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State of conservation of half-timbered walls in Burgos (Spain): Quantitative analysis of material and structural degradation

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Abstract

The systematic data collection and quantitative analysis of 225 half-timbered walls found in the province of Burgos made it possible to reach conclusions on the frequency and scope of 27 phenomena of material degradation and 11 types of structural lesions. Almost the entirety of the sample analysed presents some degree of material degradation, mostly slight atmospheric lesions such as surface atmospheric erosion and chromatic alteration and dehydration of the timber. A greater vulnerability to structural lesions, particularly structural deformation, has been observed in this type of wall. The results presented in this text form the basis for understanding the conservation and restoration needs of half-timbered walls, given the indispensability of knowledge of the most common degradation systems.

Keywords: *Traditional architecture, vernacular techniques, weathering, damage.*

1. Introduction

Half-timbering is a technique combining a timber structure with other materials and used for enclosures, rendering and insulation. Although these walls have not been as closely studied as rammed earth or adobe, they are part of Spanish traditional architecture and display a wide range of variants and typologies (Hueto Escobar et al., 2021).

Until the late twentieth century the degradation of this type of architecture was limited by the constant maintenance by its occupants, who had the necessary knowledge and local materials (IPCE, 2014). However, this conservation is currently at risk due to social issues such as rural exodus, depopulation, lack of valorization, the disappearance of traditional trades, the loss of associated knowledge and the predominance of industrial materials and techniques (Mileto et al., 2020).

In this context, in order to propose the necessary conservation and maintenance actions information is required on the state of conservation and the vulnerability of traditional techniques to the most common degradation mechanisms. It should be noted that the alterations and lesions visible at the time of study displayed some complex degradation mechanisms, which may have started long before, evolving to become more serious lesions unless action is taken to counter the principal causes (Vegas & Mileto, 2011). Half-timbered walls are found throughout the province of Burgos (García Grinda, 1988), with different infills and geometries of different complexity. The 225 samples conserved and analysed in this text were found in 45 different localities in mountainous areas with an altitude above 500 m a.s.l and less than 100 inhabitants. These are residential and agricultural buildings with 2 or 3 storeys on average, built in blocks either between party walls or on a corner.

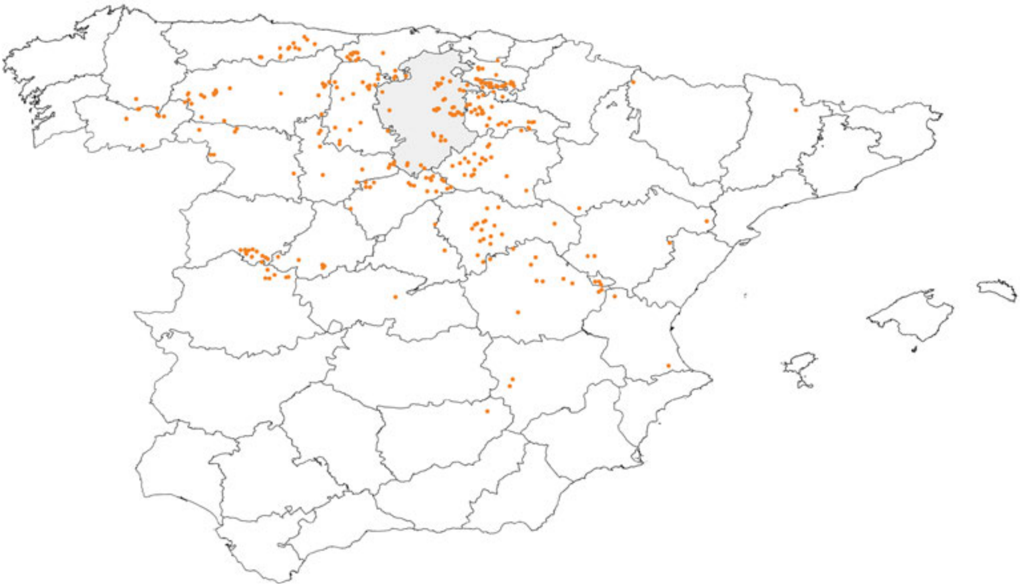

Fig. 1. Location of the cases studies that constitute the entire sample, indicating the territory of Burgos analysed in this document (Source: Hueto-Escobar, 2022).

2. Objectives and methodology

This publication is part of wider-ranging research studying the different variants of half-timbered walls in Spanish traditional architecture (Hueto Escobar et al., 2021), as well as the state of conservation and transformation dynamics affecting them. For this, a database was generated, compiling 1098 half-timbered walls found all over Spain (Fig. 1), and documented with 9170 photographs. The information was recorded in study fiches organized into three major blocks: general building information, specific data on the half-timbered wall; and finally, the state of conservation and transformation of the half-timbered wall. These were used for a scientific analysis of the information in order to obtain valid statistics (Hueto Escobar et al., 2019).

The specific objective of this text is to analyse the state of conservation of the 225 half-timbered walls documented in the province of Burgos (Fig. 1). This study aims to analyse the influence and extent of the degradation processes in a representative territory with a considerable variety of half-timbered walls, in order to propose the most suitable future maintenance and conservation actions. Based on the data collected in the final block of the fiches, a qualitative analysis was carried out on 38 types of material and structural degradations. These were identified beforehand through a review of the bibliography and a visual analysis of all the cases documented.

The main characteristic of these walls is the combination of a timber structure with other materials. Accordingly, their material degradation combines mechanisms linked to timber and to the given type of infill (Fig. 2). Furthermore, their structural behaviour, which is extremely complex, is conditioned by different factors such as the differences in rigidity and resistance of the materials, geometric position, bracing, the contribution of infill and traditional joints (Casanovas et al., 2007). Mechanisms characteristic of the timber and different infills and mechanisms relating to the structural interaction of both materials were identified.

Fig. 2. Building in Villanueva de Tobera (Burgos), showing material lesions (damp stains, erosion, loss of volumetry, rot, replacement of infill, elimination of structural elements) and structural lesions (excessive buckling of timber, lack of bonding and fissuring of the infill) (Source: Hueto-Escobar, 2022).

3. Material degradation

During the course of this research, 96% of the cases studied in the province of Burgos presented some sort of material degradation. A detailed analysis was carried out on 27 phenomena classified according to the agent causing them (Fig. 3). The degradation caused by atmospheric elements has a greater incidence.

The pathologies most frequently detected were the atmospheric erosion of infill (68.9%) and the chromatic alteration and dehydration of timber (79.6%). Among the lesions due to biological and anthropic agents it is particularly worth noting the presence of mould and lichens (44.9%), unsuitable anthropic interventions for the installation of foreign elements (42.2%) and repairs with incompatible materials (60.4%).

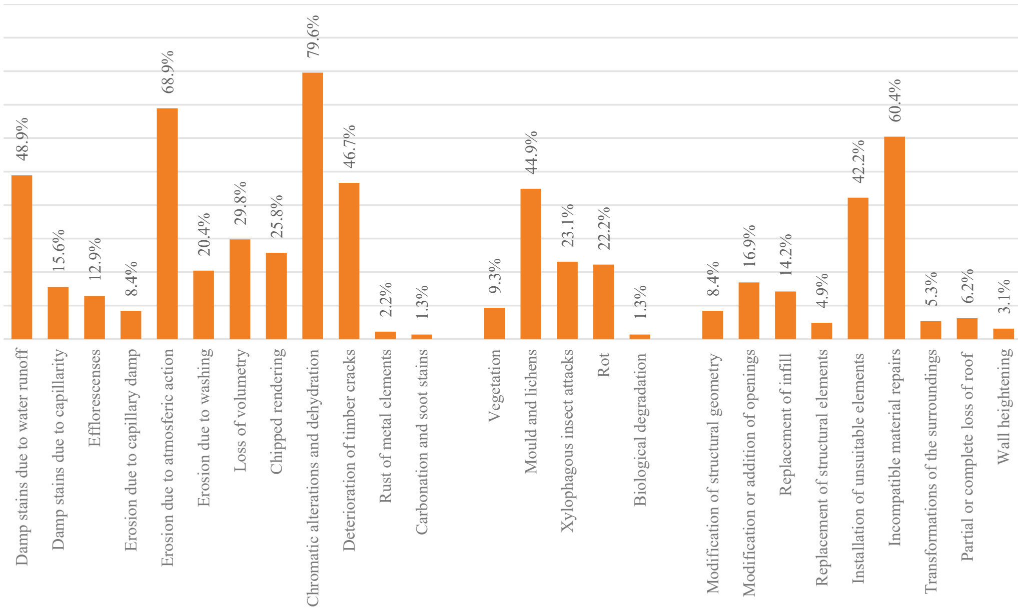

Fig. 3. Incidence of the different material degradation processes identified (Source: Hueto-Escobar, 2022).

3.1. Caused by atmospheric agents

This term refers to the influence of external factors such as water, wind, solar radiation and temperature. The hygroscopicity of the timber and infill leads to the absorption of exterior water through capillarity, infiltration or condensation. The increased humidity firstly causes chromatic stains and alterations which can lead to softening, erosion and loss of stability in the earthen infills or promotes rot and the attack of xylophagous insects on the timber (Lasheras Merino, 2009).

Damp stains were identified in 56.9% of cases studied, specifically due to water runoff in 48.9% of cases and capillarity in 15.6%. This last figure is in direct relation to the use of half-timbered walls on upper floors or on plinths with more resistant materials. Furthermore, the presence of damp can favour the migration of salts found in the soil or in the mix used for infill (Guillaud et al., 2008). These salts crystallize to form surface efflorescence or internal crypto-efflorescence which lead to increased volume and the material breaking up (Broto, 2006). Although this phenomenon was only detected in 12.9% of cases analysed, the use of cement products which incorporate soluble salts into their mix for intervention favour their formation (Mileto & Vegas, 2014). In this research, the number of intervention cases using cement and affected by efflorescence increases to 17.7%.

Erosion due to the abrasive action of rainwater and particles carried by wind was identified in 68.9% of case studies. In contrast, the erosion caused by capillary damp was detected in only 8.4% of cases and the erosion caused by water runoffs in 20.4%. The reduced influence of erosion by capillary damp is also linked to the presence of plinths and lower walls. The evolution of the erosion processes along with the possible mechanisms caused by people, animals or vegetation can lead to a loss of volume, endangering the structural stability of the infill. This degree of incidence was detected in 29.8% of cases studied, with a higher incidence in walls with brick infill where joints display weak points.

In addition, the combined action of damp, efflorescence and erosion and the difference in rigidity of materials used to make up this type of wall encourages fissuring and chipping in rendering. This type of lesion appears in 71.1% of rendered walls, with a greater occurrence in walls with brick infill.

Exposure to solar radiation causes the lignin of the timber to dehydrate and degrade, taking on a greyish hue. Although in principle this does not entail any serious risks it is the most common type of material degradation, detected in 79.6% of case studies. Equally, exposure to the elements can lead to a deterioration of cracks in the timber, as detected in 46.7% of cases studied. Although in principle these only entail structural risk in the case of radial cracks (Desch & Dinwoodie, 1996), they are a point where issues related to damp, rot and xylophagous insects can occur and worsen (McCaig & Ridout, 2012).

In addition to the timber and infill, the walls studied may include metal elements used as structural reinforcement for the joints or inappropriately used as fixtures for installation. Although only found in 2.2% of cases studied, these elements tend to be inserted into the timber and undergo a potentially damaging increase in volume when they rust. However, the limited occurrence of this lesion may be due to the fact that 71% of the cables installed are located in the upper half of the wall, with eaves partially protecting them from rainwater.

3.2. Caused by biological agents

When the correct hygrothermal conditions occur, earth infill is the ideal stratum for seeds carried by the wind to germinate and for the proliferation of different microorganisms including fungi, mould, and lichens (Mileto & Vegas, 2017). Vegetation was detected in 9.3% of case studies, compared to 44.9% with mould and lichens. The latter have been detected more frequently in monolithic infills, where the smooth surface formed is an ideal breeding ground. In principle they do not present a serious risk and mould and chromogenous fungi for example only cause changes in colour (Ridout, 2000). However, they slightly favour the accumulation of damp and infill breaking up (Feilden, 2003). In contrast, the roots of larger vegetation can grow progressively through the infill, generating internal stress which causes disaggregation, breaking up, losses and even stability problems (Reinprecht, 2016). Furthermore, the development of rot and attacks from xylophagous insects are increased when geometry, exposure or poor ventilation favour the accumulation of damp. Attacks from xylophagous insects were detected in 23.1% of case studies. Rot was detected in 22.2% of cases, mainly located in the exposed ends of the timber. As the identification of these processes is conditioned by external visual analysis the number of cases affected could be much higher. Biological degradation due to other animals, birds and insects, was only detected in 1.3% of cases and was mainly manifested by bird excrement and insect nests in adobes and joints.

3.3. Caused by anthropic agents

This group covers the lesions resulting from human action, either direct actions such as transformations, installation of elements and incompatible repairs, or indirect actions derived from lack of maintenance. Among the direct actions which entail the transformation of the walls in the strictest sense, the most common action is the modification or addition of openings, found in 16.9% of cases. Although the constructive configuration of the half-timbered walls allows the easy addition of openings, the current needs for hygrothermal and lighting comfort have given rise to modification. This may simply take the form of eliminating infills but can occasionally entail the total or partial elimination of timber elements, introducing discontinuities which affect structural behaviour. These modifications are also related to the installation of additional elements such as blinds, wrought iron bars and industrial balconies. Modifications with less aesthetic impact, consisting in the interior insulation of the wall and installation of more efficient window frames on the inner face, have also been identified. Whether due to functional needs, addition of openings or material degradation, the modification of structural geometry was identified in 8.4% of cases. This type of action covers the alteration of the original position of timber elements, as well as their elimination or replacement with other types of walls. However, in 4.9% of cases the replacement of these elements with other concrete or linear metal pieces was detected. Although this does not imply a transformation of the geometry it results in a modification of resistance and structural behaviour. In addition to the interventions on the timber structure, the replacement of infill was identified in 14.2% of cases. This may have been the result of a loss of volumetry due to the discontinuity and adherence inherent to the technique or it may have been linked to interventions to update the appearance and hygrothermal comfort needs. The replacements are generally non-rendered industrial brick which lead to an increased load and differences in rigidity, but rendered cases were also identified with problems of efflorescence caused by the cement mortar used in the joints.

However, by far the most common direct actions are the installation of unsuitable elements and repairs with incompatible materials, detected in 42.4% and 60.4% of cases respectively. Although in principle these actions are not as serious as those previously described, they are executed without considering material, structural or aesthetic compatibility and are dictated by the resources and needs of the occupants. The foreign elements installed are mostly electric cables which display the rust problems mentioned previously, as well as industrial downpipes and gutters where damp concentrates when these break due to lack of maintenance. The interventions with unsuitable materials tend to be patches, reintegration and renewal of joints using cement mortar. This in turn hinders the breathability of the wall, favouring the accumulation of damp, chipping and efflorescence.

Additionally, certain transformations external to the wall which could affect the state of conservation were identified. The main transformations of the surroundings, detected in 5.3% of the sample, are asphalting and the raising of the ground level, which causes damp to accumulate in the walls in contact with the soil or the demolition of neighbouring buildings which strip the wall of protection and favour the development of both material and structural lesions. Other external transformations detected were the wall heightening, found in 3.1% of cases and generally executed with industrial techniques and materials such as brick or concrete blocks. These favour the development of structural lesions as they increase the loads and at times lead to the modification of structural geometry.

Finally, the lack of maintenance as an indirect action mostly leads to a loss of protective elements such as rendering, eaves and roofs. The partial or complete loss of roof was identified in 6.2% of cases studied, also displaying damp problems due to water runoff and erosion due to runoff in half of cases.

4. Structural degradation

Structural degradation phenomena have been detected in 61.8% of cases studied. A total of 11 types of structural lesions, classified according to the mechanisms which generate them, has been analysed in detail (Fig. 4).

The lesions caused by excessive deformation are more common than those generated by excessive stress, mainly fissuring and lack of bonding (51.1%) in the first case and breakage of timber elements (13.8%) in the second.

4.1. Caused by excessive stress

This group covers the failure caused by structural elements with very concentrated stresses or stresses exceeding their working capacity, situations worsened at times by material in poor condition. The most common failure is the occasional breakage of timber elements, observed in 13.8% of cases. These occur mainly in the upper walers where roof load is combined with the effects of rot, favoured by water runoff and the poor condition of the eaves.

Compression of the timber was only detected in 0.4% of cases studied, specifically in an isolated case where the blind floor had suffered compression at the meeting point with the footing. In contrast, compression of the infill was detected in 6.7% of cases, mostly linked to an excessive overload which caused the buckling of an upper waler and in turn the compression of the inferior infill. This excessive buckling can also promote fissures in the upper infill, as observed in 3.1% of cases. When the waler supporting the infill is deformed it tends to descend and separate forming a discharging arch. This process tends to occur in porch walls or on the area of the openings, where there is no infill to limit deformation.

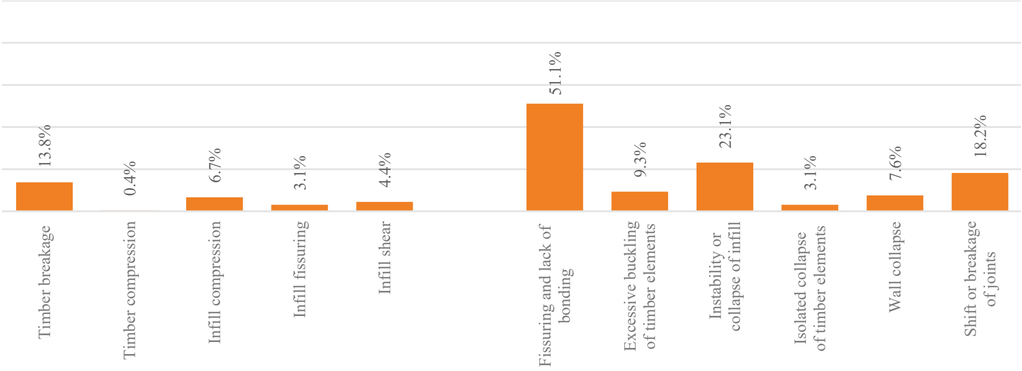

Fig. 4. Incidence of the different structural degradation processes identified (Source: Hueto-Escobar, 2022).

In addition, the concentration of loads in a specific point can increase the shear of the infill, especially when there are no elements for distribution or when the walers display deformations, entailing irregular transmission of the load. These lesions were detected in 4.4% of cases, characterized by the appearance of vertical cracks which run downwards from the supports of the joists and which in the case of brick infill run along the weaker joints (Casanovas et al., 2007).

4.2. Caused by excessive deformation

This section includes the lesions which result in movement in the elements, even modifying the load distribution scheme and influencing the appearance of lesions described previously. Half-timbered walls are structures which are highly susceptible to this type of movement due to a lack of bonding and the lack of rigidity of the joints. Fissuring and lack of bonding between elements are the most common lesions, found in 51.1% of cases studied. This is due to the constructive logic of half-timbered walls, which combines materials of different rigidity and resistance. Traditional treatises recommended different methods to counter this problem: roughening the timber, adding esparto rope or nails and incorporating slits or formwork (Arias y Scala, 1893). As a result of the discontinuity between the framework and the infill in the case of horizontal stress or material lesions endangering the stability of the infill, there can be some isolated cases of infill collapsing. This type of lesion was detected in 23.1% of cases, compared to 3.1% of cases affected by the isolated collapse of timber elements and 7.6% of cases where the entire wall collapses.

Although the main structural function of infill is to brace the wall, it also plays a part in the wall's overall resistance capacity (Santa Cruz-Astorqui & Del Río, 2014). In addition, when the timber suffers considerable material degradation which hinders its resistance, the infill is progressively subjected to stress, delaying the collapse of the wall (Gil Crespo, 2013). Therefore, 9.3% of the cases in which excessive buckling was detected mostly correspond to cases with no infill, either porches, galleries or openings. In cases where there is infill, the buckling has been limited by the infill, but other lesions such as shear and compression of the infill have occurred.

Finally, both structural deformations and the material degradation processes described previously can cause a shift or breakage of traditional joints. This type of degradation was detected in 18.2% of cases, although it occasionally affects isolated nodes.

5. Conclusions

Any intervention must be based on comprehensive knowledge of a building, including its history, techniques and pathologies. Therefore, in general, knowledge of the frequency with which half-timbered walls develop certain degradation mechanisms and their scope is of use in establishing future conservation and intervention guidelines. Throughout Burgos the most common material degradation mechanisms are the deterioration of the cracks and the chromatic alteration and dehydration of the timber, as well as damp stains and erosion of the infill. It is also worth noting biological degradations such as mould and lichen and degradations due to unsuitable anthropic actions. However, this type of material degradation could be reduced if the valorization of this technique were used to promote continued maintenance actions and more respectful interventions. A greater influence of deformation mechanisms, mostly the lack of connection and unstable infill, was observed in structural lesions. This may be due to the fact that although in half-timbered walls the elements are the right size, their degradation has caused movements which could endanger structural stability in the future.

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