# Water Repellents in Rammed Earth Heritage Conservation: Using Ancient Products as a Solution for Contemporary Challenges

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***Abstract:*** *Earthen heritage represents an important legacy regarding not only the history of construction but also the knowledge of a millenary practice based on empirical expertise, social conditions, and cultural development. Looking at nature and exploring all the local products that it could provide and how to use them to improve ways of living and building was a common strategy. And while earthen construction requires regular maintenance that is usually done by the local population, the preservation of earthen heritage sites is still a challenging endeavor requiring deeper research, especially from conservation science. It is possible to find natural materials with properties that can prevent degradation phenomena and protect earthen surfaces from typical deterioration agents, specifically from water in the form of rain and humidity. The present work aims to study four water repellents—one synthetic (siloxane) and three natural materials (gum arabic, linseed oil, and beeswax)—applied to rammed earth specimens and offer a case study. Laboratory and in situ tests—namely, the contact sponge method and microdrop absorption—were performed to assess the compatibility and efficacy of the applied products. The main results and conclusions are presented and discussed.*

***Resumen:*** *El patrimonio de tierra constituye un legado importante que tiene que ver no solo con la historia de la construcción, sino también con los conocimientos de una práctica milenaria que se basa en la experiencia empírica, las condiciones sociales y el desarrollo cultural. La estrategia más frecuente consistía en observar la naturaleza y explorar todos los productos locales que pudieran ser útiles, viendo la manera en que se podían utilizar para mejorar la forma de vivir y construir. Asimismo, la construcción de tierra requiere de un mantenimiento regular que, por lo general, realiza la población local. Sin embargo, en muchos casos, la preservación de los sitios patrimoniales de tierra sigue siendo un desafío que requiere una investigación más profunda, sobre todo, desde el punto de vista de la ciencia de la conservación. Es posible encontrar materiales naturales con propiedades que previenen el fenómeno de la degradación y protegen las superficies de tierra. Este tratamiento de protección actúa principalmente contra uno de los agentes típicos de deterioro en la construcción de tierra: el agua. Por lo tanto, la protección contra la lluvia y la humedad es un factor importante cuando se trata de este tipo de materiales. El objetivo de este documento es estudiar cuatro repelentes de agua, uno sintético (siloxano) y tres naturales (goma arábiga, aceite de linaza y cera de abejas), aplicados en especímenes de tierra apisonada, además de un estudio de caso de tierra apisonada. Las pruebas de laboratorio y en el lugar, por ejemplo, el método de la esponja de contacto y la absorción por microgotas, se realizaron con el fin de evaluar la compatibilidad y la eficacia de los productos aplicados. Se presentan y debaten los resultados y las conclusiones principales.*

**Keywords:** earthen heritage, conservation, rammed earth, water repellents, natural products

## Introduction

There is no doubt about the importance of earthen architecture since it walks side by side with the history and evolution of humankind. Acknowledging its significance and impact—not only in ancient civilizations but also in modern societies—is a step forward toward the conservation and continuation of this valuable legacy. Moreover, because local communities play crucial roles in the maintenance of their heritage, earthen construction encompasses the actual buildings as well as the social and cultural intangible values that surround them. Consequently, the involvement of the population and the study of their shared knowledge should not be neglected when designing conservation plans regarding earthen heritage buildings, as this insight can provide valuable solutions for the existing degradation problems.

As of 2019, UNESCO classified 161 earthen properties as World Heritage Sites (Joffroy 2012; UNESCO 2020). Fifteen percent of these are made with the rammed earth technique. Traditionally, rammed earth consists of manually compacting earth into a wood formwork in layers (González 2006). Rammed earth structures are commonly coated with an earthen plaster that acts as a protective and sacrificial layer. However, in severely degraded heritage buildings where this layer no longer exists, it may be necessary to protect the exposed rammed earth by applying products that act as a barrier between the surface and the main deterioration agent—water (Siegesmund and Snethlage 2014). The water repellent products should not seal the material's porous matrix, but should prevent liquid water from penetrating the surface and allow the diffusion of water vapor (Domaslowski 2003).

## The Use of Natural Products as Surface Protection

The use of natural and local products, especially as surface protection agents, is a common practice in countries that still use earth as a construction material for dwellings and monuments. The recipes generated by observing nature, including descriptions of products and procedures, have been passed down through generations (Fontaine et al. 2009; Vissac et al. 2017). There are many natural products used in these practices and people employ them based on their availability and efficiency (table 1). The use of these products constitutes proactive measures of keeping traditions alive, engaging the community, and implementing sustainable procedures. However, the use of natural products for conservation actions still requires more scientific research to understand their behaviors and interactions with earthen materials. Additionally, the application of synthetic (mainly siloxane-based) coatings to earthen heritage is gaining popularity (Martínez, Aynat, and Marcos 2012; Mileto and Vegas 2017). Although this procedure is widely studied for stone conservation, there is still a lack of scientific research for the case of earthen materials.

**Table 1 Examples of Natural Products Used for the Maintenance of Earthen Buildings**

| Country | Natural product | Application method | Reference |
|---|---|---|---|
| Peru | San Pedro Cactus | Mixed with earthen mortar | (Checa and Cristini 2012) |
| Guinea | Karite butter | Mixed with earthen plaster | (Joffroy 2005) |
| Ghana | Locust bean fruit | Applied on decorative earthen plaster | (Joffroy 2005) |
| Cameroon | Fish oil | Mixed with earthen plaster | (Joffroy 2005) |
| France | Linseed oil | Applied on top of earthen materials | (Vissac et al. 2017) |
| Mali | Gum arabic | Mixed with earthen plaster | (Correia, Guerrero, and Crosby 2016) |

## Research Aim

Given that water is one of the main causes of earthen material degradation (Aguilar et al. 2016; Elert et al. 2008; Ribeiro, Oliveira, and Bracci 2020), the present study aims to evaluate the efficacy of using natural water repellents on rammed earth. This study is focused on the degradation caused by water in its liquid state and on the protection of external walls. Three natural products and one synthetic product were selected and applied to rammed earth specimens under laboratory conditions and in a case study. The selection of these products was based on the literature review (Vissac et al. 2017) and the availability of the products in the Portuguese context. For the evaluation of the products' efficacy, water absorption (through contact sponge method) and water repellency (through microdrop absorption time) tests were performed, as well as visual assessments of the impacts of the applied treatments.

## Materials and Methods

Rammed earth specimens were prepared in the laboratory using soil collected in southern Portugal, a region known for

**FIGURE 1** General aspects of the rammed earth specimens. All photos: T. Ribeiro.

its rammed earth heritage. The specimens were produced according to traditional techniques, which involved compacting the earth manually into a wood formwork, creating cubes of approximately 10 cm/side that were then left to dry for four weeks (fig. 1). The raw material was sieved earth with no stabilizer. The size of the specimens was set at 10 cm/side to guarantee a representation of all grain sizes within the samples and to have at least two layers of compaction. The 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).

Geotechnical, mineralogical, and chemical analyses were performed to characterize the rammed earth 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 (PI) (NP-143 1969), X-ray diffraction (XRD), and energy dispersive X-ray fluorescence (EDXRF). The summary of these results is reported in table 2.

XRD analyses were carried out using a Philips PW-1830 diffractometer with 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 s. The samples were dried and ground before testing. For EDXRF, three samples from the same soil were analyzed using an ArtTAX X-ray spectrometer (Bruker), equipped with an Xflash (Si [Li]) detector, with 170 eV resolution, and operating with a molybdenum X-ray source. Elemental composition was acquired through the average of three independent spots using a tube voltage of 40 kV, a current intensity of 600 μA, and a live time of 180 s.

Four water-repellent products were selected, three natural and one synthetic: gum arabic, linseed oil, beeswax, and siloxane. Gum arabic is extracted from acacia trees and is used mainly in Africa as protection from water and for repairing the surface of earthen constructions (Correia, Guerrero, and Crosby 2016; Vissac et al. 2017). It can be dissolved in cold water and its preparation is easy, fast, and inexpensive. Linseed oil has been used since the fifteenth century for paintings and as a protective layer for earthen plasters or surfaces, especially in Europe. This oil is obtained through ground linseeds and has impermeabilization properties since it does not mix with water (Vissac et al. 2017). Beeswax is a natural wax produced by bees and was commonly used as a water repellent in European earthen constructions (Correia, Guerrero, and Crosby 2016). Finally, the siloxane used in this experimental work, SILO 112 from CTS, is a commercial product. All four products were applied directly on the rammed earth specimens' surfaces, on two sequential and perpendicular layers to guarantee a complete coating. Gum arabic was dissolved in cold water in a proportion of 1:4, linseed oil was applied without any solvent, beeswax was prepared in a 5% turpentine solution, and siloxane was applied directly following the supplier instructions (fig. 2). All products were applied to five specimens, each in a controlled laboratory environment (20°C and 60% RH). All specimens were kept in these same conditions for fifteen days for stabilization purposes before and after application of the products.

The contact sponge method was performed following the Italian Standard (UNI 11432:2011 2011), with a sponge and specimen contact time of 60 s. For microdrop absorption time (RILEM 25PEM:1980 1980), a pipette (placed approximately 1 cm away from the specimen) delivered a set of nine drops of distilled water (≈4 μl) to the surface of each specimen. The time that it took for each drop to be completely absorbed or evaporated was measured and compared with a reference surface (non-polished glass).

**Table 2 Characterization of Rammed Earth Specimens**

| **Density** (g/cm$^3$) | **Porosity** (%) | **Particle size distribution** | **Bulk density** (g/cm$^3$) | **Atterberg limits** | **XRD** | **XRF** |
|---|---|---|---|---|---|---|
| 2.19 | 0.53 | 42% gravel<br>34% sand<br>13% silt<br>11% clay | 2.65 | LL 45%<br>PL 24%<br>PI 21% | Quartz, kaolinite, feldspar, muscovite | Al, Si, K, Fe, Cu, Zn, Cr |

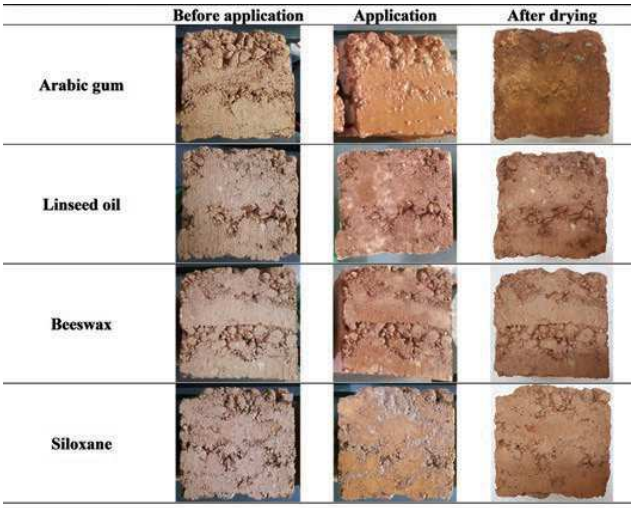


**FIGURE 2** Example of one rammed earth specimen before, during, and after the application of the three natural and one synthetic water repellent products.

## Laboratory Campaign: Results and Discussion

The contact sponge method was performed to evaluate water absorption and the main results are reported in figure 3. It is possible to observe a drastic reduction in water absorption after the application of all products, with a decrease of 98% for both beeswax and siloxane, 95% for linseed oil, and 87% for gum arabic. Microdrop absorption time was performed to determine water repellency and the obtained values are reported in figure 3. Water repellency increased for all specimens after the products' application, indicating the presence of a barrier between the surface and the water. However, when compared to the natural products, siloxane shows a water

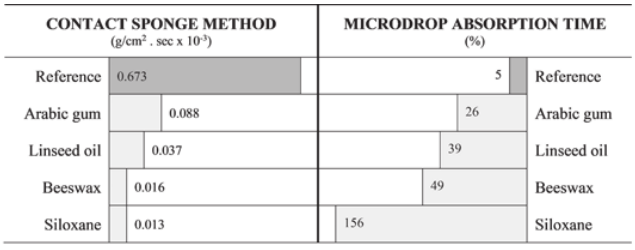


**FIGURE 3** Contact sponge method and microdrop absorption time results for the rammed earth specimens with and without the water repellent treatments.


**FIGURE 4** Examples of water droplets on top of treated and untreated rammed earth specimens during the microdrop absorption time test.

repellency level value over 100%, indicating that the surfaces became completely hydrophobic.

The microdrop absorption time test showed that all drops of water spread out and were immediately absorbed in non-treated areas and that all drops formed a spherical shape on the areas treated with water repellents (fig. 4). It is important to note that even though the natural products do not exhibit results over 100% (indicating that they are not fully hydrophobic), they still showed strong water repellency as seen by a significant decrease in water absorption, by the increase in water repellency, and by the spherical shape that drops of water assumed when in contact with the treated earthen surfaces.

## In Situ Campaign: Results and Discussion

To compare with the laboratory results previously discussed, a case study was selected and in situ tests were performed. The case study involved the Rammed Earth Portico, located at the University of Minho (Guimarães campus), that was built during a training workshop in April 2013. Two types of raw material mixtures were used: unstabilized soil (exclusively clay soil from southern Portugal) and stabilized soil (about 8% portland cement was added to a granitic residual soil from northern Portugal). As shown in figure 5, these two mixtures can be clearly distinguished by the aspects and colors of their structures, with the unstabilized soil in the column on the left, and both the right column and the lintel made with the cement mixture.

The same products tested under laboratory conditions were applied to the left column (fig. 6) using the contact sponge method. As seen in figure 7, there is a decrease in water absorption when comparing the treated and non-treated surfaces, revealing once again the efficacy of the tested products. Even though siloxane shows better results, the natural products also exhibit a significant reduction in water absorption.

**FIGURE 5** The Rammed Earth Portico on the University of Minho campus, used in the case study.

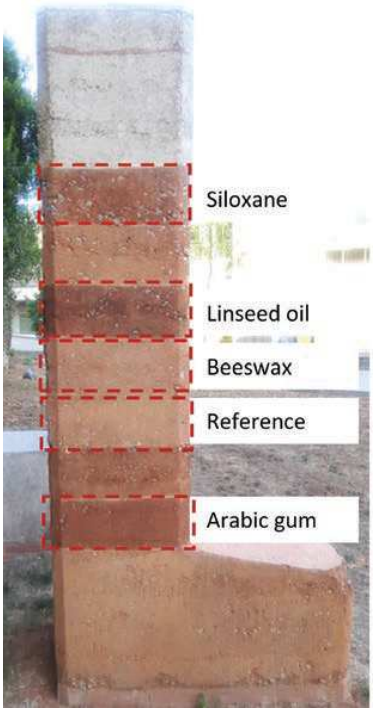


**FIGURE 6** Product application on the Rammed Earth Portico.

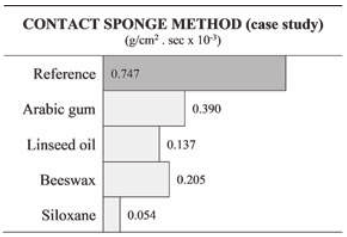


**FIGURE 7** Contact sponge method results for the tests performed in situ.

## Conclusion

Three natural products—gum arabic, linseed oil, and beeswax—were tested as water repellents and showed promising results when compared to siloxane, a commercial synthetic product. All products significantly reduced water absorption and act as water repellents, compelling the applied water drops to form spherical shapes instead of spreading out on the surfaces. Moreover, the in situ tests performed on the case study corroborated the laboratory tests, showing similar results of all applied products. The application of these products on a real case study, one that is exposed to temperature and humidity variations, will improve the understanding of these products' long-term behavior, especially related to possible degradation factors that may be associated. The natural aging process of both the products and earthen material can provide valuable answers regarding the durability aspect and, consequently, maintenance practices that may be necessary. This means that further work and more scientific research are required to support the use of natural products as a solution for protective coatings and to ensure the continuation of good practices in the maintenance of earthen heritage.

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