water. Also, microdrops test revealed a clear change in water behaviour when in contact with the earthen material – instead of spreading along the surface, the drops formed a spherical shape indicating water repellence. Moreover, both tests (contact sponge method and microdrops absorption time) proved to be useful as non-destructive methods to evaluate water absorption by earthen materials. Regarding colour change, all products presented a variation, the arabic gum being the one that induces a minor colour variation. Colour change is a very important issue when dealing with heritage, since any product applied on a surface should interfere as little as possible with appearance. Nevertheless, it is important to refer that the present study was performed in one type of soil and in adobe structures, which means that colour variation may change with other types of soils. As any other product, preliminary tests should be carried out before any intervention.

To summarise, the three natural and renewable products here tested, commonly used in the past as protective layers on earthen constructions, can be considered valid for this function, due to major improvement in reducing the water absorption. However, further research is required especially regarding durability to understand the behaviour of these products over time. Testing different soils and different constructions techniques could be an important step forward.

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Authors' *Curriculum Vitae*

Telma Ribeiro, graduated in 2008 with a Master Degree in stone conservation at the Department of Conservation and Restoration of Nova University of Lisbon. In 2009 she started working for a national private company of monuments conservation, developing several works as a conservator. Since March 2016, she is a PhD student in Conservation Science, and her project is being developed with a partnership between Conservation and Restoration Department (Nova University of Lisbon) and Civil Engineering Department (University of Minho). The aim of her research is to draw the attention for the importance of earthen heritage preservation and to contribute for the advancement of scientific knowledge in this field. Her research interests include also analysis of the interaction between consolidation and water repellent products (natural and synthetic) and the earth material; development of a methodology based on test results; and in-situ non-destructive analysis.

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Daniel V. Oliveira has a Bachelor and a Master Degree in Civil Engineering by University of Porto, and a PhD Degree in Civil Engineering by University of Minho. Currently, he is Associate Professor at the Department of Civil Engineering of University of Minho. His main research interests are related to the experimental and numerical analysis of traditional masonry structures, earthquake engineering, strengthening of masonry structures based on innovative composite materials, earthen construction, risk assessment and durability. Daniel Oliveira has been involved in several research projects in the field of masonry, funded on a competitive basis, e.g. www.heritagecare.eu and www.niker.eu. He is author of more than 300 technical and scientific publications about masonry. He worked in 4 RILEM committees as researcher and secretary, dealing with the strengthening of masonry and earthen constructions.

Susanna Bracci received a Master Degree in Chemistry at the University of Florence. From 1988 to 1993 she was fellowship at IROE-CNR (now IFAC-CNR). From 1994 to 1996 she was Researcher (3rd level) at Institute for Applied Physics "Nello Carrara" IFAC-CNR (former Research Institute on Electromagnetic waves-IROE-CNR). From 2002 to 2007 she was Researcher (3rd level) at CSCOA-CNR (from 2002 ICVBC-CNR). From 2007 she is Senior Researcher (2nd level) at the Institute for Heritage Science of National Research Council (ISPC-CNR, former ICVBC-CNR). Her research activity is mainly devoted to the study of the performances and characteristics of the materials for the conservation of stone materials. She is also leading the ISPC Mobile laboratory for the in-situ diagnostics of works of art including paintings, frescoes and glasses (mosaics and stained glass windows). She is author of more than 150 publications (including 60 international journals and 31 contributions to books) and more than 100 technical reports. She is involved in both Italian (UNI-NORMAL) and European (CEN/TC346 WG3) Technical Committee for standardization.

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