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Vernacular earthen buildings from Leiria, Portugal – Architectural survey towards their conservation and retrofitting

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Abstract

In Portugal, rammed earth monolithic walls and adobe masonry were, for several centuries, important construction techniques for dwellings. The frequent unnecessary demolition of these buildings, mainly due to lack of information related to them, lack or inadequate maintenance interventions, and advanced state of degradation, has been leading to great cultural and material loss. To preserve this vernacular built heritage and all the technological knowledge related to it, it is fundamental to understand the constructive technologies. Several earthen buildings from Leiria region were mapped and inspected, and two of them were taken as case studies. This architectural survey allowed studying their construction specificities, main building pathology, and thus contributing to Leiria's vernacular earthen buildings efficient preservation and use.

Keywords: rammed earth; adobe masonry; vernacular architecture; social heritage; earth construction.

1. Introduction

The first earth dwellings were shelters made of bushes and small wood branches, usually covered with earth mortars for air tightness and waterproofing (McHenry, 1989). These ancient constructions used the materials available in a close range (wood, stone) with low transformation processes, construction planning and associated cost. The use of earth mortars, based on clayish soil mixed with water, was necessary to assemble other materials. The variations in form and selection of these materials depended on the local environment and region of the world; hence the concept of vernacular architecture is greatly related to the concept of earth construction (Jaquín et al., 2008).

Relatively recent studies (Guillaud, 2009; Anger et al., 2011) show that half of the world's population lives in houses built with earth. Nevertheless, during the first half of the twentieth century, and mainly in the post-world war II period, the introduction of new materials and techniques in current constructions, led to a decline in the use of earth (McHenry, 1989; Oliveira and Galhano, 1992). Due to the decrease of new earthen constructions in some regions of the world, the expertise and know-how became scarce. Nonetheless, an increasing interest on using this material has been observed in the last decades, both for modern constructions and retrofitting of old buildings, largely due to ecological concerns. That is the case of the use of eco-efficient earthen plasters (Santos et al. 2017; Parracha et al., 2019a; Santos et al., 2021), adobe (Costa et al. 2018; Silva et al. 2020) or rammed earth (Fernandes et al., 2019).

To support future efficient interventions, it is critical to collect oral information related to the constructive technologies and materials used in vernacular architecture from the few senior professionals still associated with it.

Therefore, the main objective of the present study is to characterize the architecture, the original building materials, the technologies and some of the pathology associated to earth buildings from Leiria district, in Portugal, to contribute towards the design of compatible, effective and reversible solutions for their conservation and retrofit. The study was divided in two fundamental parts: the one reported in this paper aims at presenting the architectural survey and constructive technologies; a total of 98 earthen buildings, mainly built with adobe masonry and rammed earth walls, were mapped and inspected and building pathology overviewed. Two of them were taken as case studies and surveyed in more detail in order to illustrate the use of distinct constructive and materials technologies. Oral interviews with former professionals in the area were also conducted to obtain information related to the constructive technologies originally used. The other part of the study has been reported elsewhere (Parracha et al., 2019b) and includes an experimental campaign of characterization of samples collected from six of the previous 98 mapped buildings.

2. Earth construction

2.1. Vernacular rammed earth and adobe masonry

Worldwide, rammed earth and adobe masonry were the most important and widespread wall construction techniques (Houben and Guillaud, 1994), though rubble stone masonry was also frequently produced with earth mortars.

A traditional rammed earth wall is formed with *in situ* compacted humidified earth, with a relatively low clay content and a balanced grading of other earth components (silt, sand, gravel), introduced in temporary formworks, creating large-dimension blocks (Maniatidis and Walker, 2003). These blocks are made in sequence: first all the blocks to complete a first level; afterwards the same on each level, up to the top of the walls. The vernacular formwork is made of wood and immediately removed after each rammed block is completed. Therefore, that block will adhere and be connected to the lateral one (and to the basement of the wall, or to the block that was beneath) producing a monolithic wall.

Traditional adobe is a regular masonry unit obtained by molding and air drying a plastic mixture of earth (like an earth mortar, with much higher water content than in rammed earth) in a wooden mold. It is used to build masonry walls with a masonry layering mortar and can be considered the first artificial stone masonry unit. In comparison to hollow fired bricks or cement-based hollow blocks, adobe presents advantages in terms of thermal (and acoustic) properties, due to its mass, thermal inertia, and moderated thermal conductivity which, together with clay high hygroscopicity, promotes indoors hygrothermal balance (Laborel-Préneron et al., 2018; Bruno et al., 2020). As other masonry units, it is associated to simple construction methods. Since it is not fired, it is a more eco-efficient material, with low environmental impact, particularly when it is not stabilized using a chemical binder.

One of the main disadvantages of the use of earth as building material is that it may suffer physical degradation over time, mainly due to its water vulnerability (Gomes et al., 2019). However, most of these problems can be solved with simple strategies, such as appropriate roof maintenance and design, preferably with long overhang eaves to protect the surface of the walls from the rain, application of a lime-based protective compatible render, and waterproofing foundations (Aubert et al., 2013).

The increase of earth construction in the past decades, due to its recognized low environmental impact and good hygrothermal and acoustic performance, therefore eco-efficiency, must be seen as an opportunity to preserve and retrofit vernacular earthen buildings. In fact, with the regained interest in earth construction, several authors have been producing research in the last years in topics related with vernacular earthen architecture and their pathology after a long aging period, thus contributing to relearn the construction techniques, so that compatible interventions can be performed (Aubert et al., 2015; Silveira et al., 2012; Silveira et al., 2013; Fratini et al., 2011; Daoudi et al., 2017; Hamard et al., 2017; Costa et al., 2019; Silva et al., 2020; Bamogo et al., 2020; Luo et al., 2020). Some examples are given below.

Aubert et al. (2015) studied a very specific earthen construction technique observed only in a village called Castelnau-Magnoac, located in France. This unique technique, called "chequered construction", consists on alternating pebbles and adobe in staggered rows. The authors had the opportunity to study not only the constructive details associated to those buildings but also characterize some of the materials used in the original construction. They found very interesting constructive peculiarities such as the systematic alignment of vertical joints on walls without any mortar application, the lack of protection on the external surface of those walls, or even the curious inexistence of a ring beam, very common to improve the tensile strength and ensure the stability of the construction. Regarding the characterization of the materials originally used, no cracks were found in adobes, which presented a low index of plasticity, meaning this characteristic did not contribute to increase the values of mechanical strength in comparison to the values normally found in the literature for traditional adobes (Silveira et al., 2012; Silveira et al., 2013).

Fratini et al. (2011) also studied original examples of earthen buildings from Calabria, in Italy. These buildings, called "casedde", are completely or partially built in adobe masonry, normally layered using a mortar made of clay and lime. The authors characterized adobe samples collected from seven different "casedde" buildings in poor condition and found out that they were made from "fat" earths, a material that not always presented the best characteristics for adobe's formulation. The authors also produced new adobes by kneading the earth of the original ones and concluded that they present higher mechanical resistance (two or three times higher), concluding that repair actions on earthen walls can be performed reusing the original earth. In fact, it is well known that such actions are likely to be more efficient (and compatible) when performed with similar materials, like Gomes et al. (2019) have shown to be the case in repair actions of deteriorated surface of rammed earth.

Daoudi et al. (2017) performed an extensive experimental campaign to evaluate several properties of rammed earth and coating materials collected from the XVIth century Badii Palace in Marrakech, Morocco, in order to support compatible, reversible and effective conservation actions. Authors identified differences between the composition of rammed earth and the coating materials, possibly indicating they had different origin and frequently causing incompatibility problems. These problems were also identified between original rammed earth walls and coating materials applied during the course of retrofitting actions, leading authors to conclude that most retrofitting attempts have failed due to an inadequate choice of the materials applied, a consequence of the lack of knowledge concerning the original ones (previous characterization studies were not performed) and the construction processes.

Hamard et al. (2017) proposed a methodology that provides extensive information about the construction processes associated to a specific rammed earth construction. Using this innovative methodology, it is possible to identify the pedological horizon, extraction depth, and location of the materials source of rammed earth buildings of different ages and geographical contexts. Nevertheless, further studies are needed with the aim of improving the methodology and amount of knowledge.

2.2. Earth construction in Portugal

In Portugal, earth was a very common construction material for building dwellings and similar low volume constructions until the middle of the twentieth century. As throughout the rest of the world, rammed earth and adobe masonry were the most widespread and important construction techniques (Fernandes and Correia, 2005). Moreover, in periods dating back to several centuries ago many fortresses were built with earth as the main building material. The Paderne and Silves castles are two examples of Portuguese military rammed earth-built heritage (Correia, 2004; Parracha et al., 2020). However, the characterization of materials is still scarce. Some studies have already been performed on vernacular dwellings, namely lime-stabilized adobe masonry from Aveiro region (Coroado et al., 2010; Silveira et al., 2012; Costa et al., 2019), unstabilized adobe masonry from Setúbal region (Silva et al., 2020) and rammed earth from Alentejo (Gomes et al., 2014; Gomes et al., 2019) or from Western Algarve (Mateus et al., 2015; Mateus et al., 2019).

In Aveiro region (Figure 1), about 40% of all buildings have adobe masonry (Silveira et al., 2007). Between Sado and Tagus rivers (Setúbal region – Figure 1), almost all the rural old buildings have adobe masonry (Sampaio et al., 2017; Silva et al., 2020). In Alentejo (Figure 1), there is a high number of rammed earth rural dwellings and farm buildings (Gomes et al., 2014; Correia, 2007). Nevertheless, there is a significant diversity of techniques, not only in the previously mentioned constructions, but in all Portuguese earthen buildings. For example, in Aveiro, adobes were frequently air lime-stabilized, while in Leiria and Setúbal that was not the case (Parracha et al., 2019b, Sampaio et al., 2017). Also, Gomes et al. (2014) characterized earthen materials collected from six old rammed earth buildings in Alentejo and found out that even the particle size distribution can be very diverse, and not always within defined regulatory ranges.

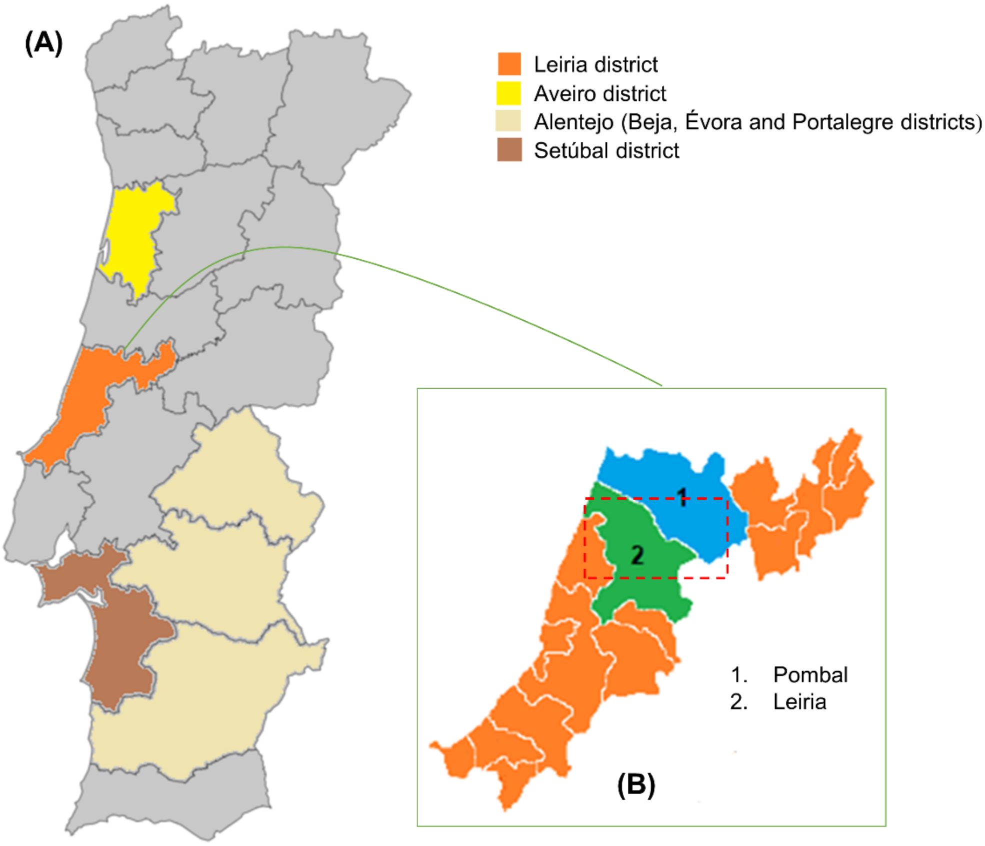


Figure 1. Map of Portugal with some regions with a significant number of adobe and rammed earth buildings: (A) location of Leiria, Aveiro and Setubal districts and Alentejo region; (B) municipalities of Leiria and Pombal in Leiria district; the red square represents the area shown in Figure 2

In spite of embedding a cultural, historical, social, and architectural recognized value, the buildings that constitute the Portuguese vernacular earthen architecture have been much neglected. The application of maintenance and efficient conservation actions over time is almost inexistent, representing a concern and a threat to their preservation. In most cases, demolition has been the adopted solution, due to their advanced state of degradation, lack of knowledge regarding properties of the materials and construction techniques originally used, or even just the land real-estate value. Nonetheless, many of these low volume constructions overcame several seismic actions (namely a Richter level 7.9 in 1969) and the structural safety remains guaranteed or can be improved. As such, it is not mandatory to perform demolition as most of the buildings' problems can be solved with constructive repairs and retrofit solutions, and new uses can be foreseen for at least some of the earthen buildings, so they can be preserved.

3. Adobe and rammed earth construction in Leiria district

3.1. Survey

Earth construction in Leiria district was mainly built during the first half of the twentieth century (Saraiva, 2011; Parracha et al., 2019b), as buildings almost entirely for domestic use, like dwellings, farm storehouses and windmills. Indeed, these types of constructions were the most common earth buildings at the time (Silva et al., 2016).

In the present study, 98 earthen buildings were mapped and inspected (Figure 2, red square of Figure 1B). These buildings are located throughout the municipalities of Leiria and Pombal, in Leiria district, in the center of the country (Figure 1). Twenty-four of these buildings are rammed earth constructions, sixty have adobe masonry and fourteen present both construction techniques (Figure 3, Figure 4A and Appendix B).

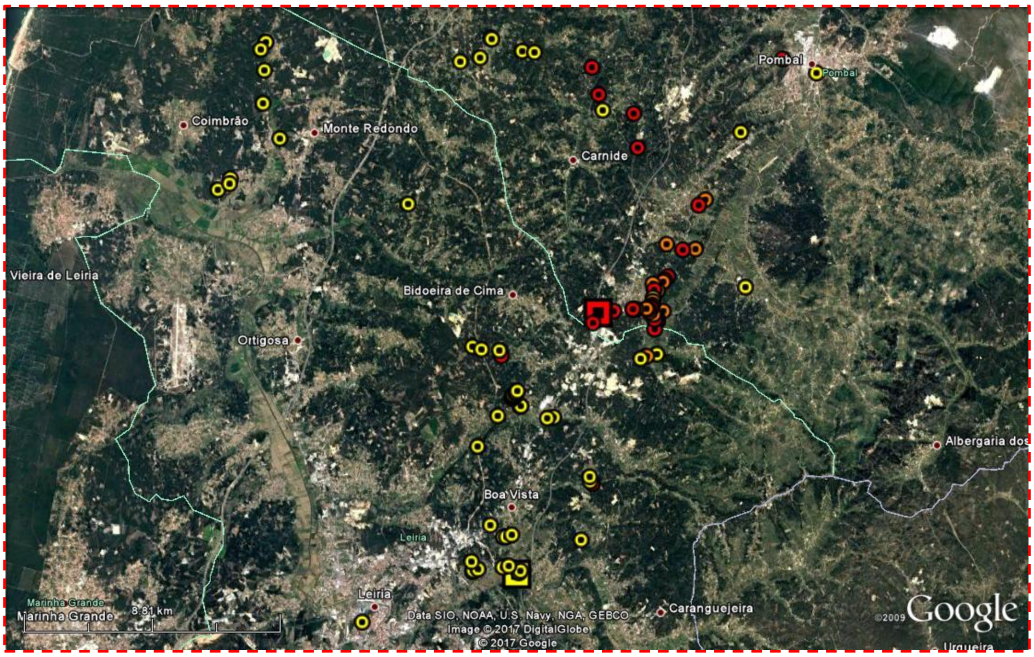


Figure 2. Mapping of the 98 inspected buildings: yellow circles – adobe buildings; red circles – rammed earth buildings; orange circles – mixed constructions (adobe + rammed earth); yellow square – adobe dwelling 4; red square – rammed earth dwelling 29

Figure 3. Some of the 98 mapped and inspected vernacular earthen buildings: A – rammed earth building 77 from Pombal; B – rammed earth building 10 from Pombal; C – adobe building 65 from Leiria; D – mixed construction 38 from Pombal; E – adobe building 93 from Leiria; F – adobe building 87 from Leiria and G – adobe building 42 from Leiria

In Pombal municipality the rammed earth construction predominates while adobe prevails in Leiria municipality (Figure 2). The reasons that led to this differentiation are not clear but a more abundant presence of water in Leiria municipality may justify it. However, in an interview with a former professional in the area (Appendix A), it was referred that adobe masonry (that could be previously manufactured, with the contribution of unskilled labor, namely from the family that intended to build the dwelling) had a lower cost compared to rammed earth. That fact could have strongly influenced the option for the more frequent use of adobe. Mixed constructions (adobe and rammed earth) are scarce. In some cases of rammed earth dwellings, adobe partition walls were used to achieve less thick walls. In other cases, adobe was used in retrofitting interventions, such as to increase the rammed earth walls height through the addition of few adobe masonry layers; the roofs were then reinstalled on top of the walls.

Gomes et al. (2014) refer that the presence of soils with a low clay and high silt, sand and gravel content promotes the choice of rammed earth construction instead of adobe masonry. That can be another justification for the differences found between Pombal and Leiria municipalities. The existence of high clay content in the soil can lead to shrinkage and cracking problems during the drying process, especially for rammed earth blocks. In the literature there is no consensus on limiting the clay content for rammed earth (Gomes et al. 2014). Based on Gomes and Folque (1953), the clay content for unstabilized rammed earth can go up to 31% in volume and when this content was too low, gravel was removed by sieving.

In the case of adobe, drying shrinkage is complete before their application on the wall, becoming a less important aspect. However, the addition of supplementary sand (or plant fibres) to the raw earth was quite common when the mason responsible for the adobe production considered that the earth, previously sieved to remove coarse gravel, was too clayish.

Most of the earthen buildings walls are rendered and plastered, preventing to see adobe sizes, the masonry assemble type, the dimensions of the rammed earth sections, among other aspects. It is the authors believe that much more earthen buildings may exist in the surveyed area. However, only when there is a lacuna in the render (or in the plaster, when the interior of the buildings was accessed) it was possible to identify the earthen material and technology (adobe masonry or rammed earth) and the building was considered in the survey. Nevertheless, even in those cases, frequently the render/plaster lacuna area was very small, allowing to identify the earth material and building technology but not enough to provide quantitative data such as to proceed with measurements. Therefore, measurements were only possible in 45 of the 98 identified buildings: rammed earth elements of 31 buildings and the adobe units of 22 buildings (Figure 4B). Appendix B shows data related to the survey of the 98 buildings where the construction year (whenever possible) and the building technology are presented.

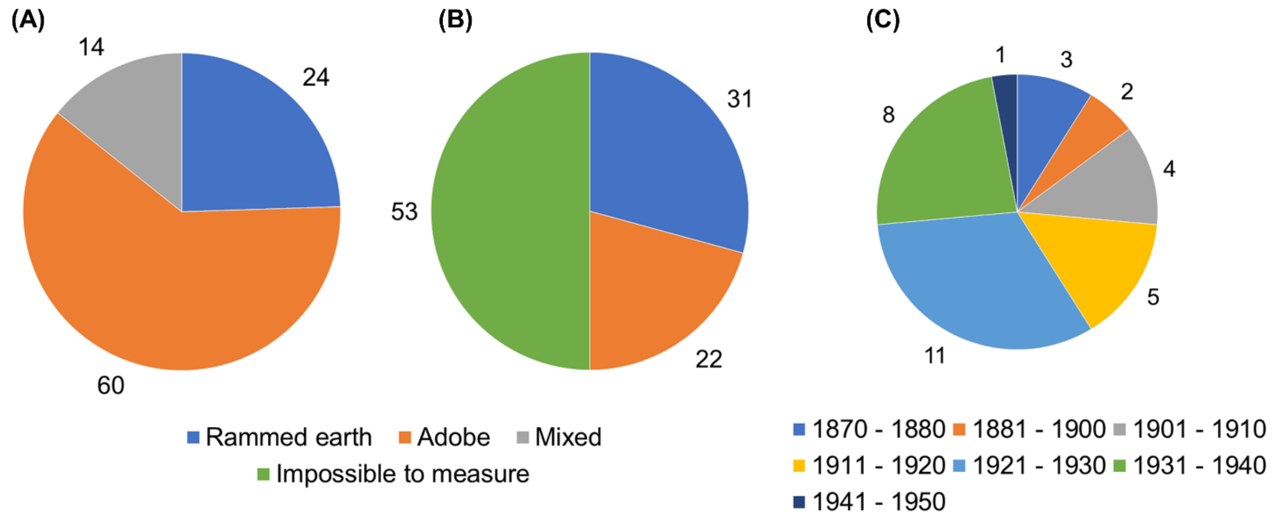


Figure 4. A – number of buildings of Leiria district that were inspected, by construction technique; B – number of buildings from where it was possible to measure the dimensions of the rammed earth sections and adobe units; C – buildings by decade of construction

In 64 of the 98 inspected buildings it was not possible to identify the year of construction. All the remaining 34 buildings were built between 1870 and 1950, covering 80 years of earth construction (Figure 4C).

Based on the 22 buildings where it was possible to measure the adobe dimensions (Figure 4B), it can be observed that adobe masonry in Leiria presents adobe of diverse dimensions: the length varies between 0.30 m and 0.46 m, the width between 0.14 m and 0.30 m, and the thickness between 0.12 m and 0.16 m (Table 1). The adobes with larger dimensions were mainly used on exterior dwelling walls, being the small ones used on interior partition walls or on storehouses. Regarding another regions in Portugal, Fonseca (2007) identified adobe with 0.40 m × 0.20 m × 0.12 m (length × width × thickness) in Avis, Alentejo, (Figure 1A), Silva et al. (2020) identified adobe with 0.51-0.50 m x 0.38-0.30 m x 0.10 m in Setúbal region, (Figure 1A), and Varum et al. (2008) and several other researchers identified adobe with 0.45 m × 0.30 m × 0.15 m in the district of Aveiro (Figure 1A). Contrary to what happens in other regions, such as Pinhal Novo, Setúbal district (Sampaio et al., 2017; Silva et al., 2020) where the adobe width defined the walls thickness, in Leiria that was defined by the adobe length in the structural exterior walls. However, the wall thicknesses were not so different between both regions as Leiria's adobe length (Table 1) seems to be close to Setúbal's adobe width (Silva et al., 2020). Therefore, dwellings envelope walls were frequently about 0.40 m thick, plus the render and plaster thicknesses. Another detail that is specific of the adobes used in structural exterior walls in Leiria district is that, in many cases, the surface of the adobe facing the exterior and the interior was 0.25-0.30 m long and had a vertical indentation dividing it in two similar almost squared areas (Figure 5). That indentation, together with the masonry joints, was probably created to promote a more effective bond of the plaster and render to the adobe masonry surface. That specificity was only detected in adobe masonry dwellings in St[a]. Eufémia parish (see Table B.1 in Appendix B). Although it was not possible to visualize any old adobe mold, oral information confirmed that the molds used to produce those idented adobes had two vertical pieces of wood to produce it. However, it was not possible to go further on understanding if this constructive detail was used by a specific adobe builder.

Table 1. Overview of the dimensions found in rammed earth sections and adobe units in Leiria district

	Adobe			**Rammed earth**		
	(length x width x thickness)	Nr. buildings	%	(length x width x thickness)	Nr. buildings	%
	0.46 x 0.18 x 0.16	5	23	2.00 x 0.70 x 0.50	2	6
	0.42 x 0.30 x 0.14	2	9	2.00 x 0.70 x 0.40	23	74
	0.42 x 0.24 x 0.12	1	5	2.00 x 0.60 x 0.40	6	20
	0.40 x 0.20 x 0.14	1	5			
	0.40 x 0.18 x 0.15	1	5			
	0.36 x 0.14 x 0.12	10	44			
	0.30 x 0.14 x 0.12	2	9			
Total	7	22	100	3	31	100

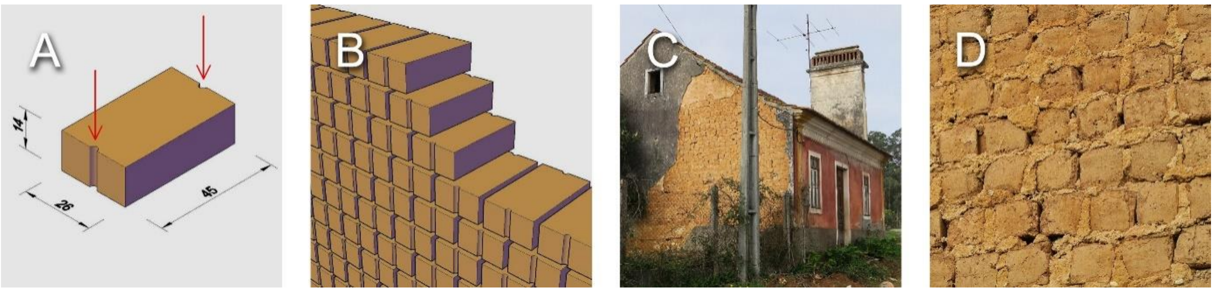


Figure 5. Leiria traditional adobe: A - schematic model of an adobe with side indentations; B - schematic model of an adobe masonry wall; C - inspected building 6 presenting adobe exterior walls; D – detail of a wall of the building mentioned in C

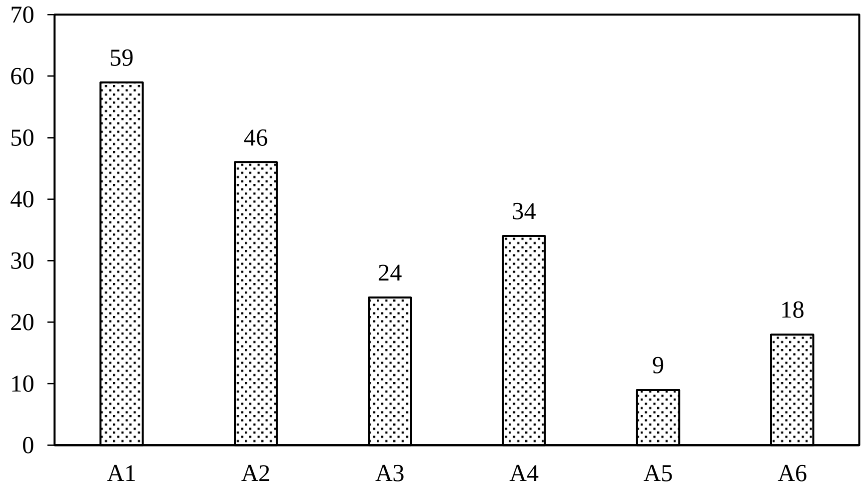
Based on the 31 buildings where it was possible to measure the rammed earth dimensions, it can be observed that these constructions in Leiria presented sections with height varying between 0.60 m and 0.70 m and thickness between 0.40 m and 0.50 m (Table 1). The total length presented average values of 2.00 m. Gomes (2013) has studied rammed earth constructions in the region of Alentejo (Figure 1A), and found sections in which the height varies between 0.45 m and 0.55 m, the length varies between 1.40 m and 1.70 m, while the thickness remains constant at an average value of 0.50 m.

3.2. Building pathology

In the present study, visual inspections were carried out to characterize the buildings and identify their main pathology. Despite being based on visual observation, which is naturally prone to some degree of subjectivity, the findings were crosschecked within the inspection team, composed of members that are used to carry out this type of surveys. These inspections were conducted using a fieldwork record form as support. That record form was previously prepared and refers to aspects such as roof, masonry and floor anomalies. In cases where it was not possible to access the interior of the building, only part of the fieldwork record was used, the one referring to the aspects that were possible to observe from the outside.

Table B.3 of Appendix B provides a list of the anomalies found in each of the 98 inspected buildings. Six types of anomalies were taken into consideration: A1 – render/plaster decohesion; A2 – rising damp; A3 – basal erosion; A4 – water infiltration from the roof; A5 – biological colonization; A6 – vegetation growth.

As shown in Figure 6, the most frequent anomalies are A1 (render/plaster decohesion), A2 (rising damp) and A4 (water infiltration from the roof), illustrated in Figures 7 and 8 and Table B.3 of Appendix B. The latter strongly increases in cases of abandoned dwellings.



A1 – Render/plaster decohesion | A2 – Rising damp | A3 – Basal erosion | A4 – Water infiltration from the roof | A5 – Biological colonization | A6 – Vegetation

Figure 6. Absolute frequency of the anomalies identified in the survey

Several researchers have deeply analyzed pathology and durability of adobe and rammed earth buildings (Bui et al., 2009; Goméz-Patrocinio et al., 2017; Illampas et al., 2013; Rolón & Cilla, 2012) and their findings support some of the observations of the present survey. Through this survey, it was possible to observe that many earthen buildings walls presented an advanced state of degradation. The damages detected can be related with the natural aging process of the adobe and rammed earth constituent materials, namely by weathering when protective renders are no longer functional. Extrinsic factors, such as human action , may have accelerate the earthen walls surface degradation. In parallel, inadequate conservation interventions over time, such as the replacement of old compatible earth and air lime renders (and plasters), and limewash finishing coatings by cementitious-based renders and water proofing finishing painting systems must have strongly contributed to accelerate and deepen degradation of the walls (Figure 7). In fact, the substitution of renders and painting systems seem to behave well but only for a short period of time. After that period, shorter if the walls have raising damp problems, the new cementitious renders detach in large panels from the earthen walls, turning visible the degradation of the masonry's surface, which in some cases can be extensive. That degradation happens due to lack of material cohesion, justified by salts action (Gomes et al., 2019) which, in turn, are due to the chemical and physical incompatibility between earthen and cement-based materials. Indeed, after some time, the accumulation of soluble salts on the earthen matrix mainly due to the low water vapor permeability of cement renders ends up damaging the wall core (either superficial degradation or even deeper), usually hidden by the render during some time, causing invisible voids and finally the render detachment. As stated before, that is caused by lack of cohesion of the earthen surfaces, where the hygroscopic salts, dissolved in the migrating water, concentrate, being more severe if successive cycles of dissolution/recrystallization/ have already occurred (Gomes et al., 2016). Therefore, the repair or replacement of the earth and air lime renders (and plasters) by cement-based ones should be avoided in order to ensure that the walls keep its capacity to dry the moisture that reaches them from the ground, or through migration from the indoor environment (Gomes et al., 2016; Gómez-Patrocinio et al., 2017).

Figure 7. Traditional dwelling repaired with cementitious-based render showing detachment after damaging the masonry surface (inspected building 17 – East facade)

This type of degradation is frequently more severe at the base of the earth walls (basal erosion) (Figure 8). Being usually caused by the penetration of ground water by capillary action (McHenry, 1989) and transport of salts to the surface when it dries; sometimes it is also increased by rainwater splash after hitting the ground and by erosion caused by the wind. Furthermore, when the earthen walls moisture content is high (due to capillary rise, difficulties on drying, or lack of protective renders) their mechanical properties may drastically decrease. Therefore, basal erosion can cause significative loss of wall thickness, and loss of support under loading which can lead to overturning (Aytun, 1981).

Figure 8. Rammed earth with several basal erosion (inspected building 20)

Many damages caused by roof anomalies were also found, largely due to the infiltration of rainwater into the buildings interior and their walls. Roof damages are generally caused by roof tiles that broke or displaced from the correct position, and could be justified by wind action, aging, but also by roof structure deformation. The roof structure of these buildings is very simple and wooden based. Thus, deformation can possibly occur due to deterioration caused by biological agents such as insects or fungi.

Finally, the general state of deterioration of the buildings was also assessed by considering not only the type of anomalies detected for each inspected building, but also the building element affected (wall, roof) and the inspection team perception of the severity of the anomaly, based on visual observation. Four severity levels were defined: 0 (ruin), 1 (bad), 2 (reasonable) and 3 (good). The scale of severity was applied also considering a comparative visual observation among the same type of anomaly detected in different buildings, thus allowing reducing the level of subjectivity on the evaluation of the buildings condition (Gaspar and de Brito, 2005).

Table B.3 of Appendix B lists the severity levels assigned to each of the 98 inspected buildings. As shown in Figure 9, it is possible to observe that 17% of the inspected buildings are in a state of ruin, 43% are in a bad condition, 31% are in a reasonable one, and only 9% of the 98 inspected buildings present a good condition. The fact that most of the inspected buildings (60%) are in a poor condition, considered ruin or bad, is justified by the lack of maintenance or incorrect interventions over time and reinforces the importance of study this type of built heritage towards their conservation and retrofitting.

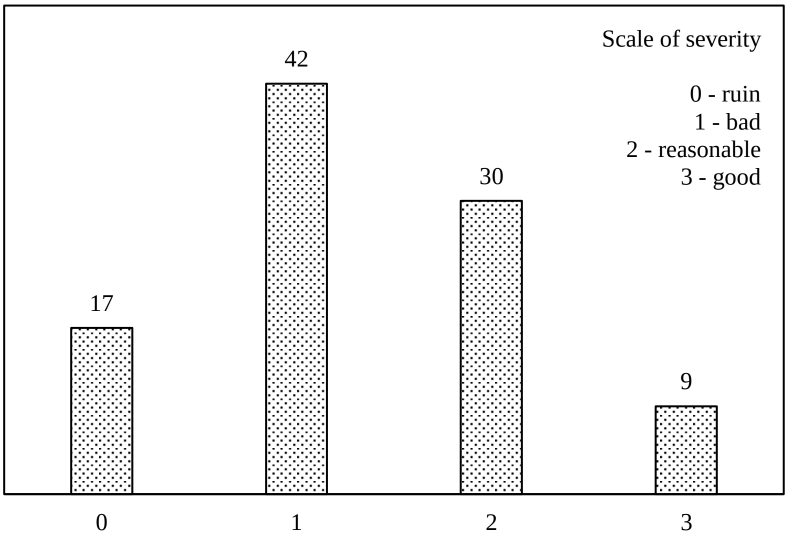


Figure 9. General condition of the inspected buildings

Apart from seismic actions (Figueiredo et al., 2013), the presence of water is indeed one of the most detrimental factors for this type of earth constructions since, by different ways (namely enhancing the aggressive action of soluble salts), it reduces the mechanical resistance of the adobes and rammed earth walls. Water can also potentiate biodeterioration not only of the walls (Santos et al., 2017) but also of the wooden structures that are supported by those walls, namely the protective roofs. Therefore, preventive actions that avoid moisture penetration are fundamental (Illampas et al., 2013).

Surface protection from weathering agents is also important, particularly for unstabilized rammed earth walls (Bui et al., 2009) and for all adobe masonry. The application of compatible renders is preferable, however, when it is not possible, compatible and effective surface treatments can also be considered (Ribeiro et al. 2020). Furthermore, whenever possible, repairs on the walls should be performed with mortars based on the same earth originally used in their construction (Gomes et al., 2018).

3.3. Case studies

The two case studies presented, dwellings 4 and 29, although not representative of all the 98 surveyed buildings (Figure 3) were chosen because they represent common types of semi-urban adobe masonry and rammed earth buildings from Leiria (see Appendix B).

3.3.1. Adobe dwelling 4

Inspected dwelling 4 (Figure 10) is located in a semi-rural area of the municipality of Leiria and was built with adobe masonry walls in 1935.

Figure 10. Semi-rural adobe dwelling from Leiria, Portugal (inspected building 4) with detail indicating the year of construction and the initials of the name of the owner

This dwelling presents a rectangular plan (Figure 11) and the main façade facing north. The kitchen is located at the left, facing south, the bedrooms at the right, also facing south, and a large living room at the right, facing both north and west. The exterior walls present a thickness of 0.45 m including the air lime render and plaster and the adobe have dimensions of 0.40 m × 0.20 m × 0.14 m (length × width × thickness). Interior partition walls are also built in adobe masonry, with smaller adobe, presenting a thickness of 0.15 m, including the plaster in both sides.

Figure 11. Architectural survey drawings of the inspected building 4

This construction has two exterior wooden doors with stonework frames (Figure 11), one of them in the main façade and the other in the façade facing east, both with dimensions 1.00 m × 2.20 m. The windows have wooden frames and present relatively small dimensions also framed with stonework. The interior wooden floor is higher than the exterior floor level, allowing a ventilated garret of about 0.40 m, being supported by horizontal wood beams, similar to buildings in Aveiro region (Tavares et al., 2014). The roof structure is also wooden made, in this case with three slopes (Figure 11) and the roof is covered with ceramic tiles (*Marselha* roof tile). Therefore, the attic is ventilated and there is a suspended wooden ceiling separating the attic from the habitational area.

This dwelling has probably been built with the intention of constituting the first terraced house of a group of two or more similar buildings. This hypothesis is based in the building morphology which presents in the east side a gable roof and a plain façade which do not follow the design characteristics and ornamentation of the remaining building (Figures 10 and 11). In the east façade the outer door is clearly unassociated with the building design (Figure 11). Although this door presents stone and wood frames similar to the north façade front door, it consists of an isolated element in the façade without any relation of symmetry or alignment with other elements of the building design. This door was probably added to the building in a later intervention, to provide direct access to the kitchen and eventually has no relation with the initial construction.

In spite of having been built using traditional materials and technologies, such as adobe masonry, this dwelling construction probably followed a design scheme previously elaborated, or at least some design guidelines derived from other previously built dwellings of similar typology. This hypothesis is formulated taking into account that it presents sequences of dimensions, alignments and symmetry design rules that reveal a certain degree of design rationalization which is difficult to achieve without having been previously planned to the construction phase. Footprint dimensions are barely round up to meter units (10.00 m × 8.05 m). All windows have similar dimensions (0.75 m × 1.20 m), are equally spaced in the façades and perfectly aligned. The building construction system, although traditional, presents aspects that can be considered as having a certain degree of standardization in the manufacturing process. The windows stone and wood frames have elaborated chapped profiles that indicate they were manufactured off site, probably in specialized craftsman workshops. The same is observed in the interior doors and ceilings' woodwork. The high pitch roof wooden structure is achieved by using wooden trusses, avoiding the need of a structural wall inside the building, as well as mitigating transmission of horizontal forces to the perimeter adobe walls. This structural system reveals a certain knowledge that can be considered beyond the vernacular construction knowledge mostly based on continued experimentation. Actually, the adobe masonry system can also be considered a systematic production method by itself as, although traditional, it required some planning ahead of the building construction.

Some of the technological and constructive aspects show that the seismic behavior was also considered in the building design and construction of this vernacular heritage, being Leiria a region with a non-negligible degree of seismicity. Concerning the wall construction, the horizontal and vertical mortar joints are uniform and completely filled and all the building walls are plastered (interior) and rendered (exterior). While the uniformization of the joints allow to make strong adobe masonry, the plaster and the render increase the strength and stiffness of the walls and provide environmental protection (Blondet et al., 2011). The existence of a stone plinth and cantonal stones in areas of high transmission of shear forces also contribute to improve the seismic performance of the building (Minke, 2012). Finally, a timber ring beam guarantees an improved seismic behavior, as this structural element connects the walls together and guarantees a box-type behavior when subjected to an earthquake (Lourenço et al., 2019).

3.3.2. Rammed earth dwelling 29

Inspected dwelling 29 (Figure 12) is located in the municipality of Pombal and was built with rammed earth walls in 1942. It is also located in a semi-rural area and presents a rectangular plan with dimensions of 10.85 m × 3.25 m (Figure 13), with the main façade facing south. In the interior, the kitchen is positioned at west, the bedrooms are facing east, and the living room is in the center (Figure 13).

Figure 12. Rammed earth dwelling from Pombal, Portugal (inspected building 29)

The exterior rammed earth walls have a thickness of 0.45 m including the air lime render and plaster. The exterior wall facing west is not rendered; therefore, it was possible to observe and measure the joints between the rammed earth blocks, as well as the holes corresponding to formwork crossing the wall thickness. The total dimensions of the rammed earth elements were 2.00 m × 0.70 m × 0.40 m (length × width × thickness).

Additionally, and according to the information obtained in an oral interview, this west façade has been continuously exposed to weathering for more than 75 years.

The dwelling presents three exterior wooden doors: one is in the main façade with dimensions of 0.88 m × 1.94 m and the other two are in the north façade and measure 0.82 m × 1.94 m (Figure 13). The windows have wooden frames and present relatively small dimensions (0.77 m × 1.04 m). In this dwelling, neither the door, nor the windows have stonework frames.

The roof is a simple pitched roof with one ridge and two gable side endings. The ridge is formed by a central wooden beam directly supported by the rammed earth walls. Both roof fields have a structure made just by spaced rafters covered with ceramic tiles. In the interior, a suspended wooden ceiling is provided to all compartments, defining a ventilated attic. As in dwelling 4, the wooden floor is also raised, with a ventilated garret of about 0.40 m, supported on horizontal wood beams.

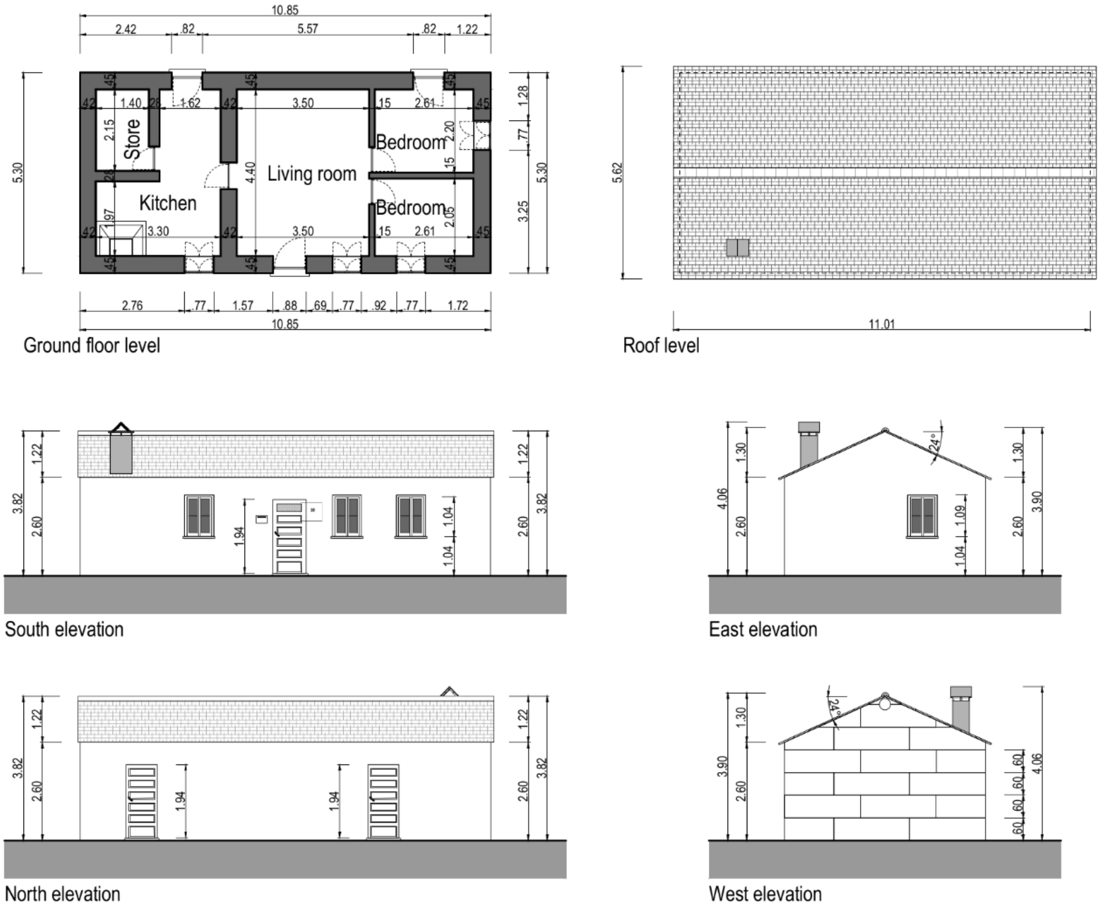


Figure 13. Architectural survey drawings of the inspected building 29

As for building 4, some technological and constructive aspects that contribute to an improved seismic behavior were also detected. Conversely to building 4, building 29 has no ring beam and the connection between the roof structure and the walls is simple, being the ridge formed by a central beam directly supported by the rammed earth walls. Also, there are no stonework frames in the doors or windows. Nevertheless, almost all exterior (except the West wall) and interior rammed earth walls are rendered and plastered with a water vapor permeable mortar and limewash system, increasing the stiffness and strength of the walls and providing environmental protection. Moreover, the wall openings (doors and windows) are limited, with small dimensions, and both the distance between such elements and between openings and the wall corners seem to have been considered and are adequate. This is important because it is well-known that openings destabilize the wall system, and diagonal cracks often occur during earthquakes, starting at the window and/or door edges. From building morphology analysis, confirmed by the oral information gathered, it was possible to determine that this dwelling was built in several phases, in a dynamic process driven by the growth of the owner's family and their needs, as well as their economic condition. Similar situation, although with adobe masonry, was observed in Pinhal Novo region, South Lisbon, for the so-called Caramela dwellings (Sampaio et al., 2017). The first part to be built was the east part, comprising two bedrooms and a living room. In a second phase, the building was extended to west to accommodate the actual kitchen and a small storage room. At that time, kitchen activities took place outside the main dwelling in a detached small building. According to the family's descendants that were interviewed during the survey, this small storage room was lastly used as bedroom due to the increase number of family members. A third building extension phase was intended but never took place; that is the main reason why the exterior west wall was never rendered.

3.4. Discussion on construction techniques, conservation and retrofitting

Considering the above description of the two case studies, it is possible to conclude that the construction processes of dwellings 4 and 29 were significantly different. In fact, dwelling 4, built with adobe masonry walls, presents a more elaborated construction system and more detailed architectural features than dwelling 29, built with rammed earth walls. This is not in agreement with the oral information gathered, where it is mentioned that adobe masonry building system was considered more affordable than rammed earth's. However, if this information is considered in a more comprehensive context it may represent just a building system evolution, so common in many other building materials and techniques. In a technical-social-economic context where both systems were available, the option for adobe masonry may just represent the option for a more efficient building system, with prefabricated masonry units, not necessarily just related to less expensive dwellings. In comparison to rammed earth, adobe masonry walls require less specialized labor, have a more manageable production process, allowing pre-production, and in some cases a thinner, flexible and faster wall construction. In fact, these may represent key factors when selecting the construction system to build dwellings with more elaborated architectural programs in a shorter timeframe. Nevertheless, many of the surveyed adobe buildings, namely storehouses, present simple design and humble details, as can be seen in Figures 3C and G, in accordance with the oral information gathered. Certainly, in these earthen buildings, either with rammed earth walls or adobe masonry, the main factors that determined their construction system, as well as the architectural details, were the requirements and the socio-cultural context of the original owners.

Particularly for the adobe construction, it is interesting to compare the architecture of semi-urban dwelling 4 with contemporary adobe buildings from other regions in Portugal, namely in Ílhavo, Aveiro district, with much more elaborated architecture (Tavares et al., 2012).

As stated before, many of the 98 surveyed building are now abandoned. It seems owners are waiting for them to fall apart, so they can sell the land without any building conservation constraints. Therefore, in order to contribute to the conservation of, at least, a part of this vernacular architectural heritage, it is urgent to propose simple and gradual intervention measures to capture the interest for the use of these buildings, fulfilling nowadays conditions of comfort and energy efficiency in Mediterranean Europe. Without intending to be exhaustive and concerning only some constructive aspects that can be considered in future earthen buildings interventions, mainly those still in use (Correia and Walliman, 2014), and also, based on the observation of inadequate interventions in the context of authors professional practice, the following can be mentioned:

- In dwellings with thick massive walls in Mediterranean climate regions the roof represents an envelope surface area with significant influence in the building thermal performance. Therefore, an affordable and minimal intrusive way to drastically increase comfort of the ancient earthen dwellings surveyed is through the introduction of a thermal and acoustic insulation material on the roof system, namely a mineral wool blanket supported by the wooden ceilings. The insulation materials are usually lightweight, meaning that they will not increase significantly the weight supported by the roof structure and the earthen walls. The space between the tiles and the insulation must be kept ventilated to avoid vapor condensation and ceramic tiles durability.

- The wooden doors and windows also may benefit from repair or replacement, if possible maintaining the use of wood and installing thermal double glazing; simultaneously, the establishment of natural ventilation openings (that previously occurred by the untightened old doors and windows) has to be considered.
- The use of a heating source for the winter period and a passive ventilation solution for night cooling in summer, along with the previous mentioned improvements will significantly increase the dwelling thermal comfort.
- The repair or replacement of the air lime-based renders or plasters by cement-based ones should be avoided, to ensure that the walls keep drying the moisture that reaches them from the ground, or through migration from the indoor environment (Gomes et al., 2016; Gómez-Patrocinio et al., 2017). Whenever needed and possible, repairs on the walls should be performed with mortars based on the same earth originally used to build them (Gomes et al., 2018).
- In the case of dwellings with a ventilated garret supported on horizontal wood beams, the ventilation of the garrets should be assured, in order to guarantee the dissipation of ground moisture and, therefore, mitigating its migration and rise in the earthen walls by capillary action.

Structural aspects, that are extremely important, are not addressed in the present paper but have been deeply studied by other researchers and can be accessed elsewhere, namely in Correia et al. (2014), Gómez-Patrocinio et al., (2013), Figueiredo et al. (2013) and Illampas et al., (2013). Nevertheless, also for structural studies and modelling, data on materials type and dimensions is extremely important. To the authors' knowledge, information about the earthen materials used in Leiria district is not available so far, justifying the effort to perform the preliminary characterization presented here and the material characterization presented elsewhere (Parracha et al., 2019b). Also, although vernacular earthen buildings present high seismic vulnerability, mainly due to their low mechanical properties, poor maintenance, and sometimes lack of good quality construction (Ortega et al., 2017; Lourenço et al., 2019), extensive research has been produced in order to minimize this vulnerability, by creating, relearning and boosting the use of traditional (Ortega et al., 2018; Lourenço et al., 2019) and/or innovative (Misseri et al., 2020; Reyes et al., 2020) anti-seismic solutions. These solutions have been applied in the seismic retrofit of earthen buildings, allowing to preserve, and even to build new, safe earth construction in countries at seismic risk.

4. Concluding remarks

The present study aims at contributing to the characterization of vernacular adobe masonry and rammed earth buildings from the region of Leiria, Portugal. With that purpose, 98 earth buildings were inspected and mapped to identify the constructive technologies and most common associated anomalies. Two of these dwellings were presented as case studies of each earthen wall technique, although a vast diversity exists.

The main conclusions obtained are the following:

- Through the mapping of the existing earth buildings in Leiria district, it was possible to notice that adobe masonry and rammed earth were the most common construction techniques, which is not surprising since these two techniques are the most widespread in Portugal. However, rammed earth predominates in Pombal municipality while adobe masonry prevails in Leiria municipality. Some reasons that led to this differentiation are pointed out supported by interviews to old people that have been or are still involved with those buildings, namely more availability of water to produce the adobe in Leiria or the possibility to perform more elaborated architectural programs in a shorter timeframe due to the prefabrication of adobe.
- The dimensions of adobe and rammed earth blocks found in Leiria differ from those found in other regions of Portugal. They present variable dimensions, being more notorious in the case of the adobes. Adobe masonry was layered allowing the length dimension of the adobe blocks to be aligned perpendicular to the wall and corresponding to the wall thickness. The adobe faces towards the wall surfaces (inside and outside) present a vertical indentation that was not found, or at least mentioned, in adobes from other regions and probably intended to assure a more efficient bond to renders and plasters.
- The oral information gathered mentioned that adobe masonry building system was considered more affordable than rammed earth walls. The survey also showed several simple adobe buildings. Nevertheless, the architectural analysis of the two case studies reveals that dwelling 4, representing a significant number of semi-urban surveyed dwellings built with adobe masonry walls, has far more elaborated architectural design and complex construction system when compared to dwelling 29, built with rammed earth walls. Therefore, it can be concluded that both the building of simple and more elaborated adobe dwellings co-existed.
- Most of the inspected buildings (60%) present a poor condition, considered ruin or bad, which reinforces the importance of studying this type of built heritage towards their conservation and retrofitting. That is

mostly due to lack of maintenance or incorrect interventions over time, like the use of cement-based mortars for repairs. Thus, characterization results are of fundamental importance to draw conclusions about materials and constructive technologies used in the past in order to support future interventions.

- To ensure the preservation of at least a part of this vernacular heritage, there is a need to increase its value to the owners, so they can choose the buildings preservation rather than let them ruin. Therefore, apart from eventual structural retrofitting, mainly needed in some roof structures, affordable and minimally intrusive interventions are recommended to improve comfort in use. The most important to be considered are the roof insulation (thermal and acoustic), the installation of a heat source for winter and a passive ventilation system that allows safe night cooling in summer. Repairs and surface protection on the earthen walls should be performed with earthen and/or air lime mortars to assure compatibility.

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APPENDIX A – Interview with a former professional in the area of earth construction

At an international level, currently there are several campaigns created by groups and/or associations, such as CRATerre and ISCEAH Committee of ICOMOS, that aims at obtaining the maximum information possible about earth-built heritage through oral interviews with former professionals in the area: information related to the architecture, constructive technologies and materials used at the time of construction.

During a visit to the village of Casal da Quinta, located in the civil parish of Milagres, Leiria's municipality, it was possible to conduct an oral interview with Mr. António Garrido (Figure 1), former professional in the area of earth construction, who passed away in 2018. Mr. Garrido had an extensive experience and a deep professional knowledge about earth construction in the region. In the course of the interview, topics such as the presence of adobe and rammed earth construction in the region of Leiria, the constructive technologies and materials used at the time, were discussed.

Full name: António Fonseca Garrido

Date of birth: 07/07/1929 (died in 2018)

Address: Casal da Quinta (Leiria)

Professions: Builder and farmer.

Interviewer (Int) – Good afternoon Mr. António, can we have a short conversation with you? We would like to know a bit more about adobe and rammed earth construction here in Leiria.

António Garrido (AG) – Good afternoon. Of course, we can talk about it.

Int – Mr. António, I was told that when you were younger you have built with earth. Is this true? Can you please tell me what adobe is?

AG – Yes, it is true that I have built with earth in the past. Adobe are earth blocks that we have used to build the houses before the ceramic brick appeared…

Int – And how did you make adobes with the earth? Where did you get the earth?

AG – The earth was collected in the field but at a reasonable depth… Not all the earth was good to build…

Int – Not all the earth was good? What do you mean?

AG – We started by digging the earth until find a “fat earth” that is not only sand and not only clay.

Int – And it was relatively easy to find that kind of “fat earth”?

AG – Here in this region… yes… almost all the earth here is good to build… further up (pointing to North) the earth is not so… has thicker stones

Int – We have seen a large number of rammed earth constructions in Pombal, more than adobe. Do you think that may be because of that?

AG – It is possible… but who knows…

Int – And here in Casal da Quinta. Have you built more with rammed earth or adobe?

AG – Here was just adobe. The rammed earth was very rare.

Int – And when you were making the adobes, have you added something to it? Like lime or straw?

AG – The straw was for the animals… and the lime... the lime was quite expensive and because of that was not to be mixed with earth…

Int – But you have used the lime for construction?

AG – Yes, I did. But not for earth construction… the earth does not need the lime. The lime was used for other things.

Int – Mr. António, concerning the adobes. Did you use any kind of mold?

AG – Yes, we had a wooden mold for it…

Int – And that mold was made by whom? By a carpenter?

AG – No… There was always someone around who knew how to do it…

Int – And after the mold was ready. How did you perform the adobe itself?

AG – We get the earth that we think it was good for it. After that, the earth was just (mixed with water and) placed inside the mold and compressed (by hand). Then the mold was removed, and the adobe was allowed to stay still for a couple of days in order to dry…

Int – And how many days to dry?

AG – I do not remember very well… it depended… if the weather was good (warm and dry) or not… if good, it was very quick…

Int – And about the rammed earth. Have you ever built with rammed earth?

AG – Not alone, no… I have just helped to do it…

Int – And how the rammed earth was made? Do you know?

AG – The rammed earth walls were made also using earth but inside wooden formwork… and we worked inside the formwork to compact the earth… while the others filled it…

Int – And… What do you used to compact the earth?

AG – Barefoot and wooden pestles… that's what we had at hand…

Int – Do you remember how the rammed earth blocks were assembled and disassembled?

AG – No, I do not know how to do that…nor they… (laughs)

Int – Mr. António, please tell me just one more thing. If you had to choose between rammed earth and adobe, which one used a high quantity of water to be made?

AG – Adobe… but here in this region there is water everywhere… and in the old days there were even more creeks than today… and we went there to take some water to do the blocks.

Int – When did you stop to build using adobe?

AG – I stopped when the ceramic brick appeared (and was affordable)… maybe 1950 or 1960…

Int – And… Why do you think that adobe or rammed earth was replaced by the ceramics?

AG – It was cheaper… and already made.

Int – Thank you very much for your time!

APPENDIX B – Data related to the survey of the 98 earth buildings

Table B.1 – Adobe and rammed earth buildings data

Building reference	Construction year	Municipality	Civil parish	GPS coordinates	Technique	Element dimensions [m]
1	NA	Leiria	Stª. Eufémia	39.76165, -8.76587	Adobe (A)	-
2	NA	Leiria	Stª. Eufémia	39.76105, -8.74865	A	-
3	NA	Leiria	Stª. Eufémia	39.76028, -8.74943	A	-
4	1935	Leiria	Stª. Eufémia	39.760322, -8.74997	A	A: 0.40 x 0.20 x 0.14
5	NA	Leiria	Stª. Eufémia	39.76250, -8.75354	A	A: 0.40 x 0.18 x 0.15
6	NA	Leiria	Boa Vista	39.77145, -8.75569	A	-
7	NA	Leiria	Stª. Eufémia	39.76210, -8.75586	A	-
8	1910	Pombal	Meirinhas	39.84101, -8.71138	Rammed earth (RE)	RE: 2.00 x 0.60 x 0.40
9	1939	Pombal	Meirinhas	39.84166, -8.70373	Both RE and A	RE: 2.00 x 0.70 x 0.40
10	1927	Pombal	Meirinhas	39.76028, -8.74943	Both RE and A	RE: 2.00 x 0.70 x 0.40 A: 0.36 x 0.14 x 0.12
11	1922	Pombal	Meirinhas	39.84158, -8.740252	RE	RE: 2.00 x 0.70 x 0.40
12	1930	Pombal	Meirinhas	39.84179, -8.69828	RE	RE: 2.00 x 0.70 x 0.40
13	1925	Pombal	Meirinhas	39.84156, -8.69761	RE	RE: 2.00 x 0.70 x 0.40
14	1930	Pombal	Meirinhas	39.84081, -8.69713	Both RE and A	RE: 2.00 x 0.70 x 0.40 A: 0.36 x 0.14 x 0.12
15	1917	Pombal	Meirinhas	39.83998, -8.69537	Both RE and A	RE: 2.00 x 0.70 x 0.40 A: 0.36 x 0.14 x 0.12

16	1931	Pombal	Meirinhas	39.83850, -8.69496	RE	RE: 2.00 x 0.70 x 0.40
17	1915	Pombal	Meirinhas	39.83546, -8.69496	RE	RE: 2.00 x 0.70 x 0.40
18	1927	Pombal	Meirinhas	39.83798, -8.69939	A	A: 0.36 x 0.14 x 0.12
19	1932	Pombal	Meirinhas	39.83813, -8.69390	RE	RE: 2.00 x 0.70 x 0.40
20	1927	Pombal	Meirinhas	39.83873, -8.69398	Both RE and A	RE: 2.00 x 0.70 x 0.40 A: 0.36 x 0.14 x 0.12
21	1890	Pombal	Meirinhas	39.83859, -8.69459	A	A: 0.30 x 0.14 x 0.12
22	1890	Pombal	Meirinhas	39.84102, -8.69151	Both RE and A	RE: 2.00 x 0.70 x 0.40 A: 0.36 x 0.14 x 0.12
23	1908	Pombal	Meirinhas	39.84761, -8.69517	RE	RE: 2.00 x 0.70 x 0.40
24	1920	Pombal	Meirinhas	39.84733, -8.69385	Both RE and A	RE: 2.00 x 0.70 x 0.40 A: 0.36 x 0.14 x 0.12
25	1928	Pombal	Meirinhas	39.85004, -8.69155	Both RE and A	-
26	1877	Pombal	Meirinhas	39.85062, -8.69093	RE	RE: 2.00 x 0.60 x 0.40
27	1940	Pombal	Meirinhas	39.85164, -8.68964	RE	RE: 2.00 x 0.70 x 0.40
28	1907	Pombal	Meirinhas	39.84946, -8.69569	Both RE and A	RE: 2.00 x 0.70 x 0.40
29	1942	Pombal	Meirinhas	39.84076, -8.71733	RE	RE: 2.00 x 0.70 x 0.40
30	1929	Pombal	Meirinhas	39.84403, -8.69569	Both RE and A	RE: 2.00 x 0.60 x 0.40 A: 0.36 x 0.14 x 0.12
31	1931	Pombal	Meirinhas	39.84283, -8.69592	RE	RE: 2.00 x 0.60 x 0.40
32	1927	Pombal	Meirinhas	39.84207, -8.69648	RE	RE: 2.00 x 0.60 x 0.40

33	1929	Pombal	Meirinhas	39.84218, -8.69645	RE	RE: 2.00 x 0.60 x 0.40
34	NA	Pombal	Pombal	39.91872, -8.64345	RE	RE: 2.00 x 0.70 x 0.40
35	NA	Pombal	Pombal	39.89616, -8.66032	A	A: 0.36 x 0.14 x 0.12
36	NA	Pombal	Vermoil	39.87536, -8.67456	Both RE and A	RE: 2.00 x 0.70 x 0.40
37	NA	Pombal	Vermoil	39.87367, -8.67725	RE	RE: 2.00 x 0.70 x 0.40
38	NA	Pombal	Vermoil	39.86014, -8.67857	Both RE and A	RE: 2.00 x 0.70 x 0.40
39	NA	Pombal	Vermoil	39.8599, -8.68368	RE	RE: 2.00 x 0.70 x 0.40
40	NA	Pombal	Vermoil	39.86166, -8.69015	Both RE and A	RE: 2.00 x 0.70 x 0.40
41	NA	Pombal	Vermoil	39.84840, -8.65850	A	-
42	NA	Leiria	Bidoeira de Cima	39.8301, -8.7681	A	-
43	NA	Leiria	Bidoeira de Cima	39.82923, -8.76447	A	-
44	NA	Leiria	Bidoeira de Cima	39.82891, -8.75730	A	-
45	NA	Leiria	Bidoeira de Cima	39.82728, -8.75650	RE	-
46	NA	Leiria	Milagres	39.81523, -8.75171	A	-
47	NA	Leiria	Milagres	39.81506, -8.75123	A	-
48	NA	Leiria	Milagres	39.81407, -8.75210	A	-
49	NA	Leiria	Milagres	39.81448, -8.75213	A	-
50	NA	Leiria	Milagres	39.81469, -8.75190	A	-
51	NA	Leiria	Milagres	39.81495, -8.75185	A	-
52	NA	Leiria	Milagres	39.81491, -8.75092	A	-
53	NA	Leiria	Milagres	39.81556, -8.75070	Both RE and A	-

54	NA	Leiria	Milagres	39.81597, -8.75049	A	-
55	NA	Leiria	Milagres	39.81647, -8.75006	A	-
56	NA	Leiria	Milagres	39.80876, -8.75793	A	-
57	NA	Leiria	Colmeias	39.80802, -8.73808	A	-
58	NA	Leiria	Colmeias	39.80831, -8.73551	A	-
59	NA	Leiria	Colmeias	39.82635, -8.7006	A	A: 0.30 x 0.14 x 0.12
60	NA	Leiria	Colmeias	39.82713, -8.69813	Both RE and A	-
61	1940	Leiria	Colmeias	39.82774, -8.69406	A	A: 0.40 x 0.24 x 0.12
62	NA	Leiria	Caranguejeira	39.77052, -8.72453	A	-
63	1914	Leiria	Stª. Eufémia	39.76076, -8.76809	A	-
64	NA	Leiria	Stª. Eufémia	39.76117, -8.76774	A	-
65	NA	Leiria	Boa Vista	39.76384, -8.76847	A	-
66	1945	Leiria	Boa Vista	39.77211, -8.75231	A	-
67	NA	Leiria	Boa Vista	39.77149, -8.75445	A	-
68	1935	Leiria	Boa Vista	39.77505, -8.76090	A	-
69	1902	Leiria	Monte Redondo	39.92382, -8.85137	A	A: 0.42 x 0.30 x 0.14
70	NA	Leiria	Monte Redondo	39.92391, -8.85111	A	A: 0.42 x 0.30 x 0.14
71	NA	Pombal	Ilha	39.91792, -8.77302	A	-
72	NA	Leiria	Colmeias	39.78788, -8.71993	RE	-
73	NA	Leiria	Colmeias	39.78858, -8.72089	A	-
74	NA	Leiria	Colmeias	39.78998, -8.72107	A	-

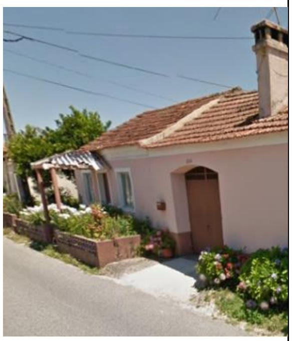
75	NA	Leiria	Milagres	39.81173, -8.74898	Both RE and A	-
76	NA	Leiria	Milagres	39.81192, -8.74864	A	-
77	NA	Pombal	Carnide	39.89136, -8.70174	RE	RE: 2.00 x 0.70 x 0.40
78	NA	Pombal	Pombal	39.90190, -8.70334	RE	-
79	NA	Pombal	Carnide	39.90293, -8.71577	A	-
80	NA	Pombal	Carnide	39.90779, -8.71740	RE	-
81	NA	Pombal	Mata Mourisca	39.91616, -8.72012	RE	RE: 2.00 x 0.70 x 0.40
82	NA	Pombal	Ilha	39.92113, -8.74810	A	A: 0.46 x 0.18 x 0.16
83	NA	Pombal	Ilha	39.9079, -8.74321	A	A: 0.46 x 0.18 x 0.16
84	NA	Pombal	Ilha	39.92528, -8.76071	A	A: 0.46 x 0.18 x 0.16
85	NA	Pombal	Ilha	39.92487, -8.76036	A	A: 0.46 x 0.18 x 0.16
86	NA	Pombal	Monte Redondo	39.91912, -8.76506	A	A: 0.46 x 0.18 x 0.16
87	NA	Leiria	Monte Redondo	39.92167, -8.85320	A	-
88	NA	Leiria	Monte Redondo	39.15220, -8.85174	A	-
89	NA	Leiria	Monte Redondo	39.90504, -8.85228	A	-
90	NA	Leiria	Monte Redondo	39.88183, -8.86533	A	-
91	NA	Leiria	Monte Redondo	39.88028, -8.86567	A	
92	NA	Leiria	Monte Redondo	39.87837, -8.87036	A	
93	NA	Leiria	Monte Redondo	39.87402, -8.79394	A	-
94	NA	Leiria	Milagres	39.79931, -8.76602	A	-
95	NA	Pombal	Meirinhas	39.84512, -8.69559	A	-

96	NA	Pombal	Pombal	39.91438, -8.62985	A	-
97	NA	Leiria	Leiria	39.74515, -8.81228	A	-
98	NA	Leiria	Leiria	39.89418, -8.84549	A	-

Table B.2 – Photos of adobe and rammed earth buildings identified in Table B.1

Nr.	Photo	Nr.	Photo	Nr.	Photo	Nr.	Photo
1		2		3		4	
5		6		7		8	
9		10		11		12	
13		14		15		16	

Nr.	Photo	Nr.	Photo	Nr.	Photo	Nr.	Photo
17		18		19		20	
21		22		23		24	
25		26		27		28	
29		30		31		32	
33		34		35		36	

Nr.	Photo	Nr.	Photo	Nr.	Photo	Nr.	Photo
37		38		39		40	
41		42		43		44	
45		46		47		48	
49		50		51		52	
53		54		55		56	

Nr.	Photo	Nr.	Photo	Nr.	Photo	Nr.	Photo
57		58		59		60	
61		62		63		64	
65		66		67		68	
69		70		71		72	

73		74		75		76	

Nr.	Photo	Nr.	Photo	Nr.	Photo	Nr.	Photo
77		78		79		80	
81		82		83		84	
85		86		87		88	
89		90		91		92	

93		94		95		96	

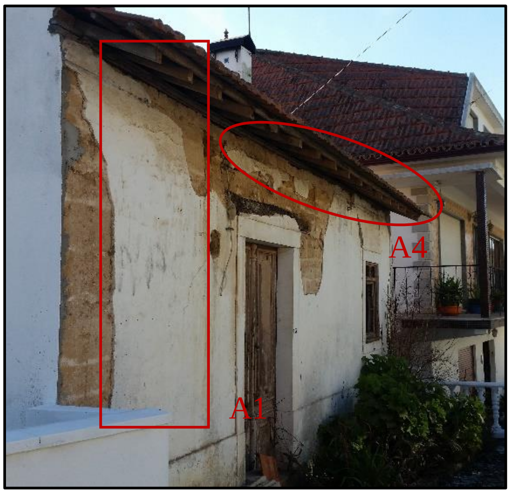
Nr.	Photo	Nr.	Photo	
97		98		

Table B.3. Building pathology and general condition

Building reference	General condition (scale from 0 – ruin to 3 – good*)	Building pathology**	Detail (when relevant)
1	0	-	See Table B.2
2	3	A1	-
3	2	A1; A4; A6	-
4	1	A1; A4; A5	 

5	0	-	

*Scale of severity: 0 – ruin; 1 – bad; 2 – reasonable; 3 – good. **If the scale of severity points to 0 (ruin), the building pathology is not mentioned; Anomalies identified in the survey, according to Section 3.2: A1 – Render/plaster decohesion; A2 – Rising damp; A3 – Basal erosion; A4 – Water infiltration from the roof; A5 – Biological colonization; A6 – Vegetation growth.

Building reference	General condition (scale from 0 – ruin to 3 – good*)	Building pathology**	Detail (when relevant)
6	2	A1; A2	
7	2	A1; A2	-
8	3	-	-
9	1	A1; A2; A3	-
10	1	A1; A2; A3; A4; A6	-
11	2	A1; A4	
12	1	A1; A2; A3	-

13	2	A1	-
14	0	-	
15	2	A1	-
16	2	A1	-

*Scale of severity: 0 – ruin; 1 – bad; 2 – reasonable; 3 – good. **If the scale of severity points to 0 (ruin), the building pathology is not mentioned; Anomalies identified in the survey, according to Section 3.2: A1 – Render/plaster decohesion; A2 – Rising damp; A3 – Basal erosion; A4 – Water infiltration from the roof; A5 – Biological colonization; A6 – Vegetation growth.

Building reference	**General condition (scale from 0 – ruin to 3 – good*)**	**Building pathology****	**Detail (when relevant)**
17	2	A1; A2	
18	0	-	
19	0	-	-
20	1	A1; A2; A3	See Figure 7 of the paper
21	1	A1; A2	-
22	1	A1; A2; A3	-
23	2	A1; A4; A6	-
24	1	A3; A4; A6	-
25	3	-	-

26	2	A1	-
27	0	-	
28	0	-	-
29	1	A1; A2; A4; A5	 

*Scale of severity: 0 – ruin; 1 – bad; 2 – reasonable; 3 – good. **If the scale of severity points to 0 (ruin), the building pathology is not mentioned; Anomalies identified in the survey, according to Section 3.2: A1 – Render/plaster decohesion; A2 – Rising damp; A3 – Basal erosion; A4 – Water infiltration from the roof; A5 – Biological colonization; A6 – Vegetation growth.

Building reference	**General condition (scale from 0 – ruin to 3 – good*)**	**Building pathology****	**Detail (when relevant)**
30	1	A2; A4	-
31	1	A1; A2; A4	-
32	2	A1	-
33	2	A1	-
34	3	-	-
35	2	A1; A2	-
36	2	A1; A2	-
37	1	A1; A2; A4; A6	

38	1	A1; A2; A4; A5	
39	1	A2; A3	-
40	1	A1; A2; A3	-
41	1	A1; A2; A4; A6	
42	1	A2; A4; A5	-

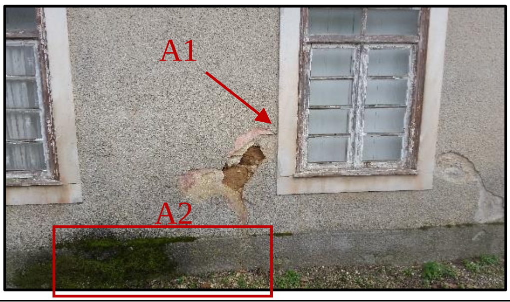
*Scale of severity: 0 – ruin; 1 – bad; 2 – reasonable; 3 – good. **If the scale of severity points to 0 (ruin), the building pathology is not mentioned; Anomalies identified in the survey, according to Section 3.2: A1 – Render/plaster decohesion; A2 – Rising damp; A3 – Basal erosion; A4 – Water infiltration from the roof; A5 – Biological colonization; A6 – Vegetation growth.

Building reference	**General condition (scale from 0 – ruin to 3 – good*)**	**Building pathology****	**Detail (when relevant)**
43	0	-	-
44	1	A3; A4; A6	-
45	2	A1	-
46	2	-	-
47	2	-	-
48	1	A3; A4; A6	-
49	1	A3; A4; A6	-
50	3	-	-
51	1	A4; A5	-
52	0	-	-
53	3	-	-

54	0	-	
55	0	-	-
56	0	-	
57	1	A1; A2; A4	
58	0	-	-
59	2	A1	-

*Scale of severity: 0 – ruin; 1 – bad; 2 – reasonable; 3 – good. **If the scale of severity points to 0 (ruin), the building pathology is not mentioned; Anomalies identified in the survey, according to Section 3.2: A1 – Render/plaster decohesion; A2 – Rising damp; A3 – Basal erosion; A4 – Water infiltration from the roof; A5 – Biological colonization; A6 – Vegetation growth.

Building reference	**General condition (scale from 0 – ruin to 3 – good*)**	**Building pathology****	**Detail (when relevant)**
60	1	A1; A2; A4; A6	
61	1	A2; A3; A4; A6	-

62	1	A1; A2; A3	
63	2	A1	-
64	2	A1; A2	-
65	2	-	-
66	3	A1	-
67	2	A1; A2; A4; A6	
68	2	A1; A2	-
69	1	A1; A2; A4; A5; A6	-
70	2	A1; A4	-
71	1	A1; A2; A3	-
72	0	-	-
73	1	A1; A2; A3; A4	-

*Scale of severity: 0 – ruin; 1 – bad; 2 – reasonable; 3 – good. **If the scale of severity points to 0 (ruin), the building pathology is not mentioned; Anomalies identified in the survey, according to Section 3.2: A1 – Render/plaster decohesion; A2 – Rising damp; A3 – Basal erosion; A4 – Water infiltration from the roof; A5 – Biological colonization; A6 – Vegetation growth.

Building reference	**General condition (scale from 0 – ruin to 3 – good*)**	**Building pathology****	**Detail (when relevant)**
74	2	A1; A2	-
75	1	A1; A2; A4	-
76	1	A1; A2; A4	-
77	2	A1; A2	-
78	1	A1; A2; A3; A4; A5; A6	-
79	1	A1; A2; A3; A4; A5; A6	-

80	1	A1; A2; A3; A4	-
81	1	A1; A2; A3; A4	-
82	1	A1; A2; A4; A5	-
83	1	A1; A2; A3; A4; A6	-
84	3	-	-
85	2	A1	-
86	2	A1	-
87	1	A1; A2; A3	-
88	2	A1; A2	-
89	1	A1; A2; A3; A4; A6	-
90	1	A1; A2; A3	-
91	0	-	-
92	0	-	-
93	3	-	-
94	2	A1; A2	-
95	0	-	-
96	1	A1; A2; A3; A4; A6	-
97	1	A1; A2; A3	-
98	1	A1; A2; A3; A4	-

*Scale of severity: 0 – ruin; 1 – bad; 2 – reasonable; 3 – good. **If the scale of severity points to 0 (ruin), the building pathology is not mentioned; Anomalies identified in the survey, according to Section 3.2: A1 – Render/plaster decohesion; A2 – Rising damp; A3 – Basal erosion; A4 – Water infiltration from the roof; A5 – Biological colonization; A6 – Vegetation growth.