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Posted Date: 12 December 2023

doi: 10.20944/preprints202312.0755.v1

Keywords: Built heritage; Earth construction; Repair; Building technology; Preservation



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Article

Conservation of Defensive Military Structures Built with Rammed Earth

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Abstract: Earth is a complex material with a mechanical and physical behavior that differs from modern building materials. The conservation of rammed earth (RE) constructions presents specific difficulties that are challenging to overcome. The lack of knowledge about RE due to its abandonment for decades and attempts to adopt materials and repair methodologies designed for new building products has led to inadequate interventions. In the case of historic defensive constructions, the doubts and technical difficulties are even greater due to the nature of the so called military RE (with physical and mechanical characteristics significantly different from those of civil, more common, RE) and, not least, due to the historical and cultural heritage value of these constructions. Some important interventions have been carried out recently and others are underway or in the planning stage, and there is a constant lack of information and technical data on the best ways to intervene. To fill this gap, the state of conservation of the RE defensive structures and the results of interventions carried out throughout history in the southwest of the Iberian Peninsula are being assessed. This article sets out the framework of the subject, identifies the material and construction techniques, and recognizes the main causes of its deterioration and decay. With special focus on the most frequent damages detected in historic military defensive structures built with RE, it analyses and discuss the most common techniques that have been used for the repair and conservation of these particular structures.

Keywords: built heritage; earth construction; repair; building technology; preservation

1. Introduction

The preservation of heritage has been a concern for communities for some time. The cultural value of monuments and buildings, their social impact and, not least, the intention to increase the economic value of regions have given rise to various interventions to restore built heritage. Much has been researched and learned in recent decades about how to intervene in built heritage, and it is now accepted that interventions should maintain the identity of the buildings and be as minimalist and reversible as possible [1].

Structures of historic architectural heritage, by their very nature and history (material and assembly), present several challenges in diagnosis, repair and conservation that limit the application of actual codes and building standards. Recommendations are desirable and necessary to both ensure rational methods of analysis and repair methods appropriate to the cultural context. ICOMOS Charter [2], sets out the principles for the analysis, conservation and structural restoration of architectural heritage, and continues to be a fundamental reference despite having been created twenty years ago.

The rationale for conservation interventions must be based on a theoretical assessment of the static, physical, chemical and even biological behavior of each built element and each specific construction, and never on simple intuition about unproven facts [3]. Thus, it is a detailed and multidisciplinary analysis of each heritage architectural object that will provide adequate information for decision-making regarding the intervention techniques. That is: it is each construction that should "tell" the technician how it should be treated!

When one intends to conserve any architectural element, it is always necessary to address a wide range of issues, which means that the approach taken is not always exclusively of a constructive or structural nature. The intangible values of buildings and construction techniques are now also recognized as important elements to maintain [4]. In the case of defensive constructions, other aspects, such as the function of the construction and its elements, are also added to the constructive problems, which are in themselves quite challenging.

With regard to historic defensive military structures built with rammed earth, the issues to be addressed are numerous and specific to each fortification in question. These structures were built with a material that is produced from the raw material earth, excavated from the soil of the site itself or from the vicinity of the construction. As the characteristics of the soil vary from place to place, it is easily understood that the characteristics of the rammed earth produced may also vary a lot from construction to construction. Another aspect has to do with the speed of production and the evolution over time of the constructions. Some military buildings were built urgently, prioritizing speed over quality, and most of them were subjected to improvements, extensions and adaptations to new combat techniques, particularly ballistics, which have evolved significantly from medieval times to more recent times [5]. Other issues have to do with the specific nature of military use, which also needs to be addressed when analyzing these structures, as it could be part of the factors that have led to their state of deterioration.

In what is specifically regarded as the conservation of earthen architectural heritage, as is the case of the rammed earth defensive structures, two main knowledge gaps can be detected in the literature: the lack of conservation theory as a background for earthen heritage interventions and the need for a clear understanding of the values and significance of a place. These two interlocking aspects contribute immensely to less conscious conservation actions and the implementation of methodologies that do not follow the basic principles of heritage intervention [6].

In many of the interventions already carried out (some directly followed by the authors), it was possible to note a lack of preparation on part of the team members, sometimes in terms of designing, preparing and monitoring the works, others when carrying out the work. Most of the time, many of those involved in the process of repairing rammed earth constructions were unaware of the specific characteristics of the earth material and product. This lack of knowledge, even in a single phase or team, resulted in inadequate and/or ineffective interventions, with irreparable damage to the rammed earth heritage or, in other situations, additional costs and time spent in adapting and correcting the measures initially proposed. The use of cement-based mortars and concrete, common in the interventions of the 20th century, has been abandoned, but even so, materials and technologies incompatible with the material "earth" are still being used.

The present study intends to analyse and discuss in more depth some of the questions mentioned above, in the context of the application of specific methodologies for the conservation of defensive military structures built with air lime-added rammed earth. The objective is to contribute to the protection and conservation of these historical heritage constructions, without destroying or damaging their material and immaterial values. It proposes the development of analysis, diagnosis and repair methodologies, with intervention techniques duly adapted to the specificity of the military rammed earth and duly framed in current cultural, constructive and normative parameters.

2. From soil to rammed earth

2.1. Earth as a raw material for building purposes

The use of earth extracted from the ground for construction purposes was most likely born out of the intention to build quickly and economically, and still achieve a robust construction. Earth is a raw material available on site, requiring very little prior preparation to turn it into a construction material and simple and inexpensive technical means for its application. Although it requires intensive labor (which was not a problem in the past), the transformation of the earth into the final product, rammed earth, is not complex, nor does it require high levels of technicality [7]. In fact, earth, excavated from local soil, was used as a building material by all ancient cultures [8]. Site excavations

and archaeological studies in diverse regions of the planet have revealed that earth has been used for construction purposes since the dawn of mankind [9]. Probably it was not used as an option, or motivated by some technical concept, but rather for the simple and previously mentioned fact that it was available in the place where it was intended to build.

The experience and knowledge accumulated over the millennia in earth construction has resulted in a very effective response to building needs and high levels of comfort, resistance and durability [7]. Shelters, dwellings, buildings with several floors (sometimes entire cities), fortresses and other defensive structures, temples and religious buildings were built with earth, using a diversity of building techniques, with the richest and most varied formal and aesthetic aspects. It will be difficult to find an inhabited continent, and perhaps even a country, that does not have heritage buildings built with earth [10]. It should be noted that sometimes earth elements, such as walls, are coated and cannot be identified. In other cases, earth constructions were demolished to build new ones using other materials.

Earth is a composite material, a natural mixture of a series of aggregates (stones, pebbles, sand and silt) and a binder (clay), similar to ordinary concrete which also contains aggregates (stones, pebbles and sand) and a binder (cement). However, there are substantial differences between these two materials. One of them has to do with the building environmental sustainability: while concrete, when applied on site, undergoes an irreversible transformation and, therefore, cannot be reused and is difficult to recycle (at least easily and without excessive consumption of energy or resources), the earth used to build a particular wall can often be reused, after its demolition or ruin, namely to build a new one. That comes from the fact that no irreversible transformation takes place and the water used to mix the earth only dries. However, it also justifies why the contact of the earth walls with water has to be restrained, to ensure a large durability.

As a raw building material, earth is conditioned by its numerous possible mineralogical compositions and proportions. These different compositions and proportions mean that certain types of earth are more suitable for some construction techniques and other to other techniques. The characteristics and properties of earth used as building material vary from place to place, which leads to different construction methods using this raw material. Thus, several methods of building with earth are worldwide known, with an infinity of variants, which translate the identity of the places, people and cultures in which they were developed.

In the second half of the 20th century, the French group CRAterre (International Centre for Earth Construction – School of Architecture of Grenoble) [11] carried out a worldwide survey of the different ways of building with earth, typifying many variants. However, some more can be added, such as the use of earth bedding mortars to produce stone masonries. They prepared a diagram with the 12 main identified methods, and structured it based on three “families” of constructive systems: monolithic, masonry and mixed structures. It is within the monolithic constructive system that rammed earth fits.

2.2. Rammed earth: materials and construction techniques

In a general way, traditional rammed earth can be defined as a product and a construction method. Rammed earth uses earth as raw material, commonly directly excavated from the soil at the construction site (to avoid transportation), where it is crushed, moistened, homogenized by mixing, placed and compacted, in layers, inside a top and bottomless wooden box working as a formwork. When the formwork is filled, it is immediately removed and placed aside for continuity or in the upper layer when the one below is completed. In this way, large blocks of compacted earth are obtained, which are produced *in situ*, sequentially and by rows, constituting monolithic walls. The resulting product is called “common” or “civil” rammed earth (Figure 1).



Figure 1. Example of civil rammed earth being produced in Santiago do Cacém, Portugal.

Figure 2 shows one of the traditional formwork sets for production of civil rammed earth in the south of Portugal. Several other examples of rammed earth formworks used in the Mediterranean region and in China were collected by Qi et al. [12].



Figure 2. Traditional Portuguese formwork for civil rammed earth.

The traditional rammed earth production presents several particularities, which give it specific characteristics:

- the raw material (earth) typically comes from the place where the building is carried out;
- the transformation of earth into rammed earth does not go much further than changing location of material, after unpacking, crushing, mixing, placing and compacting again, to increase its homogeneity, compactness and density;
- this compaction is carried out *in situ*, that is, at the construction site and at the exact location of the building built with the rammed earth, using simple, removable and reusable wooden formwork;

- for compaction, which is done with rammers, only mechanical energy is required which, in essence, simply corresponds to “arm strength”;
- the rammed earth must be protected from the action of water, at its base and at its top; therefore, a stone masonry was commonly used as basement and the walls were protected by a tiled roof;
- once produced, a rammed earth wall acts both as a structural element and as a partition of the built space;
- a building made with rammed earth can last for thousands of years, with simple surveillance and maintenance operations, whenever necessary;
- at the eventual end of the building's use cycle, the complementary materials and products could be removed (such as roof structure and tiles, windows and doors, wooden or stone lintels), the rammed earth demolished and the earth reused in another building, or left in the open air so that the material returns to the natural environment from which it came

In the case of constructions with defensive military purposes, air lime and, sometimes, other additions were added to the earth. The mixture with the earth was made before placing it inside the formwork in layers for compaction, taking on the designation of “military” rammed earth (Figure 3).



Figure 3. Example of a military rammed earth defensive fortress in Paderne Castle, Portugal; some of the visible holes are from the original formworks used.

With the stabilization by air lime as binder, after carbonation the rammed earth turned into an artificial limestone, with more resistance to weathering and to the action of rainy water. However, the earth used on military rammed earth could not be reused, contrary to the civil rammed earth; only easily recycled. Before the recognition of the value of defensive rammed earth structures, there are examples, such as *Alcácer do Sal* Castle, where parts were cut and sold as masonry units [13].

To facilitate and speed up the velocity of the defensive structures construction, quick lime, calcium oxide (CaO), was added to the earth instead of hydrated air lime, calcium hydroxide (Ca(OH)₂) [14,15]. The use of hydrated lime implicated a previous slaking of the CaO with abundant water, that would need time and space for producing high volumes. Alternatively, the direct mixing of the CaO stone with the humid earth would simplify the procedure (less space and time needed) and could also ensure a better bonding between the earth fractions and the lime by the caustic action of the CaO when slaking. Furthermore, it would be simpler to turn homogeneous the mix of earth and CaO (small and porous stones) than the mix of earth with hydrated lime putty. On the other

hand, the volume of CaO double when hydrated to $\text{Ca}(\text{OH})_2$ after the mixing with the humid earth, turning the effective lime addition percentage higher than if made directly with hydrated lime. The direct use of CaO in the production of military rammed earth can be most probably identified by the appearance of lime lumps due to a lower level of hydration (Figure 4).



Figure 4. Detail of the presence of lime lumps in military rammed earth.

After the carbonation of the lime, which can take several years and even decades, the military rammed earth has a porosity lower than that of common rammed earth and a hardness similar to that of air lime concrete.

The percentage of CaO added is difficult to assess but it is important to find old documents that could present some data. If not, the available possibility is to evaluate the percentage of calcium carbonate (CaCO_3) present in old military rammed earth samples from several constructions. In that case, one has to bear in mind that: the earth could have CaCO_3 aggregates and the percentage found may not be only from the binder; the percentage found is the one existing at the age of test and some fractions of lime could have been washed out during the weathering of the wall along its lifetime.

Concerning the production of the military rammed earth, beside quick lime other additions to the earth where made, such as crushed red ceramic waste (from bricks, tiles) and medium size stones (Figure 5). Nevertheless, the intentionality of adding these materials is uncertain. Due to the fact of being military defensive structures, they required fast construction, and fast reconstruction. For that purpose, the collection of building materials was always made in the nearby, and the available supplies easily could include debris from former constructions destroyed by war.

The defensive military rammed earth walls were most probably rendered whenever possible. The renders were applied in a way to simulate the wall was built with big ashlar stone masonry, probably more impacting for the enemies. So at least one of the reasons was aesthetic related to military issues. The renders are frequently no longer present; only trace elements show how they were in the past (Figure 6).



Figure 5. Detail of crushed red ceramic and medium size stones added to earth, in a rammed earth fortification.



Figure 6. Detail of simulated ashlar stone masonry, in a rammed earth fortification.

2.3. Rammed earth deterioration

Whether due to extrinsic causes (action of atmospheric/climatological, telluric, biological, anthropic agents, ...) or intrinsic causes (composition of original raw materials, construction type, natural ageing/degradation of materials, ...), the general state of any built structure is the result of a complex situation composed of favorable parameters (to be preserved) and potentially harmful parameters (to be controlled or eliminated).

One of the most deleterious elements for earthen materials is the water, but it is generally the combination of many factors that prompts deterioration processes [16]. It is known that the phenomena of degradation of buildings with earth are mostly related to the action of atmospheric agents and factors of anthropic origin. More, and like any other type of building, the state of

conservation of a building made with rammed earth depends on its evolution (construction, maintenance, successive transformations ...) and its context (geographical, historical, cultural ...); so the causes that are at the origin of its degradation are usually multiple and often combined [17].

Typifying, the main deterioration agents of rammed earth constructions are: mechanical actions, erosion, infiltration and absorption of water, condensation of water vapour [18]. The presence of weeds and vegetation is also an important factor in degradation of rammed earth, especially in constructions more exposed, such as fortresses (which do not have roofs), buildings where maintenance is low and/or in areas that are difficult to access.

The consequences of the action of each one of these agents often potentiate the action of the others, and many are correlated; for instance, capillary rising damp and roots from plants may significantly reduce the mechanical performance of rammed earth. The application of new coatings acting as water vapour barriers can imply concentration of salts and their destructive cycles action [19], producing lack of cohesion on the rammed earth substrate. The application of a surface waterproofing treatment can also cause that harmful action [20].

It should be noted that in general, mainly in civil constructions, rammed earth wall coating solutions were adopted (e.g. painting with air lime milk - limewash) which, when carried out periodically, ensured the durability of the walls. The walls of military buildings were often cleaned and cleared of vegetation, actions that were stopped more than a century ago, i.e. since these buildings ceased to have a military purpose.

3. Military defensive rammed earth structures

3.1. The use of rammed earth in military defensive structures

As mentioned before, the use of earth, extracted from local soil, for the construction of defensive military structures has also been constant throughout human history. Different cultural groups, at different times and in the most diverse places resourced to that material for such purpose.

The city of Jericho, Palestine [21], the Great Wall of China, in the Jyaiyuguan region [21], the palace-fortress of Alhambra [20], the defensive wall of Seville [22], in Spain, the Fernandina Wall of Lisbon [15], the Lines of Torres Vedras [23] and the Fortress of Juromenha [24], in Portugal, are some of the many examples of the use of earth in the construction of defensive military structures. Although using the same raw material, the above-mentioned constructions were built with different techniques. Among these, the military rammed earth technique stands out, as it is the object of the present study.

In the southern half of the Iberian Peninsula there is a significant number of defensive military structures built with rammed earth. Most of them were built, or rebuilt, during the period of Islamic occupation of this territory. The Muslim invasion of the Iberian Peninsula was relatively quick and their presence in this territory was long.

The Islamic presence in the Iberian Peninsula is being marked by six major periods [5] where defensive structures were extensively built: Emirate of Córdoba (756-912), Umayyad Caliphate (912-1031), Taifa Kingdoms (1031-1091), Almoravid Empire (1086-1146), Almohad Empire (1147-1223) and Nasrid Kingdom of Granada (1235-1492). Among them, the Almohad Empire stands out as it was the one in which rammed earth was used the most. Most of these structures remain, and still retain enough elements that make possible their detailed study, crossing the information provided by the observation of the physical object itself with the respective historical documentation.

The *Reconquista* (re-conquest of the territory by the Iberian Christian kingdoms) was much slower than the Muslim invasion (Figure 7) and during this period there was damage, repairs and adaptations to the military buildings, and later, during the Christian period, various interventions and modifications. Many of these fortifications, such as Juromenha, were later modified during the Iberian Wars of the 17th century (Figure 8).



Figure 7. Schematic representation of the stages of the *Reconquista* (Christian re-conquest) of territories occupied by Muslims in Iberian Peninsula, with the Portuguese territory in the southwest, marked with a green line [25].



Figure 8. Example of a military rammed earth structure, built and rebuilt in different historical phases (Juromenha, Portugal).

3.2. The deterioration of rammed earth in historic military defensive structures

The significant number of military defensive structures built and rebuilt with rammed earth during the Islamic occupation of the Iberian Peninsula, and still existing at the end of 20th century, is an indicator of their importance as heritage elements. Most of them showed clear signs of degradation, mainly due to the abandonment to which they were voted, but they have lasted for centuries with a reasonable state of integrity.

In terms of building preservation it is interesting to study which factors affect the resistance and durability of this type of structures, especially in the face of threats that are considered more aggressive for earthen constructions. Among them, stands out the action of water, such as, for

example, heavy and prolonged rain or the capillary rise of water from the ground soil [26]. The water infiltration and the presence of cracks and fractures enhance the presence of vegetation, which greatly accelerates the degradation of the walls and other rammed earth structures.

There is another important issue to consider with defensive structures: the damage done to walls due to attacks by enemy troops. In order to restore their defensive capabilities, the elements damaged by the war were (sometimes very quickly) reconstructed and these reconstructions were often taken up with the construction of new elements to improve the defensive efficiency. In fact, towers and walls of fortifications that reached the 21st century often feature different types of rammed earth and also stone masonries. As a result, many fortifications show different types and levels of material deterioration in the same element.

Therefore, the conservation of these historic structures requires that diagnosis and intervention techniques should be very specific for each building.

4. Conservation of rammed earth historical defensive structures

4.1. Analysis and diagnosis

The ICOMOS Charter mentions in its point 1.3 that “the value of each historic building is not only in the appearance of individual elements, but also in the integrity of all its components as a unique product of the specific building technology of its time and place” [2]. In the context of the conservation of heritage structures built with rammed earth, it is therefore essential that far-off techniques, and/or materials, be not applied, as they could cause incompatibilities with the pre-existing environment or distort the constructive concept or the original architectural or cultural language. To this end, a basic protection and conservation protocol must be established, with tested procedures and technical controls throughout all the intervention process [27].

Thus, any process of conservation of any element of built heritage must begin with the collection and recording of the greatest possible amount of data about its history, the physical object itself and its surroundings. At the same time, the intervention criteria must be defined based on the general principles set out in the theory of conservation and restoration. It is also of chief importance to proceed with the characterization and evaluation of the operability of the preservation, protection and reinforcement systems for these structures. Moreover, it is fundamental to be aware that, among the dangers that historical and archaeological sites face, are those that inexperienced, unskilled or incompetent restorers (and builders) cause during the process of restoration [28].

When analysing the causes of deterioration and loss in an historic building, the following questions must be posed: “(1) *What are the weaknesses and strengths inherent in the structural design and the component materials of the object?* (2) *What are the possible natural agents of deterioration that could affect the component materials? How rapid is their action?* (3) *What are the possible human agents of deterioration that could affect the component materials or the structure? How much of their effect can be reduced at source?*” [1].

Multiplying the sources of information, diversifying, and expanding the amount and type of data collected will allow obtaining a comprehensive knowledge of the object, not only about its material, but also about its immaterial components. This often provides answers to questions that a simple physical examination fails to provide. No information about the origin and evolution, past and history of the building that is intended to be conserved should be disregarded, whether related to its physical component or its cultural component: the material object, its use and its functions throughout history are an inseparable whole.

Among the various types of data to be collected, those that make it possible to have a detailed knowledge of the existing rammed earth stand out, both in terms of its component as a constructive system, or in terms of its constituent matter.

Diagnosis is the entire investigation process that goes through several stages, from analyzing the symptom of the anomaly to repairing it. Its main target is the detection of the primary causes, which must be eliminated or controlled, before proceeding with the repair of the anomaly [29].

The analysis of the pathology of earth constructions makes it possible to distinguish a main set of degradation agents, whose effects and consequences it is important to know, in order to better understand the processes according to which they manifest themselves and, against them, to be able to act effectively [18].

Thus, the initial characterization of the existing rammed earth and the understanding of the causes and processes of its deterioration constitute the basis of the technical diagnosis. Being a first approach to the building, this diagnosis will open the way to the indication of relevant technical answers to intervene with respect for the building, both on the construction itself and on its surroundings. It implies a reading of the object at various levels, which does not dwell on the material components of the building and its surroundings, but also takes into account its immaterial dimensions, such as its use and history.

One of the specificities of the technical diagnosis of military rammed earth consists of understanding the balance between the presence of water and the structural stability of each building element in question [17], since these are the two main causes of deterioration: the action of water and structural failure. Moreover, generally one enhances the other (Figure 9).



Figure 9. Action of water and structural failure in a military rammed earth structure (Juromenha, Portugal).

4.2. Rammed earth repair and conservation techniques

The conservation of military rammed earth structures attracts increasing interest, as it is one of the techniques presenting the highest complexity in conservation practices [21].

Literature review reveals that, in general, the intervention techniques applied in the conservation of rammed earth military defensive structures in the Iberian Peninsula are closely linked to three fundamental factors: (1) the original constructive technique, (2) the diagnosis of the pathologies present at the time of the intervention and (3) the intervention criteria specific to the author of the conservation project or the project's objectives [30].

Most part of interventions cover a wide range of combined conservation, reintegration and reconstruction actions, with varying percentages between these three components. Often, in a single intervention, actions are carried out for the conservation of the rammed earth (cleaning, consolidation, protection, etc.), but also for the reintegration of more or less important gaps in the walls and/or the reconstruction of walls to avoid collapse. In this way, the interventions that have

been carried out in the rammed earth fortifications can be classified into four large groups [30], as follows:

- 1) **Conservation and protection of the walls:** in which, accepting certain levels of deterioration, the conservation of the original material is favored over the recovery of the original image of the fortification.
- 2) **Consolidation of the walls:** which corresponds to superficial consolidation of the walls or, mainly, the filling of large gaps, with material similar to the existing one or with other materials, to restore the constructive consistency of the built element.
- 3) **Recovery of volumes:** in the sense of recovering the profile and the mass of the construction through the reconstruction of some missing parts, which allow the reading of the original construction before its deterioration and simultaneously decreasing the degradation path (Figure 10).
- 4) **Reintegration or replacement of the finishing surface:** which, in addition to the necessary protection against collapse of the walls that are eroded by the action of atmospheric agents, also changes the visual appearance of the building with the creation of a homogeneous and unitary surface.



Figure 10. Recovery of volumes in a military rammed earth fortress to avoid collapse (Reina, Spain): a) before intervention; b) after intervention [31].

Often the approach of a conservation intervention includes tasks from more than one of the above mentioned groups, depending on the specific element, namely on large defensive structures.

In order to accomplish a more precise classification of interventions, the selected criteria may be gathered into three categories, according to (1) formal-constructive, (2) pathological-risk and (3) technical reliability responses [22].

The analyses and evaluation of a number of recent actions of repair and conservation of military rammed earth structures reveal that foreign techniques and/or materials were applied in conservation actions, and they frequently caused incompatibilities (Figure 11) with the pre-existing environment and often distort the constructive concept or the original architectural or cultural language.

In addition to the fact that there are few or no regulations on building rammed earth walls, there is no consensus on this technique, but a wide variability of proposed values due to the large number of variables related to earthen construction. All these aspects make the regulation of this building technique and its repair and conservation more complex. Even in the majority of references in the literature that propose tests or reference values, the procedures to their verification on site are still scarce and not very precise [32].



Figure 11. Detail of incompatibility of materials in an intervention for conservation of a rammed earth fortification, causing damage in the structure.

5. Discussion and final remarks

In the southwest of the Iberian Peninsula, there is a large number of air lime-added rammed earth fortifications, mainly the ones from 12th and 13th centuries, which constitute a unique historical legacy. This built heritage is currently recognized as assets to be preserved, for social, cultural, technological and economic reasons. For its preservation, which includes not only material values, but also immaterial values, regular maintenance and conservation actions are necessary. On the one hand, these actions should not destroy its original characteristics and, on the other hand, really contribute to its protection.

However, achieving a conscious conservation of rammed earth fortifications is a quite challenging task, which begins with the issue of the variability of the raw material with which they were built: the earth extracted from the local soil. Next, comes the uncommon building technique, itself and its variations from one location to another, plus the usage of assorted building technologies depending on the circumstances of each location and historical period.

The present study started with the analysis of the raw materials and the characterization of the existing military rammed earth structures and their constructive systems, in comparison to civil, more common, rammed earth. Ensuing, it proceeded with the study of the pathology and the remarks of the most common anomalies they reveal. Additionally, the reconnaissance of the most frequent damage that this type of military defensive structures suffered throughout history, and still suffer at present time, was presented.

Subsequent work revealed that current methodologies and intervention techniques for repair and conservation of rammed earth fortifications fail in a number of cases, leading to unsatisfactory results, including serious damages in the original structures.

Moreover, considering the diversity of raw materials used in the construction of these structures and the diversity of types of interventions throughout history, the establishment of a “universal recipe” for their conservation would be inadequate.

As result of the analysis of all these issues, it was assumed that a basic protection and conservation protocol must be established, specific to each structure to be conserved, with tested

procedures and technical controls throughout all the intervention process. The definition of the general structuring lines of that protocol is part of the future developments of the research project within which the present study is included.

Therefore, in the context of preserving the historic defensive military structures built with rammed earth in the southwest of the Iberian Peninsula, above referred, further research is needed to assess conservation actions, more precisely in terms of material and structural compatibility, as well as in what concerns to durability.

Author Contributions: Conceptualization, M.R., P.F. and A.G.; methodology, P.F. and A.G.; validation, P.F. and A.G.; formal analysis, P.F. and A.G.; investigation, M.R.; resources, M.R. and P.F.; data curation, M.R.; writing—original draft preparation, M.R.; writing—review and editing, M.R., P.F. and A.G. All authors have read and agreed to the published version of the manuscript.

Funding: The study described is an integral part of the ongoing work leading to the completion of the first author's doctoral thesis, which is financially supported by the *Fundação para a Ciência e a Tecnologia* (Portuguese Foundation for Science and Technology) and by the *Direcção Geral do Património Cultural* (Portuguese General Directorate of Cultural Heritage) through the PRT/BD/152878/2021 doctoral grant.

Acknowledgments: The authors thank *Fundação para a Ciência e a Tecnologia* (Portuguese Foundation for Science and Technology) for the doctoral grant PRT/BD/152878/2021 and the support to the Research Unit CERIS (UIDB/04625/2020).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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