Material weathering and structural damage in historic adobe constructions in Spain: preliminary results of a quantitative approach.

F. Javier Gómez-Patrocinio, Camilla Mileto, Lidia García-Soriano & Fernando Vegas López-Manzanares

Instituto de Restauración del Patrimonio, Universitat Politècnica de València, Valencia, Spain

Universitat Politècnica de València, Building 8B, Access L, Floor 0. Camino de Vera s/n, 46022 Valencia (Spain).

F. Javier Gómez-Patrocinio (Corresponding author): fragmepa@upv.es; ORCID: 0000-0003-0560-2230

Camilla Mileto: cami2@cpa.upv.es; ORCID: 0000-0002-6987-8802

Lidia García-Soriano: ligarso@upv.es; ORCID: 0000-0001-9696-7045

Fernando Vegas López-Manzanares: fvegas@cpa.upv.es; ORCID: 0000-0003-0315-6839

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This article presents the study of the main phenomena of material weathering and structural damage that affect traditional architecture built in adobe, analysing the damage found in 553 case studies, representative of different technical varieties of adobe construction in Spain. The analysis methodology proposed in this text made it possible to quantify and identify the risks of damage appearing, establishing its impact and identifying its main mechanisms and causes. At the same time, the behaviour of adobe construction systems was further studied, observing how specific modifications in technique can promote or hinder deterioration and establishing the probable causes of the different responses to these phenomena.

Keywords: Traditional architecture; Earthen construction; Adobe; Degradation

1. Introduction

Adobes are earthen masonry blocks, usually parallelepiped, that are obtained by moulding and drying in the open air a mixture composed of the earth with some shrinkage limiter: plant (fibres), animal (hair, bristles) or mineral (aggregate, lime, gypsum, etc.). Metrical analysis of blocks coming from buildings included as case studies in this paper showed an average size if 36x18x9 cm[1], although there have been detected variations as significant as 40x40x7 cm or 24x11x8.5 cm. The preparation of earth in small units allows better control of the drying process, making it easier to establish the quality of the materials as well as to handle it during the construction process[2].

In the building process, the masonry units can be placed forming different bonds (mainly stretcher, header, rowlock and shiner bonds, as well as different combinations among them), depending on the features desired and the wall thickness needed. Adobe walls are usually built over a stone or ceramic brick plinth to prevent earthen walls from being affected by rising damp and crowned by protruding eaves to protect them from rain[3].

Regardless of the organization of the blocks, mudbrick walls can also be erected in combination with structural elements (such as buttresses, wall plates or wooden frames) or be reinforced with insertions in the fabric or the joints (shards, flat stones, reeds, etc.)[4] to make the most of available raw materials and to adapt the building to the geographic and climatic conditions of the location[5] (Fig. 1).

The use of earth in masonry walls goes back to the same origins of Architecture[6], as shown by archaeological evidence found on the banks of the Tigris and Euphrates rivers, dating from 9.000 – 8.000 BC[7]. Specifically, the final development and the dissemination of the use of mudbricks in Spain and the western Mediterranean is commonly related to the late Bronze Age[8, 9], as proven by a great number of archaeological sites such as Cuesta del Negro[10], Cerro de la Virgen or Soto de Medinilla[11]. The use of adobe kept spreading during the Iron Age [12, 13, 14] and was mentioned by several classical authors, such as Pliny the Elder, Palladius, Cato, Varro, Columella, Strabo, Plautus or Vitruvius[15], who dedicated a whole chapter of his treatise *De architectura* to this material[16].

Etymologically, the term adobe comes from the Egyptian *thobe* or *tûb* and directly from the Arab *ottob*[17] and already appeared in a written document of the Iberian Peninsula in 1157[18]. During the Islamic rule of the region and the subsequent period of Christian conquest (c VIII – XVI), adobe endured as an extensively used technique in the Peninsula. However, while rammed earth was used to erect many of the most important palaces, castles and temples of the period, mudbrick construction was circumscribed to non-monumental architecture.

In the early modern period (c XVII-XIXIX), proliferates the publication of treatises on construction and mason handbooks with encyclopaedic or academic purposes. Throughout this centuries, writers such as Caramuel[19], Rejón de Silva[20], Villanueva[21], Bails[22] or Marcos y Bausá[23] describe in their texts the process of fabrication and construction with adobe. In 1902, the treatise of Florencio Ger y Lóbez[24] still pointed out that mudbricks and rammed earth are very common in rural constructions.

However, in the last century, there has been a progressive decline of these constructive systems to be gradually replaced by new industrially manufactured materials. As a result, earthen architecture has been increasingly regarded as poor or unworthy, being much of it been abandoned, demolished or repaired with modern materials that are not suited to its behaviour. At present numerous adobe constructions show a wide range of weathering phenomena which must be studied and identified to propose interventions able to resolve these problems, guaranteeing the survival of this architecture.

Despite the existence of these transformation dynamics has been known for decades, it was not until the 1970s that a growing interest in the study and conservation of this low-cost and sustainable architecture appeared. This objective was spurred on by the energy crisis of 1973 and brought about the first congresses on the conservation of adobe, including the first International Conferences on the Conservation of Mud-brick Monuments, precursors of the current Terra World Congresses on Earthen Architecture.

In these early symposia, some texts regarding intervention techniques for adobe walls already appeared[25, 26, 27]. However, these papers barely mention the importance of the previous diagnosis of the decay processes that these techniques must revert.

Following these first works, numerous books on the conservation of adobe constructions[28, 29, 30] and practical handbooks[31, 32, 33] have been published. In the past years, important research efforts have been made to identify and describe weathering processes damaging earthen architecture[34, 35] and to test how this decay processes behave[36, 37, 38, 39]. However, these texts tend to either examine the weathering of real case studios qualitatively or to quantify how the behaviour of the decay processes changes in different kinds of laboratory samples.

This study presents a different approach to the subject by assessing the impact of 16 different types of weathering on a wide sample of case studies covering the main mudbrick construction techniques existing in Spain. The weathering phenomena analysed in the article were selected for their potential to damage these constructions or the frequency of their appearance in studies previously undertaken[40, 41].

2. Material and Methods

The analysis presented in this article is part of a broader investigation on traditional earthen architecture in Spain. In this work, a simple random sampling of localities distributed among the country was made, aiming to identify vernacular structures built with earth. As a result, 1,696 study cases divided among 328 localities of 40 provinces were identified (Fig. 2a). This sample was subsequently divided into three strata, regarding the three main families of earth-building techniques existing in traditional Spanish architecture: rammed earth, adobe and half-timber with earthen filler[42]. The research for this article comes from the analysis of the Adobe stratum of the sample, including 553 case studies (Fig. 2b).

2.1. Technical classification of cases

Before the study of weathering phenomena, each case of adobe constructions was classified to identify its constructive family based on the following technical features (Fig. 3):

(1) The presence of structural elements, such as buttresses or wall plates, ensembled with the adobe walls (Fig. 3a).

(2) The description of the construction, through the bond and types of pieces used (Fig. 3b).

(3) The use of mortars with varying proportions of bonding agents other than clay (lime, gypsum, etc.) to attach the mudbricks and the employment of any plasters (mix of lime, gypsum, vegetable fibres, etc.) to cover them (Fig. 3c).

These case studies were classified into four groups of techniques to facilitate the interpretation of the data, identifying trends and obtaining statistically representative results[43].

2.2. Identification of weathering phenomena

The analysis of weathering phenomena was based on a literary review, that was completed with the study of the sample to identify and describe as many processes of material and structural damage potentially affecting adobe. Once the range of damage was drawn up, 16 types of damage were selected to carry out a quantitative study of their impact. These phenomena were selected for their capacity to weather adobe constructions or to the frequency with which they appear in the sample.

This study focused on how different variants of the technique can influence their vulnerability to damage. The following equation was applied to estimate the reliability of the sample and the different strata extracted from it and obtain the sampling error[44]:

$$\left(e = \sqrt{\frac{z^2 \cdot p \cdot q}{n}}\right)$$

In statistical terms, the case studies we considered as *n* samples of an infinite population (N > 30,000). The level of trust in the results was set in an average value of 95% ($\alpha = 5\%$), translated into a *z* value of 1.96, and the variability of the estimated response for the population was established as maximum (*p* = *q* = *0.5*) to remain conservative in the expected error. Table 1 gathers the resulting sample errors.

2.3. Classification fiches

The sample analysed was studied in detail, identifying all the cases with visible damage and grouping them into families by technique. The fiches used in this study are structured as follows (Fig. 4):

(1) **General description of the phenomenon**: descriptive name, adscription to a family of damage (material or structural) and description table for a quick summary of the nature of the damage.

(2) **General details of the phenomenon**: brief definition, observations relating to the analysis carried out and the main case representative of how the damage described appears.

(3) **Description of phenomenon** and location of the weathering (base, body or crowning of buildings).

(4) **Impact of the process on techniques studied,** showing the number of cases in each family that are affected by each type of damage.

(5) **Other cases** in which the main case, referred to above, can be complemented with up to three further cases.

3. Results

Table 2 shows the results of the quantitative analysis undertaken. During this study, detailed work was carried out on the complete sample, trying to identify the cases in which every kind of damage could be seen.

3.1. Material weathering phenomena

In the course of this study, 11 kinds of material weathering were analysed in detail (Fig. 5). Material weathering of any kind appeared in 12.81% of cases, with mould and lichen as the most common phenomena (22.24%) and graffiti as the least frequent (3.25%).

3.1.a. Damp stains

Damp stains are alterations in the colour of the earth mass due to an increase in its humidity (Fig. 6a). This type of weathering was identified in 20.8% of cases studied, mostly affecting the bottom of the walls due to rising damp from the ground.

The presence of a plinth in damp-resistant material impedes damp rising to the earth mass and the appearance of this type of damage[4]. 24.3% of cases studied which had no plinth presented damp stains, as compared with 17.1% in the constructions which did have a plinth.

Although damp stains mostly appear at the bottom of the walls, they may also appear in higher parts of the walls when lower constructions lean against them or when the eaves and scuppers of the roof cannot provide enough protection from rainwater. These alterations can occasionally appear on the crowning of the walls located under leaking roofs. However, these areas are usually well ventilated and exposed to the sun so that humidity tends to evaporate before causing these alterations[9].

Only minor variations of the influence of this weathering on the different types of adobe constructions can be observed. The presence of damp stains is slightly lower in constructions with mortar with added binders (17.98 %) than in constructions with earth mortar (21.34%). This slight difference may be due to the addition of binders to mortar, reducing porosity and preventing rising damp through the bed joints. Besides, the different instances where this weathering appears, between plastered constructions (23.33%) and those without plasters (20.30%) show that reducing the breathability of plastered walls can encourage the appearance of this damage.

3.1.b. Fluorescence

The damp in the mass of a wall can cause soluble salts to migrate to the surface. When water evaporates, salts dissolved in it crystallise in the walls forming the deposits known as fluorescence (Fig. 6b), found in 5.42% of cases studied.[45] The formation of fluorescence is more likely following the use of products with cement content during the repair or intervention of traditional buildings, as the composition of these materials includes salts that are likely to dissolve in water[46].

Regardless of the type of binder used, lime or cement plasters encourage this alteration by reducing the breathability of the wall and providing the surface with a uniform finish which increases the visual impact of the alteration. Consequently, fluorescence is noticeably higher in plastered buildings (14.44%) than in constructions with no plaster (3.67%).

The continuous presence of water in the wall promotes fluorescence and is slightly more likely to appear in earthen walls in direct contact with the ground, rising from 4.46% to 6.34% in the statistics. According to this the main risk factor for the appearance of fluorescence in earthen architecture is the presence of plasters and other elements made of materials which can contain soluble salts with the potential to migrate to the surface.

3.1.c. Erosion due to rising damp

The water found in the ground can rise by capillarity towards the bottom of the earthen walls in direct contact with it. When this happens, the damp content of the wall mass increases and the material weakens, temporarily returning to its original plastic state. If this situation persists, resistance is lost, encouraging the surface to come away at the bottom of the wall[7] (Fig. 7a).

If no interventions are carried out to prevent and halt rising damp, this superficial disintegration increases, worsening the effect of the mechanical impacts caused by the action of the wind - carrying suspended particles and waving nearby vegetation - or by the rub of passing people and animals. This accumulation leads to a gradual erosion of the section of the bottom of the wall, potentially causing it to collapse[12] (Fig. 7b).

8.68% of the case studies showed signs of superficial erosion caused by rising damp. In 48.7% of the buildings affected by this kind of weathering – that is 3.98% of the whole studied sample –, erosion had developed to produce significant problems of loss of volume, sometimes even menacing the stability of the walls. This data demonstrates the high potential for these phenomena to evolve into damage capable of jeopardising the same survival of earthen constructions.

As this problem derives from the direct contact between the earthen element and the ground, incorporating a plinth made of water-resistant material is effective in preventing these erosion issues.

Earthen walls are especially vulnerable to the adverse effect of water, given that their cohesion is usually the result of the bonding properties of clay[47]. Clay bonding occurs through a physical transformation, and its capacity can vary with the humidity content[48]. Therefore, earthen walls stabilised with binders such as lime or gypsum combine this physical cohesion with chemical transformations which reduce the risk of the surface becoming detached as a result of the presence of water.

In adobe walls attached with earthen mortars, loss of volume due to rising damp was almost twice (4.31%) as frequent as in case studies where lime or gypsum bond the wall (2.25%) (Fig. 8). However, buildings using these elements show a similar amount of surface detachment problems that those not using them. Thus, it seems reasonable to conclude that although mortars with added binders do not prevent wall surfaces from becoming detached, they do slow down this process, reducing the risk to building stability.

3.1.d. Erosion through the action of the wind

The particles suspended in the blowing air impact against the most exposed areas of the wall, wearing their surfaces (Fig. 9). Therefore, immediate surrounding conditions are key factors in the vulnerability of a building, especially in the direction of the prevailing winds, as close structures or nearby vegetation can shelter it from this kind of weathering[9].

Corners are highly susceptible to this type of weathering, as they normally are the most exposed areas of a building, being in this part of the isolated case studies built completely with earth where wind erosion focuses. Therefore, the corners of earthen constructions are often built using materials such as stone or brick, which are more resistant to abrasion. During this study, clear evidence of erosion on walls due to the action of wind appeared in 14.65% of the cases analysed. The execution of plasters provides a resistant envelope, which can be easily replaced and can slightly lower the appearance of this type of weathering (12.22%) compared to walls with no plaster (15.12%).

3.1.e. Erosion due to washing

As rainwater falls on earthen walls, it runs down the surface or seeps down into the mass until it evaporates or reaches the base[11]. The falling raindrops drag down the mud from the upper areas to the ground, slowly washing the earth away and causing a gradual loss of volume. If the wall repeatedly suffers from the erosive action of rainwater, this erosion may lead to major loss of volume (Fig. 10). This erosive action is much more intense in the upper sections exposed to the elements and tends to accumulate in unprotected crownings and sills with no gutters.

In the course of this study, signs of superficial erosion due to washing appeared in 14.47% of cases. In 37.5% of these 80 study cases – that is, 5.42% of the whole sample – problems of erosion due to washing had already developed to significant volume losses in the crowning of the walls. In any case, it should be noted that 8% of cases mentioned in this study are fencing elements with no roof or very limited protection elements and thus are highly exposed to the effects of rain washing.

Superficial signs of erosion due to washing are slightly more common in study cases without plasters (14.90%) than in those rendered with lime or gypsum (12.22%). Regarding only affected case studies, it can be observed that this weathering has evolved from superficial erosion to loss of volume in 42.02% of the buildings that have no plasters, in contrast with only 9.09% of the rendered ones. Based on the comparison of this data, it seems clear that plasters are efficient in preventing the evolution of wall washing.

3.1.f. Mould and lichen

The constant presence of damp in earthen walls favours the proliferation of fungus, mould and lichen (Fig. 11a). As they expand, these colonies of organisms hinder the dissipation of humidity, damaging the cohesion of the outer faces of the wall and causing detachment from the surface[11].

This weathering tends to be concentrated on north-facing elements or elements with few hours of direct solar radiation and in more humid areas, such as the bottom of the walls in direct contact with the ground or the meeting points with the roofs of lower buildings. The proliferation of mould and lichen is one of the most frequent types of weathering in adobe architecture, appearing in 22.24% of the sample studied. This weathering appears with slightly higher frequency in constructions with an exterior plaster (24.44%) than those without (21.81%).

3.1.g. Vegetation growth

In suitable hygrothermal conditions, earthen buildings are ideal settings for the growth of vegetation (Fig. 11b). The germination of seeds transported by the wind and deposited in constructions is more likely in walls eroded and with high humidity. For this reason, the bottom of walls in direct contact with the ground or areas with mould and lichen encouraging damp are particularly sensitive to the development of these organisms.

As they grow, the plants form a network of roots which spreads throughout the mass of the wall, causing cracks and endangering stability[12]. In the course of this study, vegetation growth was detected on walls in 7.96% of cases analysed.

A detailed study on the different types of adobe walls shows a slightly lower impact in plastered buildings (5.56%) than in those with no plaster (8.42%). This variation could be since the existence of protective plaster prevents seeds blown by the wind from settling.

3.1.h. Loss of the roof due to lack of maintenance

Roofs are constructive elements which are especially sensitive to the lack of maintenance. If an individual leak on a roof is not repaired, it can lead to beams rotting and the partial loss of the roof. The remaining constructive elements in the building are then left exposed, and their weathering speeds up (Fig. 12a).

The sample studied (excluding fencing elements as they never had roofs) recorded an occurrence index of 15.35%. This rate of appearance may be due to the frequency with which buildings in adobe are often standalone constructions or non-residential buildings, likely to fall into disuse.

3.1.i. Partial collapse of the walls due to lack of maintenance

Without regular maintenance, earthen walls can suffer a partial or total collapse (Fig. 12b). Considering the weathering derived from natural phenomena and excluding cases of those due to deliberate demolitions, this type of weathering appeared in 9.58% of cases studied. A lower percentage of partial collapse incidents appeared in walls where joints used mortars with added binders (7.87%) than in those that only used earth mortar

(9.91%). Joints are usually the weakest points of a wall, where the damage more likely occurs. Therefore, improved joints should noticeably increase the overall resistance of the construction.

3.1.j. Graffiti

Graffiti are acts of vandalism that modify the appearance of the construction and alter its character. This type of weathering is found in 3.25% of cases, making it the least common material degradation phenomenon in the sample. Buildings near urban centres are the most vulnerable to vandalism as easy access combines with the isolation of the building.

3.1.k. Compatibility problems in the introduction of industrialized materials

Occasionally, intervention or maintenance tasks introduce industrialized materials in the building. The introduction of modern materials such as cement or plastic paints can bring about the appearance of different compatibility issues, such as cracking due to differences in thermal expansion, adherence problems or the accumulation of damp in earth mass caused by poor breathability[7].

This section only analysed cases in which industrialized materials were introduced during maintenance tasks (20.36% of the total sample), looking for those in which compatibility problems occurred (19.64% of the reduced sample). In most of the cases identified, the compatibility problems are due to the placement of elements impermeable to water vapour, which prevent the wall from breathing while they encourage the appearance of adherence problems. It was also observed that most of the repairs using brick generate no major incompatibility beyond visual impact and the minor issues of bond and rigidity.

3.2. Structural degradation phenomena

Five different types of structural damage, appearing in 7.48% of cases on average, were analysed in detail (Fig. 13). The most common were the cracks due to lack of interlocking between constructive elements (12.30% of the sample), while cracks due to problems in the building foundations on the ground are the least frequent (2.71% of the sample).

In this section, the analysis has not distinguished among case studies with or without plasters, as these are non-structural elements that do not affect the mechanical behaviour of the building.

3.2.a. Cracks due to concentrated loads introduced by beams

The absence of timber sleepers to support beams of floors and roofs can lead to highly concentrated loads on the point of the wall on which they rest, leading to topical crushing and shear failure. The appearance of this kind of cracks is highly probable in cases where the loadbearing elements of the horizontal structure transmit their load irregularly due to the concentration of weight or the absence of a timber slab over the beams to distribute loads.

This type of damage appeared in 6.69% of cases studied and is usually manifested through the appearance of cracks, starting below the support of the beams and moving downwards, almost vertically, in the transmission direction of the loads[8] (Fig. 14a). Weak points in the area of influence of the load tend to attract these cracks, which move away from the vertical direction (Fig. 14b).

This type of damage is slightly less frequent in buildings using mortars with added binders (4.49%) than in those bonded in earth mortar (7.11%). The use of mortars with added binders can noticeably improve the mechanical properties of adobe walls, enhancing their response to concentrated actions[49, 50].

3.2.b. Cracks due to structural weakness introduced by openings

Door and window openings always introduce discontinuity into the adobe structure, at times leading to the appearance of cracks and deformations in these walls (Fig. 15). The analysis included in this section shows case studies that reflect structural problems deriving from the presence of openings, without recording how they manifest. It was thus possible to identify this type of damage in 8.14% of cases studied.

Masonry walls act as homogeneous structures in which openings introduce discontinuity, adding stress in some sections and lightening it in others, encouraging stress concentration at specific points[10]. According to the study results, the use of mortar with added binders does not improve the response of walls to the discontinuity caused by openings and this damage is found in both groups in similar proportions (8.19% compared with 7.87%).

3.2.c. Cracks due to wall rotation from roof thrust

Poor fixing of the rafters in the loadbearing structure at the ridge can lead to major horizontal thrust in the crowning of the walls below the eaves. These intense stresses, far from the bottom of the wall, can shift the façades from their plane, giving rise to deformation and cracks[10] (Fig. 16).

As the weights that the rafters of a sloping roof are usually similar, they tend to transmit similar horizontal loads to the crowning of the wall. From wall rotation, these concentrated loads appearing at constant gaps are equivalent to a homogeneous one positioned along the entire crowning of the wall. The deformation usually manifests through vertical cracks in the joint between the wall under rotation and the perpendicular elements. However, at times transversal walls retain the ends of the roof, which is mostly exerting thrust in the centre. In these cases, the deformation concentrates in the central section of the façade, where vertical cracks appear[51].

7.59% of the case studies included in the sample are affected by cracks due to roof thrust, being far more common in walls bonded with binders (13.48%) than in walls bonded with earthen mortars (6.47%).

3.2.d. Cracks due to lack of interlocking between constructive elements

Construction of elements which are adjoining but poorly interconnected can bring about major material discontinuity in earthen constructions[52] (Fig. 17). These poorly connected elements are weak points which show cracks caused by limited stress and deformation. The risk of these cracks appearing is even greater when the materials of the poorly connected elements have different rigidity and thermal expansion properties.

Cracks due to poor bonding are common phenomena are found in 12.30% of cases studied. This behaviour was slightly improved in constructions with mortar with added binders (10.11%) compared to those with earth mortar (12.72%), probably due to a slight increase in cohesion and solidness.

3.2.e. Cracks due to foundation failure

Buildings exert pressure on the ground they stand on, progressively compacting it, and gradually causing the construction to settle. When this compacting occurs homogeneously, the load transmission scheme of the structures does not suffer major alterations. However, some soils – such as expansive ones, those including compressible strata of a variable thickness or soils whose water table experiences significant seasonal fluctuations – can lead to irregular settlements and cause major stress to the construction, bringing about the appearance of major cracks and deformations. Missing or insufficient foundations can also hinder the dissipation of the loads transmitted to the ground, generating higher tensions at localised points of the ground and triggering irregular settlements. Buildings constructed with superficial foundations in steeply sloping land are also likely to suffer sliding movements able to distort the structure, producing cracks.[53]

The analysis featured in this section has identified all the cases manifesting problems deriving from their support on the ground (Fig. 18), which affect 2.71% of the sample. There is virtually no distinction in the frequency in which this kind of damage appears in adobe walls bonded either with mud mortars (2.59%) or other binders (3.37%). Deformations triggered by foundation movements can introduce very intense stress into the structures, turning the variation of the mechanic strength of the walls due to the use of a specific type of mortar into almost negligible.

4. Conclusions

The study herewith presented has included data gathering and visual characterisation of a representative sample of adobe architecture in Spain, including 553 study cases. This sample, stratified attending to different criteria, has been examined to detect the presence of 16 different decay processes. The most frequent type of material weathering among them is the proliferation of mould and lichen, found in 22.24% of cases analysed. Whereas the most frequent type of structural degradation derives from poor interlocking between constructive elements, identified in 12.30% of buildings studied.

It has been observed that some kinds of weathering enhance the subsequent development of other types of damage. For instance, an increase in the humidity of the wall can favour fluorescence or moldiness. Therefore, case studies showing damp stains are more likely to suffer this pathology. Equally, erosion due to washing is more likely to appear in buildings that have lost their roof, leaving the crowning of the walls exposed.

Some types of weathering can be directly considered the natural evolution of others. Such is the case with damp stains and erosion due to damp rising, as it is the rise of the damp content of the wall – manifested through a darkening of the earthen mass – what triggers the erosion of its surface. 50.00% of case studies suffering from erosion due to damp rising also show damp stains. However, while damp stains are transitory, erosion remains once the source of the dampness has disappeared. As a result, case studies suffering from this kind of erosion, but not showing damp stains, must correspond with situations in which the cause of decay is no longer active.

Data show that variations in the technique can enhance or hinder the appearance of different kinds of weathering. Case studies including plinths in a damp-resistant material, such as stone or brick, show 29.70% less damp stains (from 24.3% to 17.1%) and 29.67% less fluorescence (from 6.34% to 4.46%).

Case studies using lime or gypsum, rather than earth mortar, to bond the wall reveal better response to damp stains (from 21.34% to 17.98%) and erosion (reducing the evolution from superficial to volumetric erosion in 41.43% for erosion due to rising damp and 50.00% for erosion due to washing) but reveal a higher tendency to fluorescence (increasing from 4.96% to 7.87%). Furthermore, they show 36.85% less cracks due to concentrated loads (from 7.11% to 4.49%), 20.52% less cracks due to lack of interlocking between constructive elements (from 12.72% to 10.11%) and 20.59% less problems of wall collapse due to lack of maintenance (from 9.91% to 7.87%).

External plasters protect earthen walls from atmospheric agents, such as rain or wind, but they necessarily reduce their transpiration. As a result, case studies including these elements show 19.16% less erosion through wind (from 15.12% to 12.22%) and 17.99% less erosion due to washing (reducing the evolution from superficial to volumetric erosion in 78.37%), but they reveal a higher tendency to damp stains (increasing from 20.30% to 23.33%), fluorescence (increasing from 3.67% to 14.44%) and proliferation of mould and lichen (increasing from 21.81% to 24.44%).

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Family	No. cases	Sample error
Adobe walls	553	4.2%
Adobe walls bonded with earth mortar	485	4.5%
Adobe walls bonded with lime or gypsum	68	11.9%
Earth-plastered walls in adobe	463	4.6%
Adobe walls plastered with other materials	90	10.3%

Table 1. Constructive families used in the statistical study.

	Adobe walls	Adobe walls bonded with earth mortar	Adobe walls bonded with lime or gypsum	Adobe walls plastered with earth	Adobe walls plastered with other materials
Damp stains	20,80%	21,34%	17,98%	20,30%	23,33%
Fluorescence	5,45%	4,96%	7,87%	3,67%	14,44%
Erosion due to rising damp	8,73%	8,84%	7,87%	8,86%	7,78%
Erosion through action of the wind	14,60%	14,01%	17,98%	15,12%	12,22%
Erosion due to washing	14,50%	15,09%	11,24%	14,90%	12,22%
Mould and lichen	22,24%	23,92%	13,48%	21,81%	24,44%
Vegetation growth	7,96%	7,76%	8,99%	8,42%	5,56%
Loss of roof due to the lack of maintenance	15,40%	13,58%	16,85%	14,04%	14,44%
Partial collapse of the walls due to the lack of maintenance	9,58%	9,91%	7,87%	10,37%	5,56%
Graffiti	3,25%	3,45%	2,25%	3,24%	3,33%
Compatibility problems with modern materials	19,64%	16,67%	37,50%	17,02%	33,33%
Cracks due to concentrated loads introduced by beams	6,69%	7,11%	4,49%		
Cracks due to structural weakness introduced by openings	8,14%	8,19%	7,87%		
Cracks due to wall rotation from roof thrust	7,59%	6,47%	13,48%		
Cracks due to lack of interlocking between constructive elements	12,30%	12,72%	10,11%		
Cracks due to foundation failure	2,71%	2,59%	3,37%		

Table 2. Types of material weathering and structural damage analysed in the study sample.

Figure 1. Adobe constructions in Urueña, Valladolid.

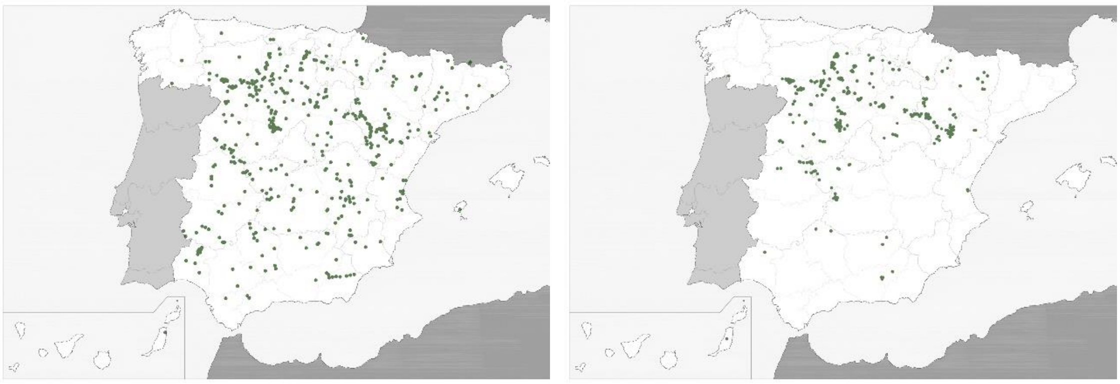

Figure 2. Location of the individuals of the main sample of the study (2a) and the individuals of the adobe stratum (2b).

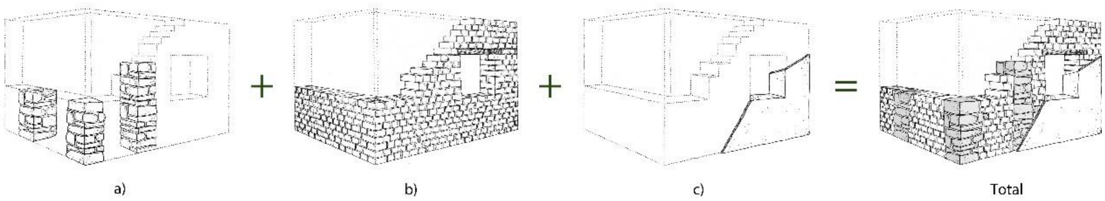

Figure 3. System of successive classifications used to describe the constructions in the case studies.

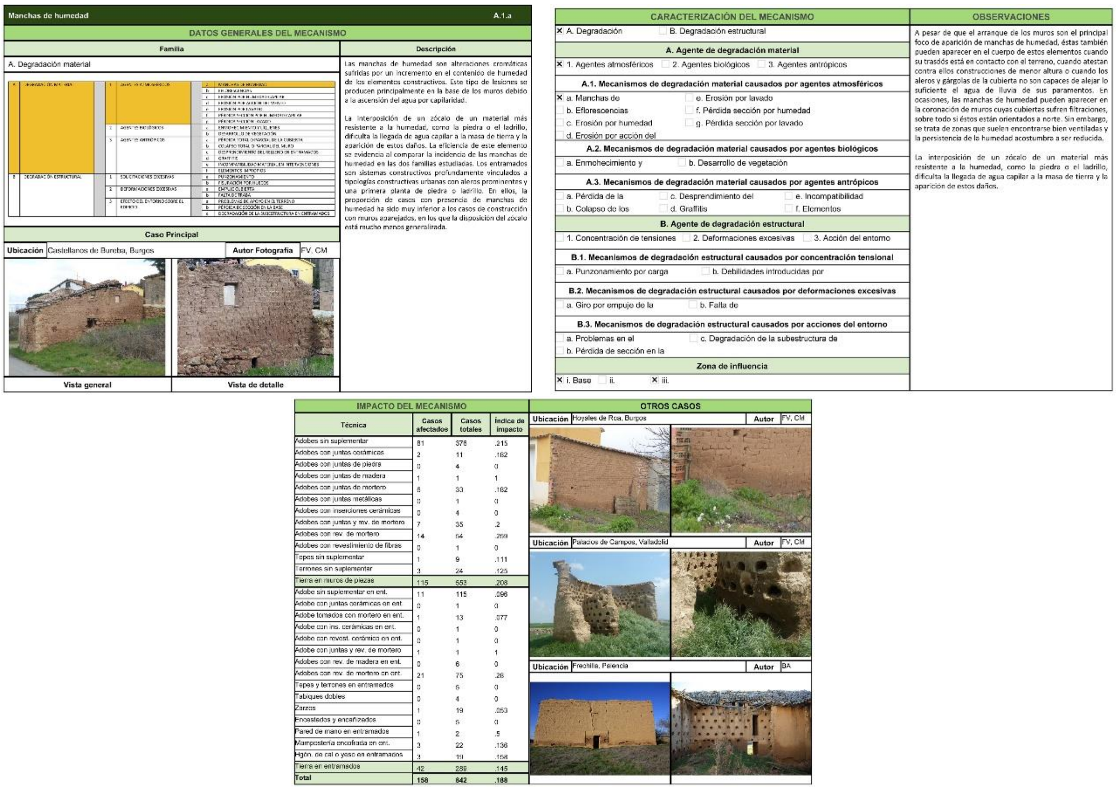

Figure 4. Fiche used to record the study of weathering phenomena.

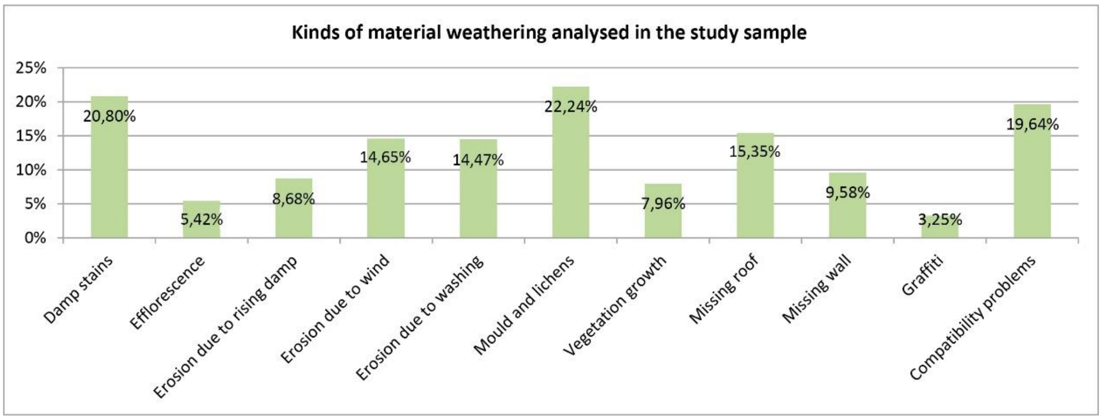

Figure 5. Kinds of material weathering analysed in the study sample.

Figure 6. Damp stains (left) and fluorescence (right).

Figure 7. Superficial (left) and volumetric (right) erosion due to rising damp.

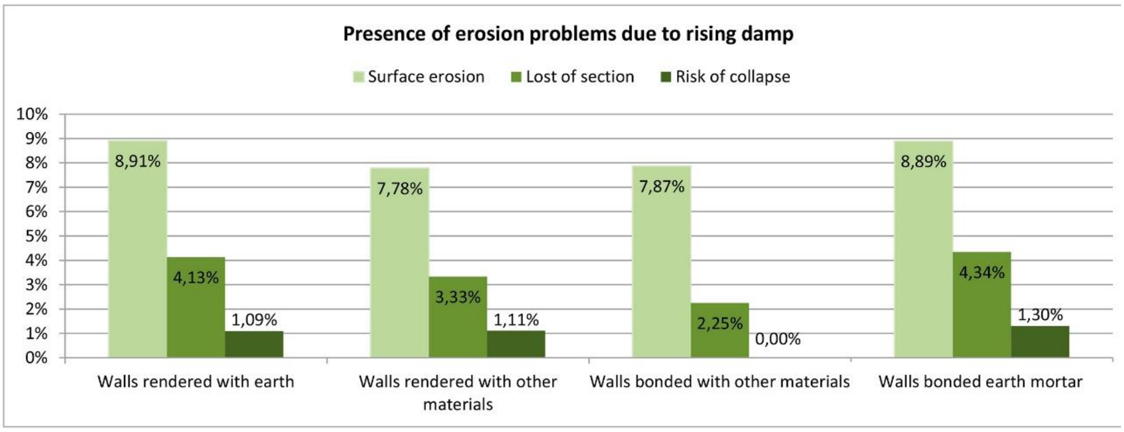

Figure 8. Presence of erosion problems due to rising damp.

Figure 9. Erosion through the action of the wind.

Figure 10. Superficial (left) and volumetric (right) erosion due to washing.

Figure 11. Proliferation of mould and lichen (left) and vegetation growth (right).

Figure 12. Localised (left) and complete (right) loss of the roof and subsequent collapse of the wall.

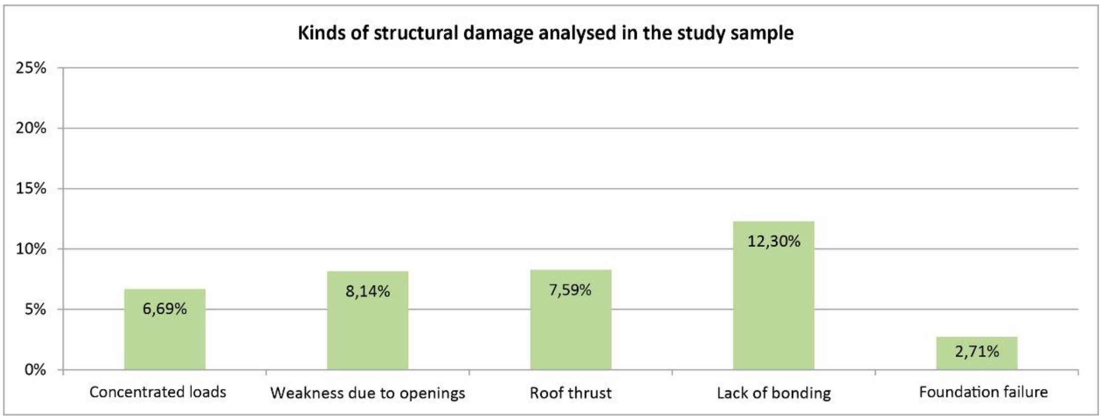

Figure 13. Kinds of structural damage analysed in the study sample.

Figure 14. Cracks due to concentrated loads introduced by beams.

Figure 15. Cracks due to structural weakness introduced by openings.

Figure 16. Cracks due to wall rotation from roof thrust.

Figure 17. Cracks due to lack of interlocking between constructive elements.

Figure 18. Cracks due to foundation failure.

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