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ABSTRACT
Traditional architecture is the result of collective experience in the optimum use of available materials in a given location and adapted to specific conditions and needs. Although forms and groups also depend on other cultural and social issues, the constructive techniques used depend mostly on geographical conditioning factors such as altitude, hydrography, lithology, climate, etc. This text aims to analyse the possible relationships among the multiple variants and specific geographical conditioning factors of each location; in turn, this should provide an understanding of the reasons motivating or reducing their use and the mechanisms adapting these techniques to these conditioning factors. The analysis cross-referenced GIS systems from a database compiling information on 1160 half-timbered walls with a series of themed maps containing information on geographical factors. The conclusions reached show that a single technique adapts to different geographical conditioning factors, giving rise to a wide range of solutions which can provide greater durability and improved habitability. This capacity to adapt to the location is a lesson in sustainability that can be applied at present and is above all part of the intrinsic wealth and value of traditional architecture.

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1. Introduction

Vernacular architecture is defined as that built by the community itself, the result of experience acquired in the optimum use of the resources available in a location in order to adapt to specific conditions and needs (Oliver 1997). The wide range of constructive solutions, structural systems, architectural typologies, and urban models presented is mainly the response to the geographical conditioning factors of the place, with factors such as relief, type of soil, climate, and vegetation. Other influences from cultural and historical conditioning factors include traditions, religious beliefs, available technology, social organization, and agricultural practices (Rapaport 1969; Torres Balbás 1933). Within this great diversity (Figure 1), half-timbered walls are defined as the constructive combination of a vertical timber frame which fulfils most of the structural function together with other materials used for the enclosure, finish, and protection of the spaces created by this framework (Maldonado Ramos y Vela Cossío, 1999). Its origin as a constructive technique dates back to the first shelters built by humans using branches and clay mortar. These evolved thanks to the advances in joinery, in step with cultural and technological diversity, material availability, and the geographical and climatic factors of each place, resulting in wide range of constructive solutions and systems. In addition to their good structural behaviour in seismic events, their geographical expansion is due to the use of local materials which require little transformation, making it possible to build up higher and thinner walls than those used in other systems, and generating projections which increase the interior usable space. Most Spanish cases are between 2 and 3 storeys high, but some buildings constructed with half-timbered walls reach 4 and 5 levels. The dimensions of the timber elements are generally between 10 and 20 cm; the construction of such high walls with other techniques would have required a greater wall thickness. The buildings known as San Martin's Skyscrapers in Cuenca are a paradigmatic case, with facades overlooking the valley with up to 8 storeys built with half-timbered walls (García-Soriano, Cristini, and Diodato 2020).

Although this can be considered one of the main constructive systems in the Middle Ages (Foliente 2000; Maldonado Ramos and Rivera Gámez 2005), there are few specific references to half-timbered walls in Spain. In general, historic architectural treatises dedicated very few pages to this compared with other

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Figure 1. Example of a half-timbered wall with stacked masonry infill and wattle-and-daub screen, in La Cuenca (Soria). Source: Alicia Hueto Escobar.

constructive techniques more characteristic of monumental architecture (Hueto Escobar, Vegas López-Manzanares, et al., 2022). The catalogues of Spanish popular architecture published in the 20th century were indispensable to valuing this type of heritage (Caro Baroja 1982; Feduchi 1974; Flores 1973; García Mercadal 1930, 1984; Torres Balbás 1933). However, these catalogues proposed a formal custom-oriented study which did not examine the technical issues necessary to understand half-timbered walls as a constructive system in depth. The 1970s energy crisis brought about a great boost to the study of traditional constructive techniques given their sustainability and relationship with the environment of vernacular architecture. However, most of the publications on the Spanish case focused on constructive techniques such as rammed earth or adobe, with little or no reference to half-timbered walls with earth infill. Although some recent studies further explore this type of constructive technique for walls (Benito Martín 1998; García Grinda 1988; Moreno Dopazo 2014; Santa Cruz Astorqui 2012), these projects focus on specific typologies or regions and do not provide a global overview of the variety of case studies in Spain.

In European countries such as France, Germany and England half-timbered walls follow certain models which have evolved partly conditioned by stylistic issues over centuries. In countries with high levels of seismic activity the solutions have mostly evolved to improve the structural behaviour of the systems and their resilience (Dutu et al. 2012; Ruggieri 2017). However, these initial hypotheses cannot be applied directly to the context of Spanish vernacular architecture, where half-timbered walls must be interpreted fundamentally as a way to organize the structural skeleton of a building (Nuere Matauco 2000). Their characteristics generally answer to geographical factors such as the type of climate or materials available in the region, but also to more specific conditioning factors such as building type, urban setting or specific needs, economic status and cultural characteristics of occupants. The constructive quality of these walls is initially dependent on the knowledge and experience of the joiners in the region who, based on their guild knowledge, built half-timbered walls with straight and regular spans and well-executed infill. Furthermore, in a popular context, much of the vernacular architecture of a place is built by local residents following constructive traditions and directly observing other built examples, leading to more varied and subjective solutions with varying degrees of constructive quality (González Iglesias 1945).

Over the last century, the process of industrialization, rural exodus, and the introduction of new constructive materials have led to the progressive abandonment of traditional techniques and related artisanal trades (Benito and Timón 2014). In the case of half-timbered walls, this process began earlier due to deforestation in Spain and the fear of fires (Hueto Escobar, Mileto, and Vegas López-Manzanares 2022). The examples still standing are in and of themselves a local constructive tradition of great wealth, providing lessons in sustainability that should be analysed and applied to modern construction, especially as regards adaptation to place, use and optimization of available materials, and the specific needs of each community (Correia, Dipasquale, and Mecca 2014). In environmental terms, traditional techniques in general, and half-timbered walls in particular, have adapted to the climatic and geographical conditions of specific locations thanks to the development of different variants and constructive solutions. They are also socioeconomically sustainable as they use local materials, optimizing design based on resources, local knowledge, and the specific needs of the place, community, and inhabitants, while using different constructive strategies geared towards protecting and lengthening the useful life cycle of the buildings.

2. Methodology and objectives

As a result, wider research was carried out in order to document and identify the different variants of half-timbered walls found in Spanish traditional architecture, as well as analysing their state of conservation and related transformation dynamics. This study has been focused on walls that are visible from the outside, whether they are façades or party walls. The case studies featured in earlier research projects (Mileto et al. 2017) and a comprehensive bibliographical review of many regional catalogues and studies on popular architecture made it possible to identify areas of interest for the research, carry out different fieldwork campaigns, and document buildings with half-timbered walls. Following this process, the database compiled information on 1160 half-timbered walls in 916 buildings throughout 320 locations, mostly on the Cantabrian coast and in the northern plateau of Spain. This is because several half-timbered walls may be built in the same building, which must be considered separately due to their location, construction technique, geometry or other characteristics. Even though the review covered the whole of Spain, it is worth noting the lack of bibliographical evidence on the use of mixed wood walls in exterior façades in most of the south and north-east (Nuere Matauco 2000, 30).

In order to compile, manage, and analyse all the information, organizing it systematically, the proposed study fiche model was structured into three major blocks: general information on the building, detailed information on the wall, and information relating to state of conservation and transformation of the wall (Hueto Escobar et al. 2019).

This text aims to provide an analysis of the possible relationships between the most common variants of half-timbered walls in Spain and the specific geographical conditioning factors of the locations where they are most frequently found. This helps to understand why their use was encouraged or limited in certain places, as well as the adaptation mechanisms of these techniques to these conditioning factors. While this specific objective is in keeping with earlier research analysing the relationships between geographical conditioning factors and traditional earthen architecture in the Iberian Peninsula, it focuses in greater detail on a constructive technique with a wider range of materials and on specific strategies developed for adaptation (Mileto et al. 2019). This requires a methodology capable of organizing a large amount and variety of information, as well as the georeferencing and spatial representation of this information for the different analyses (Rodríguez Pérez 2015). Firstly, the different documented case studies were imported to a GIS system using UTM WGS84 geographical coordinates for the later classification and analysis depending on the different sections included in the study fiches. This information was subsequently cross-referenced with themed maps from different Instituto Geográfico Nacional (2004, 2019) publications. This process enabled the statistical analysis and graphic representation on a series of maps of the correlation between different constructive characteristics and some geographical conditioning factors of interest.

3. Progressive classification of half-timbered walls

Traditionally, half-timbered walls were classified according to the structural importance of the timber and materials used, making a distinction between half-timber with infill in heavy materials such as adobe, masonry or brick; wattle-and-daub which uses branches interwoven with an auxiliary timber substructure, generally rendered in earth mortar; and finally, walls where timber acts as an auxiliary reinforcement element embedded into the construction (De Hoz Onrubia, Maldonado Ramos, and Vela Cossío 2003). However, aspects such as the structural behaviour, constructive process, and durability of this type of wall are all greatly conditioned by the connections with other elements such as plinths, flooring or roofs and the presence of protective elements such as rendering (Hueto Escobar et al. 2021). Therefore, a broader progressive classification system is proposed, covering wall typology by layout and function within the building structure as a whole, the geometric composition of the timber frame, the material used as infill or enclosure of this structure, and finally the finish, rendering, or protective materials of the wall. The study and classification of half-timbered walls in Spain is complex due to the numerous characteristics and variables which increase the number of case studies exponentially when combined.

3.1. Typological variants

Half-timbered walls can be used to construct simple elements such as façades, partition walls, and gable walls but can also form more complex structures with galleries, arcades and overhangs. The vertical elements or uprights run from floor to floor and extend the ceilings to create changes in plane in the form of projections which increase the interior usable space or arcades which form a covered public space. As this technique also makes it possible to build thinner walls, its use has been favoured in urban settings or walled cities, where there was usually limited space for this type of construction.

In order to correctly classify half-timbered walls it is firstly necessary to define the typology, that is, the form and layout of these walls within the built complex. As it is possible to change planes the distinction can be made between continuous walls where structural loads run continuously across the same plane, and discontinuous planes, where the loads are distributed across different elements or planes (Figure 1). In constructive and structural terms continuous walls are simpler and are used mostly for façades, party walls, and interior walls (Figure 2a). In contrast, the loads on discontinuous walls can be concentrated or redistributed on different planes, at times requiring reinforcement elements. For example, projections (Figure 2b) can incorporate multiple joists, timber braces or stone corbels. The porticos (Figure 2c) and arcades (Figure 2d) can use side walls, stone pillars or timber pillars to redistribute the loads of the upper floors to specific points, leaving a large space free that can used as access for carts and animals or to shelter people from the bad weather (Correia, Dipasquale, and Mecca 2014, 197). Galleries (Figure 2e) generate a discontinuous space on the upper floors of the wall which could be used as a building annex or for drying foodstuffs. Whether lined up with the lower wall or projecting, timber pillars or other elements are needed to redistribute the loads on the roof.

3.2. Geometric variants

Half-timbered walls are always made up of a series of main structural elements, understood as the uprights that go from one floor to another and are interlinked at the ends by the beams. However, another series of intermediate structural elements can appear, connecting the main elements, reducing their buckling length, increasing bracing or capacity to absorb horizontal force, and forming window and door openings. The presence of these elements also helps contain the infill more efficiently, reducing the likelihood of it becoming completely detached and preventing the spread of cracks (Dutu et al. 2018).

The proposed geometric classification is based on the presence and possible combination of these intermediate elements (Figure 3), which could be uprights (V) subdividing the panels to reduce the spaces to be filled in or

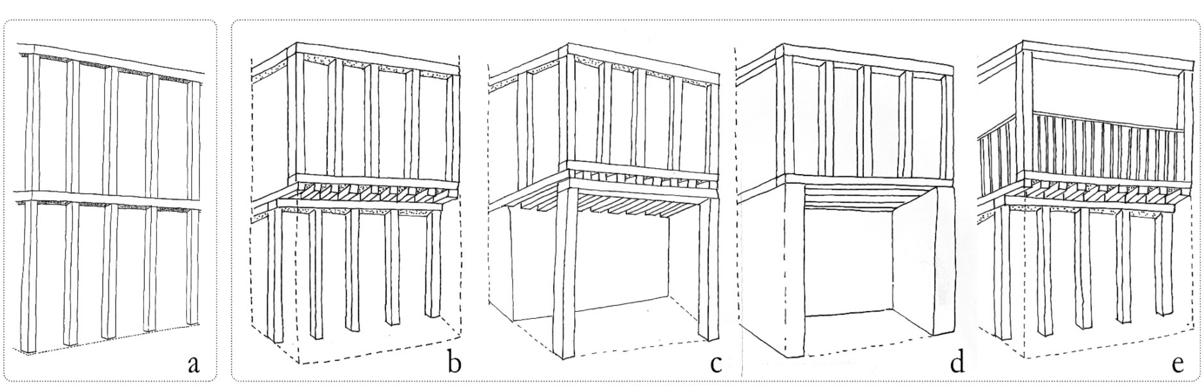

Figure 2. Classification of the different typological variations from left to right: continuous wall (a), projecting discontinuous wall (b), discontinuous wall in portico layout (c), and discontinuous wall in arcade layout (d), and discontinuous wall in gallery layout (e).

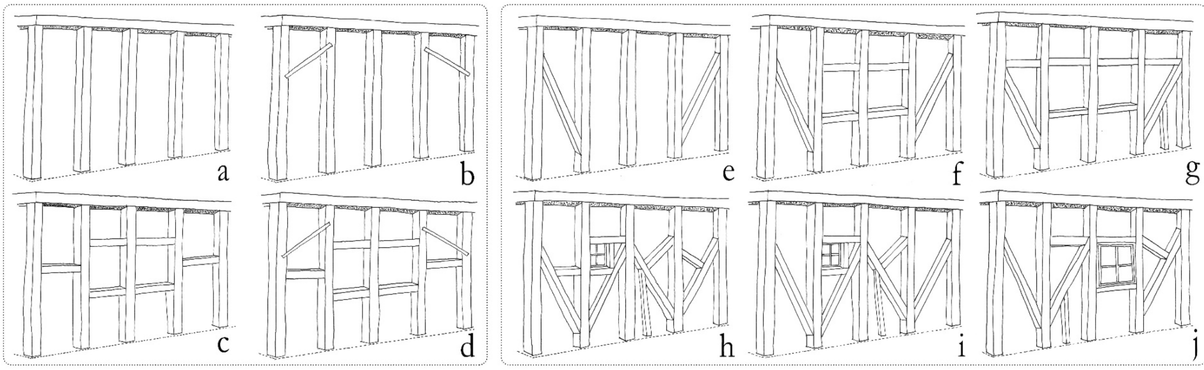

Figure 3. Classification of different geometric variants, from left to right: group of simple geometries (V (a), V with braces (b), V + H (c), V + H with braces (d)) and group of complex geometries (V + D (e), V + H + D (f), V + H + X (g), V + X (h), V + X + D (i), V + H + D + X (j)).

closed with screens; horizontal breaks (H) subdividing the panels or forming openings; diagonal elements (D) which brace the corners, or even elements (X) made up of a complex combination of elements going in different directions. It was deemed convenient to group the possible combinations into simple geometries made up solely of vertical and horizontal elements with no triangulation, and complex geometries which can also include diagonal and composite elements triangulating the structure, involving more elaborate constructive behaviour and interpretation.

Although the geometries have an aesthetic and compositional component in other countries with half-timbered walls, such as France, Germany or England (Kowalska 2013), the presence of diagonal elements in the Spanish half-timbered walls is mainly related to the structural need to stabilise a slightly isostatic structure. While even elements that are not structurally essential are added in the first cases to create decorative forms, the only structural element with relative compositional value in the Spanish territory is the denominated *cruces de San Andrés*, formed by two opposing diagonals. However, both the presence of diagonal elements and other complex elements are generally limited to specific areas of the wall without generating an aesthetic design, except in certain areas of Navarre, the Basque Country and Catalonia which could have received European influences.

3.3. Material variants

The spaces formed by the timber structure can be filled in or enclosed with numerous materials, depending not only on conditioning factors such as the nearby availability of raw materials, but also on specific conditioning factors such as the building's importance and function or the financial situation of its owners. The different variants documented in Spain have been classified according to the associated constructive logic, grouped into monolithic infills relating to the use of formwork, masonry infills stacking pieces that were carved beforehand, lightweight rigid screens made up of laths, boards or other firm elements, and finally flexible screens built with malleable plant elements such as branches, wattle or reeds.

3.3.1. Monolithic infills

These heavy infills are characteristically homogeneous single mass elements which use formwork, with solutions ranging from simple earth to masonry (Figure 4). The piled earth infills (Figure 4a) are simply based on the successive stacking of lumps of earth, sometimes aided by a single-sided formwork, the execution of which is determined by the material's characteristics and capacity to remain bonded. However, the most common solution is pouring an earth mix fluid enough to fill all corners into formwork, and it is necessary to wait a prudent length of time before removing the mould and moving onto the next stretch. Mineral composites or plant fibres can be added to the mix to improve resistance and prevent the appearance of cracks during the drying process. The addition of gypsum, for example, speeds up the setting process and improves the general resistance of the infill; this technique is very widespread in parts of the Iberian System where it is known as gypsum-Crete or *tapialete* (Figure 4b) (Mileto and Vegas 2017). Although historical treatises recommended gypsum as a bonding material, possibly prompted by the slight chemical and hygroscopic incompatibility of timber and fresh lime, some examples have been found which appear to be filled with a mix of earth, lime, and gravel. This mix is closest to lime and earth concrete (Figure 4c) which displays a considerable bonding function, even in low concentrations of around 10% (Gómez Patrocinio 2018).

When the amount or size of the masonry added to this mix of earth, gravel and lime is considerable it is

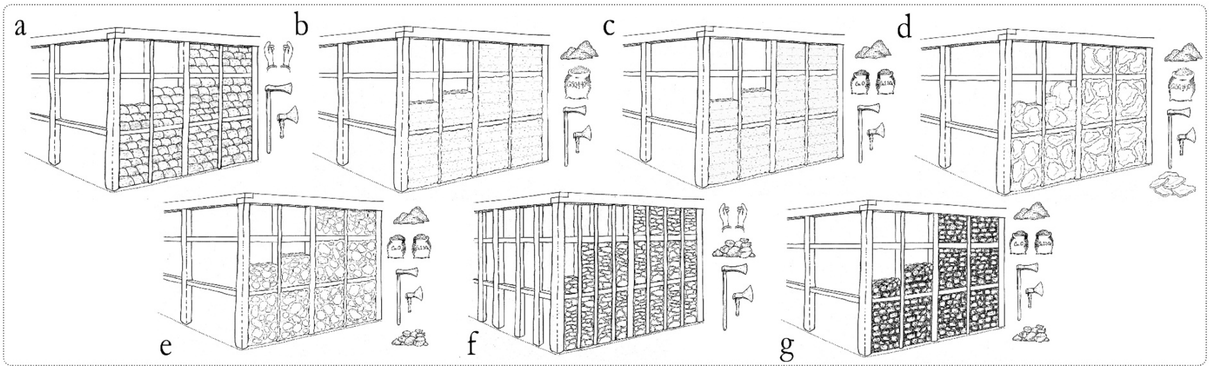

Figure 4. Classification of the different material variants with monolithic infills, from left to right: piled earth (a), *tapialete (b)*, lime and earth concrete (c), stone slabs in formwork (d), formwork masonry (e), stacked masonry (f) and ordinary masonry (g).

possible to speak of formwork masonry (Figure 4e). Sometimes, the earth mix is lower and acts more as a bonding mortar bearing a closer resemblance to ordinary masonry (Figure 4g). When the uprights, cross-pieces or other elements are very close together they hinder the placement of masonry, almost making it look like piled masonry (Figure 4f). Finally, cases have been detected which use stone slabs (Figure 4d) placed vertically with the aid of formwork instead of masonry. In all these cases, the elements act as a single mass element to a greater or lesser degree, but it is made up of elements which have not needed to be worked previously and which do not follow a clearly ordered bond.

3.3.2. Masonry infill

In contrast, masonry infill is characterized by the use of previously executed pieces and can be classified depending on their bond or placement (Figure 5). The pieces directly made from earth can be simple sod and marl, and in the case of the former, vegetation can include grass, moss, heather or peat (Figure 5a) (Mileto and Vegas 2017). However, it is far more common to employ a process where earth is mixed, moulded, and dried to create adobe. Depending on the geometry dictated by the timber structure, the adobe can be laid following different bonds, generally with a suitable horizontal bond (Figure 5f) taking care not to create continuous vertical joins and cutting pieces when necessary. However, more complicated geometries require the selection of another type of bond. When the uprights are very close together, they must simply be piled (Figure 5b) or slightly sloping as it is not possible to cut pieces small enough to ensure the correct bond. However, cases have been documented where this

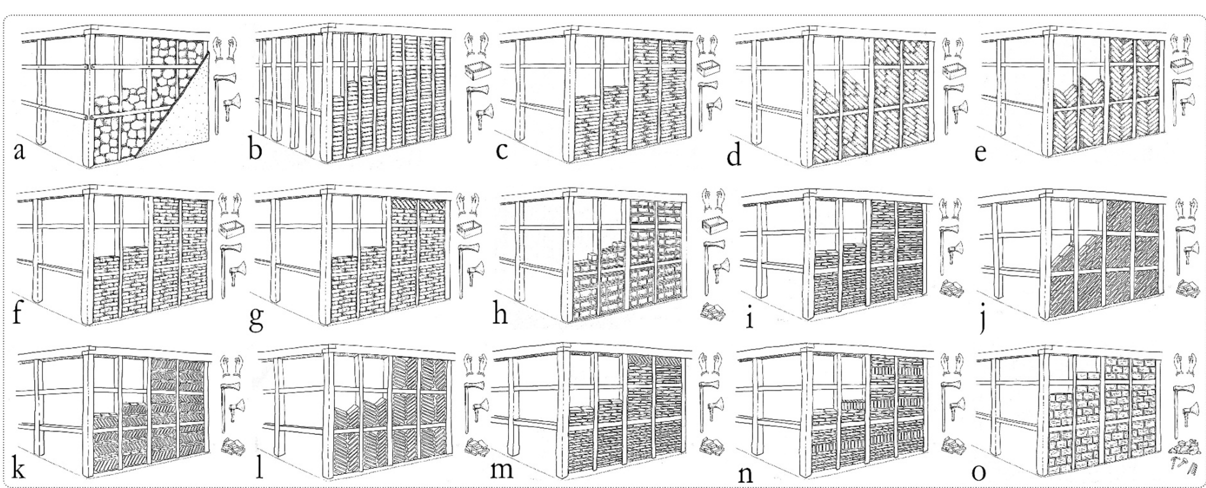

Figure 5. Classification of the different material variants with infill, from left to right: sod and marl (a), stacked adobe with uprights close together (b), stacked adobe without uprights close together (c), adobe sloping in a single direction (d), adobe sloping in two directions (e), adobe with horizontal bonds (f), finished-off adobe bonds (g), adobe with bricks (h), bonded bricks (i), sloping bricks (j), bricks in horizontal herringbone layout (k), bricks in vertical herringbone layout (l), finished-off brick bonds (m), bricks laid out in horizontal courses (n) and ashlar (o).

distance is greater and, when placed in piles, continuous vertical joins are formed which can favour structural damages (Figure 5c). The presence of diagonal elements also entails difficulties so that on occasion these are simply placed sloping following the diagonal and thus avoiding problems on the edges of the timber structure. The sloping placement in either one (Figure 5d) or two directions (Figure 5e) forming a herringbone pattern also helps to adapt to complex geometries or elements with irregular axes, as the mortar easily absorbs the differences on the edges. It should be noted that on occasion the adobe blocks from the final course are placed vertical or slightly sloping to finish off the upper bond (Figure 5g). This arrangement is sometimes associated with irregular timber beams where the vertical or inclined positioning makes it easier to adjust to the imposed borders. However, it is much more common to find it with regular and straight elements, which could be a way to facilitate the placement of the last courses in a limited space.

The use of other more durable materials such as brick or stone is limited, probably due to the lack of available material and above all the economic situation of the building's owners. However, some individual cases are found combining adobe courses with brick courses (Figure 5h). The use of complex geometries with brick infill is less common and for the most part the examples detected display a suitable horizontal bond (Figure 5i). Although there are also examples with bricks sloping in either one (Figure 5j) or two directions (Figure 5l) it appears that this type of layout is more the result of aesthetic considerations than of geometric imposition. Notable examples include the appearance of a horizontal herringbone pattern (Figure 5k) and the use of vertical courses in the central area (Figure 5n). As in the case of the adobe blocks, examples have been identified where the upper course is placed slightly sloping to adapt better to the geometric limits (Figure 5m). Finally, examples have also been documented with correctly bonded ashlar (Figure 5o), mostly in areas where rock that can be easily worked with can be found.

3.3.3. Rigid screens

In contrast with the use of heavy elements other solutions incorporate rigid wooden elements such as boards or laths, either individually or in combination with other materials in order to improve durability and insulation (Figure 6). Infills which use timber alone can mostly be distinguished by their placement in vertical and horizontal boards. These can be laid together to create a closed face and the joins must be correctly designed to avoid problems stemming from the expansion of the timber (Figures 6b,d). On other occasions they can be placed separately forming an open face (Figures 6a,c) which avoids these associated problems and provides ventilation to the interior; this solution has often been identified in upper floors used for the storage of agricultural products.

Among the solutions incorporating other materials, one of the most frequently identified is that of the lath-and-daub made up of laths placed apart (Figure 6e). These laths can be placed forming a simple lath-and-daub when fitted into slots and openings created on the sides of the uprights, before finally being covered with an earthen mix. In certain areas of Comarca del Bierzo and surroundings, cases have been documented where laths have recently been wrapped in esparto grass to improve insulation and adherence with earth, a technique locally known as *pared de barretes* (Figure 6f) (Font Arellano 2013). The laths can also be placed forming a double lath-and-daub by being nailed to the outer sides of the uprights, thus generating an internal space which can be left empty to make the wall lighter but which is more often filled with earth, sand and straw to improve insulation (Figures 6g,h). Furthermore, very unusual cases have been documented of an infill of dry stones

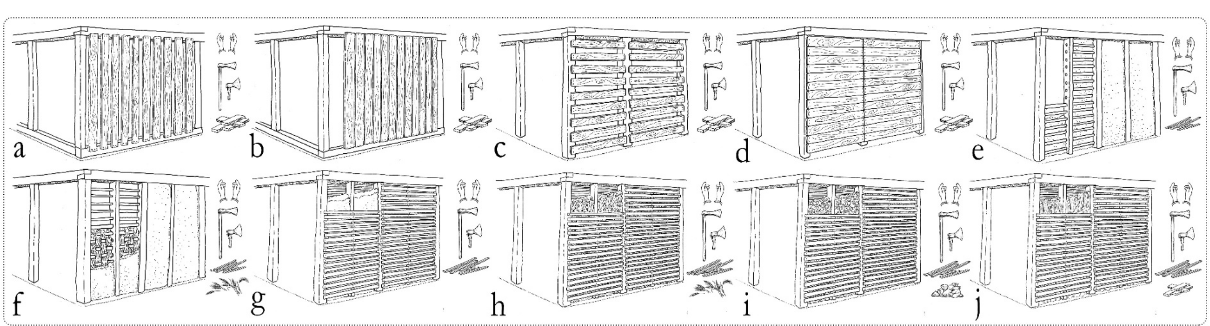

Figure 6. Classification of the different material variants with rigid screens, from left to right: open vertical laths (a), closed vertical laths (b), open horizontal laths (c), closed horizontal laths (d), simple lath-and-daub with earth (e), simple lath-and-daub with plant fibres (f), double lath-and-daub with earth (g), double lath-and-daub with earth and plant fibres (h), double lath-and-daub with stones (i), and double lath-and-daub with boards (j).

and rubble (Figure 6i) and with laths, boards and branches (Figure 6j).

3.3.4. Flexible screens

This type of solution is characteristic for its use of flexible plant elements combined with an auxiliary supporting substructure to create the enclosure of the half-timbered walls, where the main distinguishing feature of both elements is the bond (Figure 7). The most widespread variant is that of wattle-and-daub (Figure 7a), a technique which uses fine branches interwoven horizontally with a series of close-set uprights which can either be roughly trimmed branches, laths or boards. These uprights are occasionally made of the same material as is used for weaving (Figure 7b), placing several thin branches close together to provide rigidity and support for the mesh. Reed screens (Figure 7c) are slightly different from the above, as plant elements are not interwoven, but fitted in or sewn to the uprights. This configures a screen made of reeds piled horizontally on top of one another to close off the space. While slightly different, these techniques are extremely lightweight and therefore well-suited to the execution of walls and partition walls on the upper floors, preventing the transmission of excessive loads to the structural elements below (De Hoz Onrubia, Maldonado Ramos, and Vela Cossío 2003).

3.4. Cladding and rendering variants

Rendering is mainly conceived as a protective layer against the degradation processes affecting half-timbered walls, although historically it has also been promoted as a measure to prevent fires from spreading in urban nuclei. In the more northern areas of Europe, where rainfall and damp conditions are stronger determining factors, timber is often left non-rendered in order to improve breathability and drying. However, in the Mediterranean climate, atmospheric agents and solar UV radiation are more determining processes so that it is therefore more common to find half-timbered walls rendered with a wide variety of solutions (Maldonado Ramos y Vela Cossío, 1996). Among these a distinction must be established between continuous rendering with mortar and discontinuous rendering based on the use of pieces (Figure 8). At the same time, according to the level of coverage mortar renderings should be classified as mortars which protect only the infill or mortars hiding the whole timber structure and infill.

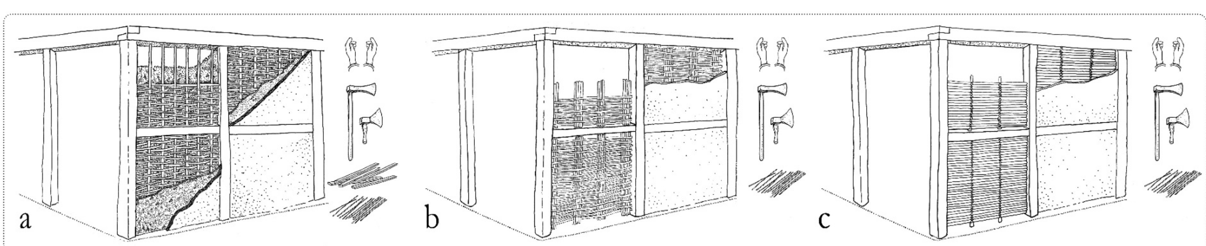

Figure 7. Classification of the different material variants with flexible screens, from left to right: wattle-and-daub (a), mesh (b) and reed structures (c).

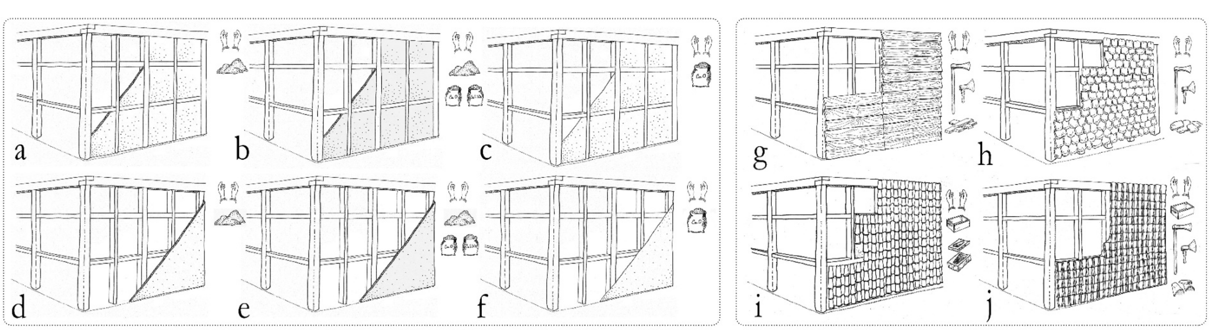

Figure 8. Classification of different rendering variants, from left to right: group of continuous renderings (earth on infill (a); lime and/or gypsum on infill (b); limewash on infill (c); completely earth (d); completely lime (e); completely limewashed (f)) and a group of discontinuous renderings (boards (g); slate slabs (h); convex and concave roof tiles (i); only convex roof tiles (j)).

The simplest solution is earth rendering (Figure 8a, d), which can sometimes incorporate plant fibres to reduce shrinkage during the drying process. However, the use of lime and/or gypsum mortar (Figure 8b,e) is far more frequent as they are more durable and resistant. Another rendering option is whitewash (Figure 8c,f), a single layer of limewash which requires greater periodical maintenance. In any case, the difficulties observed in the adherence between mortar and the timber surface of the structure, as well as the natural discontinuity between infill and structure, are two issues critical to the maintenance of rendering. To improve this situation, it is common to make small marks with an adze in the timber, creating a rough surface that rendering adheres to more easily and which lasts longer. Examples of nails and esparto rope have also been documented.

A very common solution in terms of rendering generated with pieces is the use timber laths (Figure 8g) nailed to the structure. This is designed to prevent problems in the joins due to the infiltrations and expansions caused by thermal variations in the material. Other solutions require the use of materials that are more resistant, but conditioned by local availability and the economic situation of the owners. This is the case for example of the use of slate slabs (Figure 8h) in Comarca de El Bierzo (Velasco 2013) and the use of ceramic tiles (Figure 8i,j) in Sierra de Béjar (Domínguez Blanca and Moro Rodríguez 2004).

4. Correlation between technique and territory

Presented below is an analysis of the different geographical conditioning factors which may have influenced the expansion of this type of technique, reasons which have motivated or deterred from its use in certain areas, and issues which may have influenced adaptation to the specific conditions of a place. Morphological factors analysed include altitude, correlation with the presence of forest masses and proximity to rivers; geological factors such as the lithology of the terrain; and climate factors such as rainfall, humidity, temperature, solar radiation, and wind.

4.1. *Altitude*

The Iberian Peninsula has a characteristically high mean altitude of 650 meters above sea level (masl), mostly due to the existence of an interior plateau surrounded by major mountain ranges such as the Cantabrian Mountains, Iberian System or Central System (Instituto Geográfico Nacional 2019, 85). Altitude, in relation to climate, lithography, slopes, hydrography, and other factors, clearly conditions the presence, distribution, and features of the different forest species throughout Spain. Therefore, half-timbered walls are concentrated in relatively high altitude areas, specifically at a mean altitude of 760 masl, where trees considered optimum for construction are to be found (Figure 9).

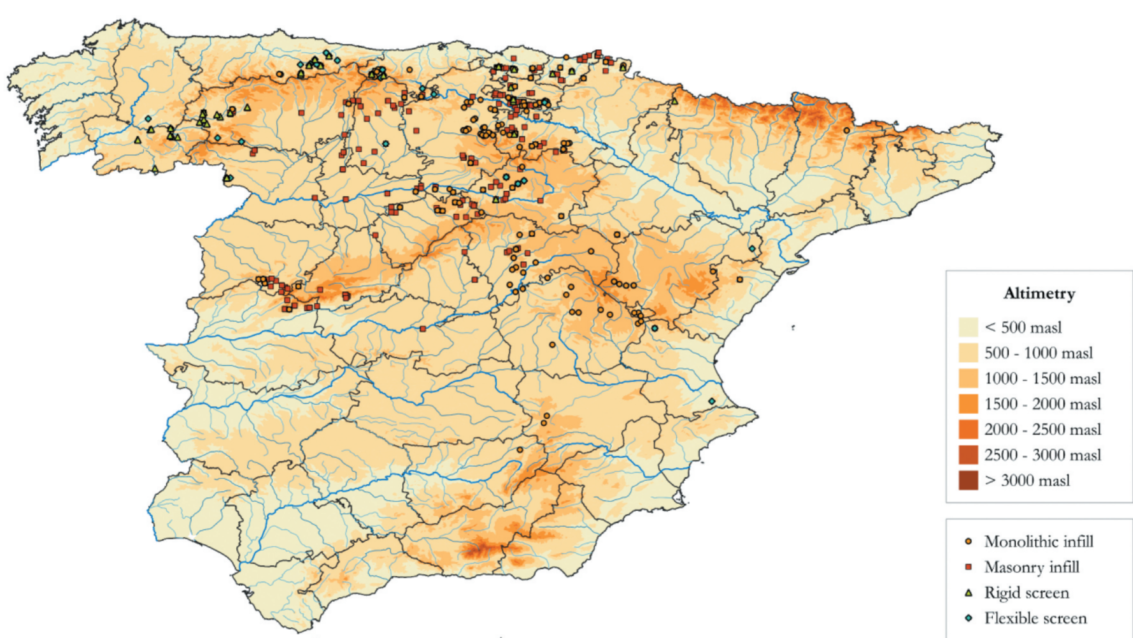

Figure 9. Altitude and half-timbered walls, classified by material variant. Source: Authors, based on Atlas Nacional de España (Instituto Geográfico Nacional 2019).

Table 1. Correlation between altitude and documented half-timbered walls, classified by material variant.

Altimetry	All techniques		Monolithic infill		Masonry infill		Rigid screen		Flexible screen	
0–100 masl	44	3.8%	7	1.8%	31	4.6%	2	2.4%	0	0.0%
100–200 masl	24	2.1%	9	2.3%	13	1.9%	1	1.2%	2	3.2%
200–300 masl	21	1.8%	7	1.8%	10	1.5%	7	8.5%	4	6.3%
300–400 masl	16	1.4%	3	0.8%	7	1.0%	2	2.4%	5	7.9%
400–500 masl	57	4.9%	4	1.0%	35	5.2%	13	15.9%	6	9.5%
500–600 masl	171	14.7%	22	5.6%	124	18.4%	28	34.1%	2	3.2%
600–700 masl	130	11.2%	39	9.9%	65	9.6%	20	24.4%	15	23.8%
700–800 masl	163	14.1%	59	15.0%	104	15.4%	2	2.4%	7	11.1%
800–900 masl	144	12.4%	51	13.0%	91	13.5%	3	3.7%	2	3.2%
900–1000 masl	166	14.3%	84	21.4%	83	12.3%	4	4.9%	1	1.6%
1000–1100 masl	161	13.9%	63	16.0%	94	13.9%	0	0.0%	14	22.2%
1100–1200 masl	51	4.4%	35	8.9%	17	2.5%	0	0.0%	4	6.3%
1200–1300 masl	5	0.4%	4	1,0%	0	0.0%	0	0.0%	1	1.6%
1300–1400 masl	7	0.6%	6	1.5%	1	0.1%	0	0.0%	0	0.0%
1400–1500 masl	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1500–1600 masl	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	1160		393		675		82		63	

Although half-timbered walls have been documented in areas with altitudes from 5 masl to 1386 masl, 66.7% of cases are located in areas between 500 and 1000 masl (Table 1). A tendency to use lightweight screens has been observed in lower altitude areas, and 26.8% of rigid screens and 23.8% of flexible screens are found in areas below 500 masl. In contrast, heavy infill is used at higher altitudes, as 27.5% of monolithic infills and 16.6% of masonry infills are in areas at 1000 masl or higher.

4.2. Correlation with main forests

The presence of forests and the size, durability and workability of the forest tree species available in a place are the main conditioning factors for the use of half-timbered walls in Spain. When analysing the correlation between these techniques and forests it should be noted that this type of technique is mostly used in built urban settings (Hueto Escobar et al. 2020). Although these locations are found in areas which were not catalogued as forest according to the analytical maps available, they are located relatively near to some of the main forests in Spain (Figure 10). Specifically, while 96,9% of the studied examples are located in urban environments, only 45,9% of those cases are considered non-forested areas (Table 2). A tendency can be seen towards the use of half-timbered walls in 13.8% of areas with hardwood forests compared to 5.4% of cases near conifer forests (Table 2).

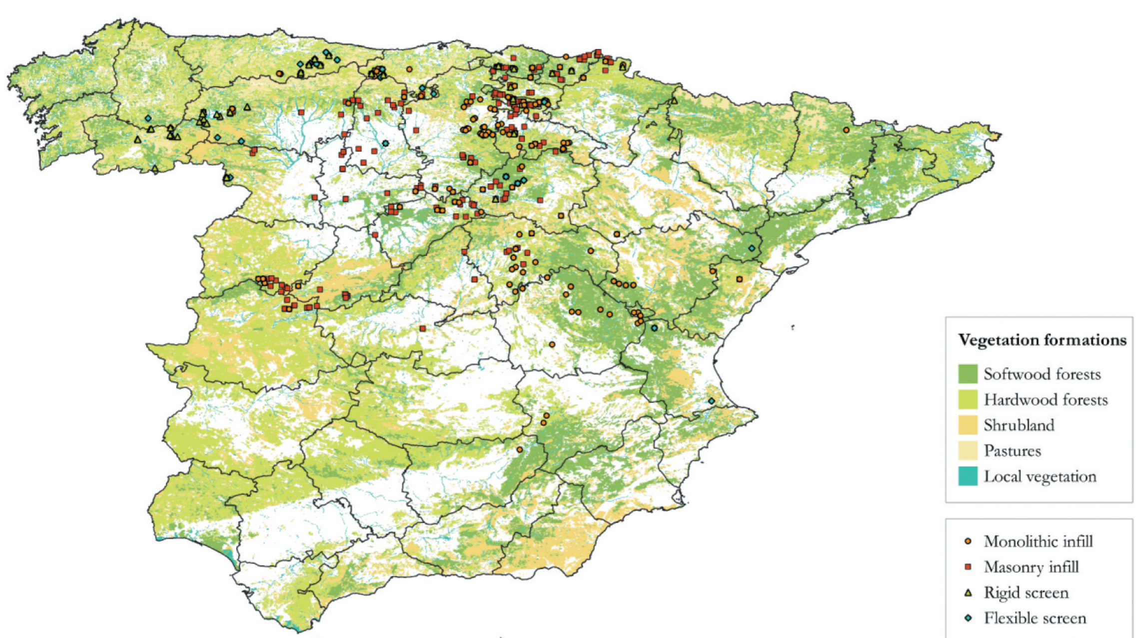

Figure 10. Vegetation formations and half-timbered walls, classified by material variant. Source: Authors, based on Atlas Nacional de España (Instituto Geográfico Nacional 2019).

Table 2. Correlation between forest formations and documented half-timbered walls, classified by material variant.

Vegetation	All techniques		Monolithic infill		Masonry infill		Rigid screen		Flexible screen	
Hardwood forests	160	13.8%	62	15.8%	58	8.6%	34	41.5%	20	31.7%
Softwood forests	63	5.4%	13	3.3%	32	4.7%	3	3.7%	0	0.0%
Shrubland	73	6.3%	53	13.5%	26	3.9%	0	0.0%	0	0.0%
Pasture	7	0.6%	7	1.8%	5	0.7%	0	0.0%	0	0.0%
Local vegetation	324	27.9%	120	30.5%	186	27.6%	16	19.5%	18	28.6%
Non forested	533	45.9%	138	35.1%	368	54.5%	29	35.4%	25	39.7%
	1160		393		675		82		63	

This study was combined with the microscopic identification of 23 timber samples from different case studies in Asturias, Burgos, Cantabria, León, Ourense, Palencia, La Rioja, Soria and Segovia. The use of relatively resistant woods for structural elements stands out, with examples of hardwoods like oak and beech and softwoods like mediterranean cypress, common pine and cluster pine. However, there are also cases of poplar structures despite their limited durability and strength, probably conditioned by local availability. Chestnut wood is used for both structural elements and screen construction, since the trunk is strong and durable enough to form an architectural structure, but the relatively young branches are also flexible enough to be woven. Certain shrub type species with branches that can be interwoven are also used for this purpose, including hazel, alder and willow. Although they are quite susceptible to degradation, woven screens are easily replaceable or repairable.

All the above suggest that the choice of timber among the species available on each site depends on their main characteristics, but also on the execution process of each type of construction element. The choice of species may reflect the builders' technical knowledge — whether trained joiners or simply residents — of the different types and characteristics (Diodato and De Gregorio 2015).

4.3. Correlation with rivers

Historically, the presence and accessibility to water have been conditioning factors determining the location and types of human settlements (Nourissier et al. 2002). The greater presence of water resources and subsequent fertility of all of northern Spain has enabled a less concentrated occupation of the territory, compared to other drier areas where settlements had to be located near rivers, streams, lakes, springs or any other water resources constantly supplying water (Torres Balbás 1933). Initially, proximity to rivers is not a determining conditioning factor for the presence of half-timbered walls in Spain (Figure 11), where 52.7% of cases are

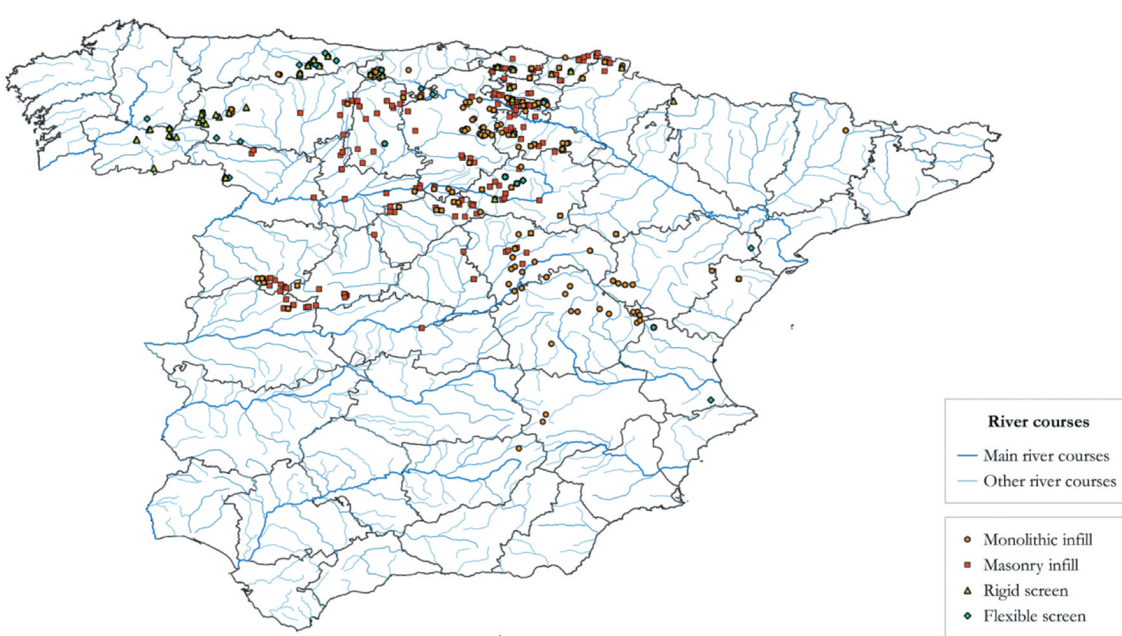

Figure 11. Rivers and half-timbered walls, classified by material variant. Source: Authors, based on Atlas Nacional de España (Instituto Geográfico Nacional 2019).

Table 3. Correlation between rivers and documented half-timbered walls, classified by material variant.

Rivers	All techniques		Monolithic infill		Masonry infill		Rigid screen		Flexible screen	
Close to main rivers	157	13.5%	41	10.4%	113	16.7%	5	6.1%	2	3.2%
Close to other rivers	533	45.9%	188	47.8%	282	41.8%	48	58.5%	33	52.4%
Far from rivers	470	40.5%	205	52.2%	393	58.2%	34	41.5%	30	47.6%
	1160		393		675		82		63	

more than 15 km from any river (Table 3). This may be due to the greater presence of forest masses and the fact that they are concentrated in mountain areas where the sloping ground often prevents them from being located close to rivers. While the major waterways used for timber trade have resulted in the spread of this type of technique to areas where forest masses were difficult to access, only 13.5% of cases can be found less than 15 km from these rivers.

However, access to water is a key conditioning factor for the execution of many of the material variants identified, mostly in infills using earth as a raw material. 60.4% of cases using earth and 65.6% of cases using earth combined with plant elements are located near main or secondary rivers (Table 4), compared to 43.9% of cases with stone and 34.1% of cases with brick. A greater tendency to use screens near smaller rivers was also detected, with 60.2% of rigid screens and 50.0% of flexible screens. This may be due to the type of forest tree species used to build these screens, as the microscopic identification carried out revealed examples of species such as hazel, alder, or chestnut, which are associated with humidity and rivers.

4.4. Lithology

The soil is a complex element made up of an original material which, over time, is subjected to different formation factors, mainly climate, through rainfall and temperature conditions; and relief, through exposure to erosion processes or direct or indirect human action (Instituto Geográfico Nacional 2019, pp. 134–135). Four major areas can be distinguished in Spain depending on the main material: siliceous domain, calcareous domain, clayey domain and finally, volcanic domain (which is only found in the Canary Islands). The type of rocky material found in a given place is one of the main geographical conditioning factors of traditional architecture, as it uses the materials that can be found as near as possible with the least transformation possible in order to cover its constructive needs (Morán Rodríguez 1998). Half-timbered walls are found rather homogeneously in three major areas of the Spanish mainland (Figure 12). This may be because this technique combines a timber structure with different infills, allowing them to be built with thinner walls than in other techniques. As long as there is timber available, the infill can be adapted to the local soil. In general, heavy infill can be found homogeneously in the major lithological domains, while the lightweight screens are more often found in siliceous territory (Table 5).

A detailed analysis of the raw materials which make up the different variants shows a greater presence of stone infill in siliceous and limey terrain, in 42.7% and 32.2% of cases, respectively (Table 6). Although these are mostly heavy masonry infill, numerous cases have been found using stones, relatively easy to extract and work, to generate ashlar infill such as *piedra de toba* in some regions in Burgos for example. In contrast, earth infill can be found homogeneously throughout the territory analysed, although with a slightly higher presence, 37.3% of cases, in the clayey domain. Although clay is needed

Table 4. Correlation between rivers and documented half-timbered walls, classified according to the main material used for infill or enclosure.

Rivers	Stone		Bricks		Earth		Timber and earth		Timber	
Close to main rivers	18	10.5%	22	10.6%	103	16.2%	5	5.4%	2	3.7%
Close to other rivers	57	33.3%	49	23.6%	280	44.2%	56	60.2%	27	50.0%
Far from rivers	99	57.9%	140	67.3%	254	40.1%	35	37.6%	28	51.9%
	171		208		634		93		54	

Table 5. Correlation between lithological domains and documented half-timbered walls, classified by material variant.

Lithology	All techniques		Monolithic infill		Masonry infill		Rigid screen		Flexible screen	
Limey	415	35.8%	146	37.2%	267	39.6%	8	9.8%	21	33.3%
Clay	298	25.7%	117	29.8%	181	26.8%	5	6.1%	2	3.2%
Siliceous	447	38.5%	130	33.1%	227	33.6%	69	84.1%	40	63.5%
	1160		393		675		82		63	

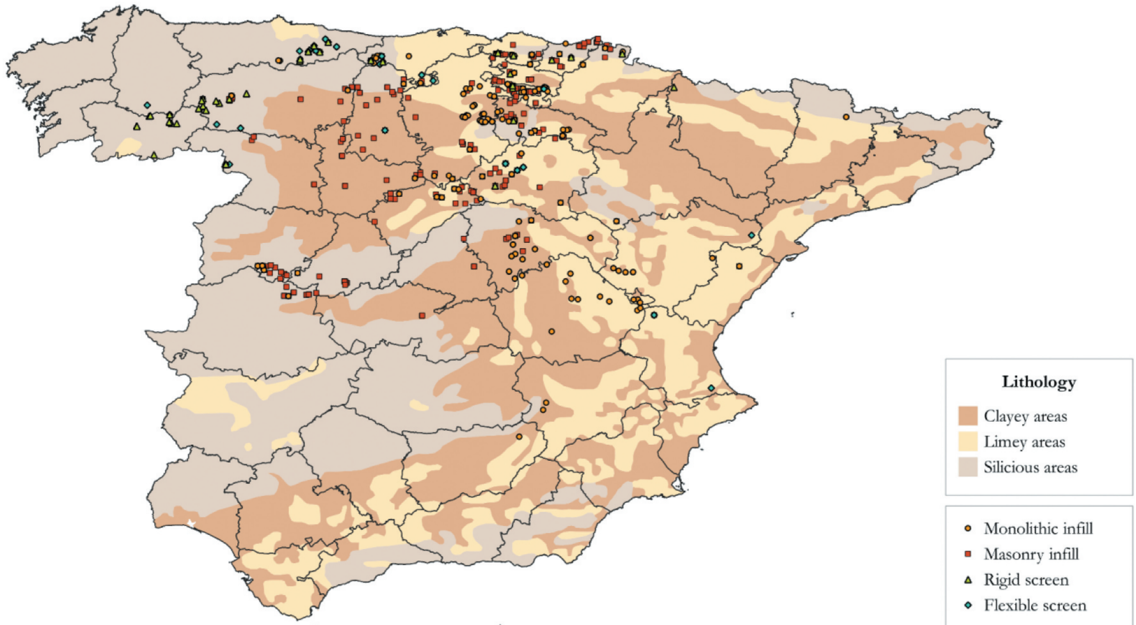

Figure 12. Lithological domains and half-timbered walls, classified by material variant. Source: Authors, based on Atlas Nacional de España (Instituto Geográfico Nacional 2019).

Table 6. Correlation between lithological domains and documented half-timbered walls, classified by main material used for infill or enclosure.

Lithology	Stone		Bricks		Earth		Timber and earth		Timber	
Limey	62	36.3%	98	47.1%	211	33.3%	21	22.6%	8	14.8%
Clay	36	21.1%	43	20.7%	239	37.7%	5	5.4%	2	3.7%
Siliceous	73	42.7%	67	32.2%	184	29.0%	67	72.0%	44	81.5%
	171		208		634		93		54	

in the mix to guarantee the cohesion of the mass, earthen techniques are widely found throughout Spain due to material availability and ease of execution (Mileto and Vegas 2017). When the properties of the available soil are not suitable it is possible to resort to different stabilization methods such as densification through compression; the use of organic, mineral, and synthetic additives; or the incorporation of plant, animal, and synthetic fibres (Houben and Guillaud 1994). In the absence of other more resistant materials like stone or brick, either due to constraints of distance or economy, earth is a material suitable for the infill of half-timbered walls, and can be improved with mineral additives such as gypsum and lime in some monolithic variants, or plant fibres left over from agricultural activity for the adobe brick infill.

4.5. Climate

Climate is a complex concept defined as the interaction between geographical conditioning factors and variable weather conditions such as rainfall, temperatures, solar radiation, humidity, wind, etc. The combination of climate with other geographical factors such as topography, type of soil, and hydrography determines the presence, distribution, and characteristics of the different forest tree species throughout Spain (Gavilán García 1994). Equally, climate is a conditioning factor in traditional architecture and in the solutions developed to provide comfort conditions suited to the inhabitants (Correia, Dipasquale, and Mecca 2014). In order to carry out a general analysis of this concept the classification proposed by Köppen-Geiger in 1936 was used, combining mean monthly rainfall and temperature values with the influence of these factors in the distribution of vegetation and human activity (Essenwanger 2001). Different types of climate are thus described based on the main climate, rainfall and temperature, each identified with a letter (Table 7).

According to this classification, almost the whole of Spain corresponds to a warm climate C with humid regions throughout the year in the north of the Iberian Peninsula Cf and areas with dry summers in the rest of the country Cs, although there are also some arid areas B and cold areas associated with large mountains D (Instituto Geográfico Nacional 2019, 104). It is therefore

Table 7. Climate classification following the method proposed by Köppen-Geiger (Essenwanger 2001).

Main Climates		Rainfall		Temperature	
A	Equatorial	W	Desert	h	Hot arid
B	Arid	S	Steppe	k	Cold arid
C	Warm temperature	F	Fully humid	a	Hot summer
D	Cold	S	Summer dry	b	Warm summer
E	Polar	W	Winter dry	c	Cool summer
		M	Monsoonal	d	Extremely continental
				f	Polar Frost
				T	Polar tundra

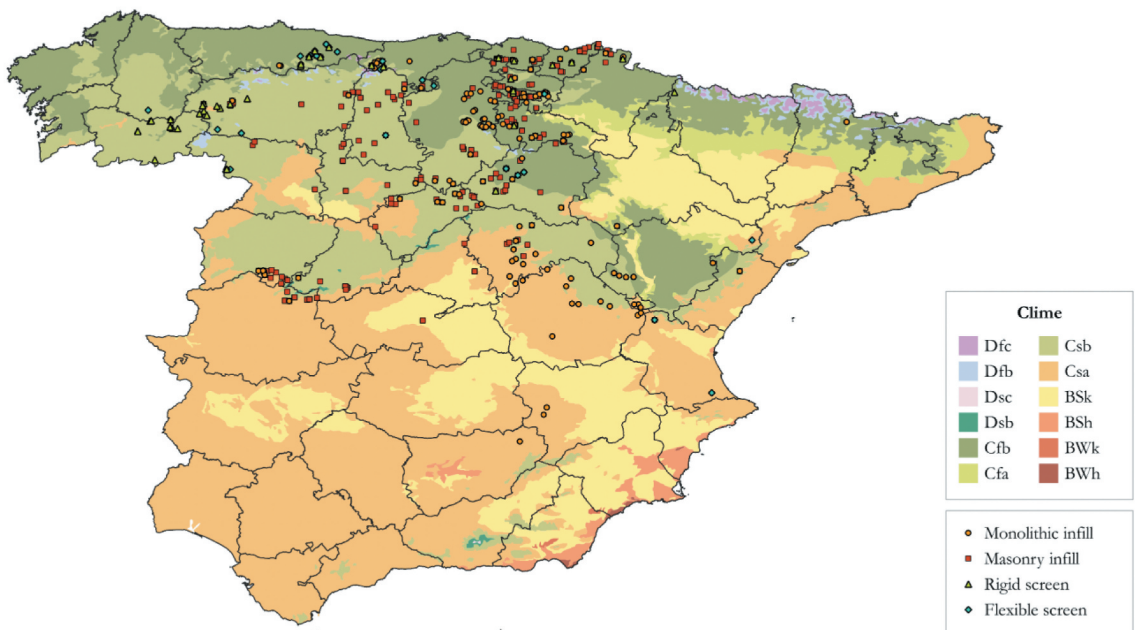

Figure 13. Climate classification and half-timbered walls, organized by material variant. Source: Authors, based on Atlas Nacional de España (Instituto Geográfico Nacional 2019).

logical for most of the half-timbered walls documented to be located in warm areas, whether with constant annual rainfall or with dry summers (Figure 13).

Heavy infill was used rather homogeneously in warm areas with maximum temperatures above 22°C, and very little influence of the general rainfall regime. 45.2% of cases with monolithic infill and 39.4% of brick infill were found in areas with constant rainfall all year round, compared to 33.8% and 40.3% respectively in areas with dry summers (Table 8). This may be due to the slightly higher capacity of monolithic infill to withstand atmospheric agents, either because they are made of stone or because techniques using earth tend to incorporate stabilizing agents like lime, generating a

Table 8. Correlation between climate classification and documented half-timbered walls, classified by material variant.

Climate	All techniques		Monolithic infill		Masonry infill		Rigid screen		Flexible screen	
BSh	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
BSk	13	1.1%	3	0.8%	10	1.5%	0	0.0%	0	0.0%
BWh	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
BWk	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Cfa	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Cfb	476	41.0%	178	45.3%	266	39.4%	22	26.8%	41	65.1%
Csa	204	17.6%	79	20.1%	127	18.8%	0	0.0%	3	4.8%
Csb	467	40.3%	133	33.8%	272	40.3%	60	73.2%	19	30.2%
Dfb	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Dfc	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Dsb	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Dsc	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	1160		393		675		82		63	

continuous surface that acts as rendering. There is also a tendency to use screens in warm climates with temperatures above 22°C, but 73.2% of the rigid screens are found in areas with dry summers Csb, and 65.1% of flexible screens are in areas with no dry summer Cfb. It should be noted that no cases were identified in Cfa zones with rain all year round and with maximum temperatures below 22°C. This was probably due to the vulnerability of these techniques to water and the walls being too thin to provide sufficient insulation.

4.6. Rainfall

Spain is characterized by major differences in rainfall, with some areas in the north found among those with the heaviest rainfall in Europe (Instituto Geográfico Nacional 2019, 97). As a result, three major sectors can be distinguished depending on annual mean rainfall: the humid or rainy zone above 800 mm; the dry zone or transition zone, with an annual mean rainfall of 300–800 mm; and finally, the arid zone with rainfall below 300 mm. Half-timbered walls are generally used in zones where rainfall encourages the growth of tree species considered optimum for construction (Figure 14), with 61.6% of cases in transition zones and 38.4% of cases in humid zones (Table 9). Heavy infills are concentrated homogeneously in areas with lower rainfall, with 67.9% of monolithic samples and 63.9% of masonry samples in areas with a mean rainfall between 300 and 800 mm. In contrast, the use of screens is concentrated in humid areas with a higher rainfall, with 75.6% of rigid screens and 63.5% of flexible screens in areas with a rainfall above 800 mm.

In terms of frequency and intensity, rainfall is a determining factor in the degradation of half-timbered walls and clearly conditions their durability, with the

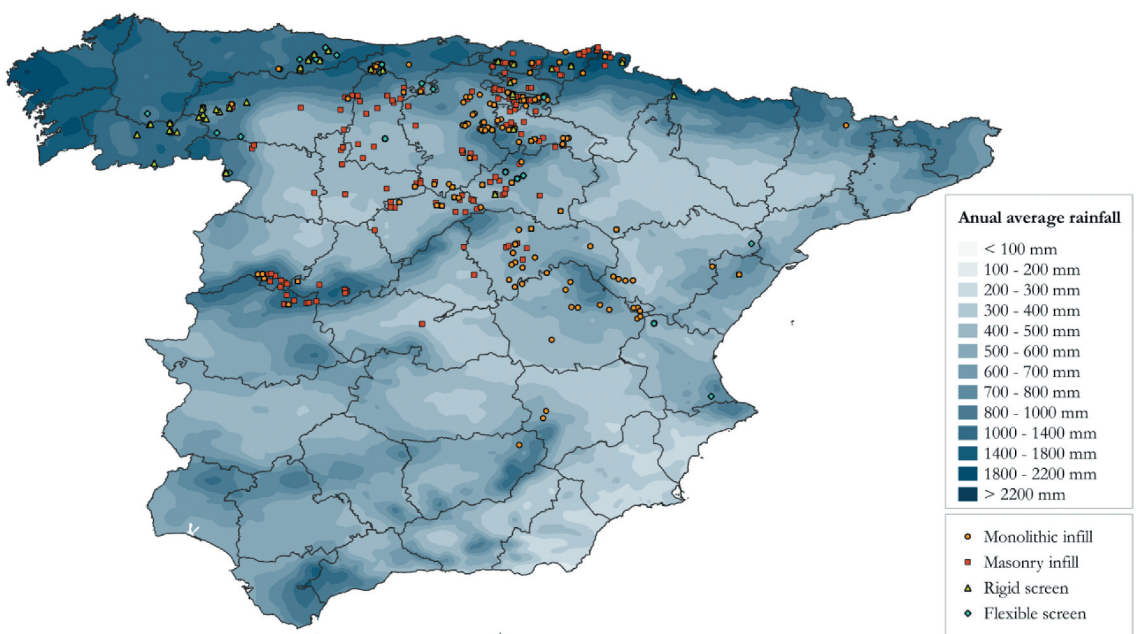

Figure 14. Annual average rainfall and half-timbered walls, classified by material variant. Source: Authors, based on Atlas Nacional de España (Instituto Geográfico Nacional 2019).

Table 9. Correlation between annual average rainfall and documented half-timbered walls, classified by material variant.

Annual Rainfall	All techniques		Monolithic infill		Masonry infill		Rigid screen		Flexible screen	
100–200 mm	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
200–300 mm	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
300–400 mm	15	1.3%	6	1.5%	9	1.3%	0	0.0%	0	0.0%
400–500 mm	181	15.6%	67	17.0%	114	16.9%	3	3.7%	2	3.2%
500–600 mm	148	12.8%	66	16.8%	85	12.6%	0	0.0%	1	1.6%
600–700 mm	254	21.9%	95	24.2%	149	22.1%	8	9.8%	17	27.0%
700–800 mm	117	10.1%	33	8.4%	74	11.0%	9	11.0%	3	4.8%
800–1000 mm	142	12.2%	66	16.8%	45	6.7%	25	30.5%	12	19.0%
1000–1400 mm	254	21.9%	48	12.2%	161	23.9%	33	40.2%	28	44.4%
1400–1800 mm	38	3.3%	8	2.0%	31	4.6%	2	2.4%	0	0.0%
1800–2200 mm	11	0.9%	4	1.0%	7	1.0%	2	2.4%	0	0.0%
	1160		393		675		82		63	

relatively common presence of damp patches due to water (Hueto Escobar et al. 2022). Although all of the cases have pitched roofs, different constructive strategies have been identified to further reduce the impact of these weather phenomena. These include the presence of rendering, large eaves, consecutive overhangs, and plinths in more resistant materials. The dimensional characteristics of the eaves are a key factor in relation to rainfall, as they can indicate a tendency to use larger overhangs in the eaves as the annual rainfall increases. 71.6% of eaves under 25 cm and 64.1% of eaves between 25 and 50 cm are located in areas with average rainfall between 300 and 800 mm, while in areas with rainfall above 800 mm, 61.3% of eaves between 75 and 100 cm, and 86.7% of eaves larger than 100 cm are found (Table 10). This shows that the builders had knowledge of the damage caused by rainwater in half-timbered walls.

In terms of the use of coatings it is necessary to balance the protection conditions of the infill and the need for timber to breathe, bearing in mind that both materials are hygroscopic and that the absorption and constant accumulation of humidity is harmful. Non-rendered cases are concentrated in areas with a lower probability of rain damage, with 60.2% of the samples in areas with an annual mean rainfall of between 300 and 800 mm (Table 11). In the case of rendered walls there is a higher presence of rendering covering only the infill in areas with heavier rainfall, with 42.4% of cases in areas with rainfall above 800 mm compared to 33.6% of examples with full rendering. This can be linked to the need for timber to breathe and be able to eliminate the humidity absorbed, as is the case with the half-timber more characteristic of wetter and colder climates in the rest of Europe (Maldonado Ramos and Vela Cossío 1999).

Equally, the different typologies of half-timbered walls make it possible to configure overhangs, arcades and porticos forming a place for protection from rainfall. The use of multiple consecutive overhangs provides protection from the effect of rain on the upper floors, while the arcades and porticos form a public space protected from these events. Areas with a higher rainfall present 55.8% of discontinuous walls compared to 33.8% of continuous walls (Table 12).

4.7. Humidity

The need for ventilation in traditional architecture increases in proportion to the range of relative humidity of a given place (Paniagua Padilla 2015).

Table 10. Correlation between annual average rainfall and the size of the eaves in documented half-timbered walls, classification by approximate range.

Annual Rainfall	Less than 25 cm		25–50 cm		50–75 cm		75–100 cm		More than 100 cm	
100–200 mm	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
200–300 mm	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
300–400 mm	4	1.0%	10	1.8%	1	0.7%	0	0.0%	0	0.0%
400–500 mm	114	27.9%	64	11.4%	2	1.4%	0	0.0%	1	3.1%
500–600 mm	67	16.4%	73	13.0%	4	2.8%	2	13.3%	1	3.1%
600–700 mm	79	19.3%	143	25.4%	31	21.8%	0	0.0%	8	25.0%
700–800 mm	29	7.1%	70	12.5%	17	12.0%	0	0.0%	3	9.4%
800–1000 mm	57	13.9%	72	12.8%	10	7.0%	0	0.0%	2	6.3%
1000–1400 mm	54	13.2%	116	20.6%	57	40.1%	6	40.0%	14	43.8%
1400–1800 mm	3	0.7%	13	2.3%	17	12.0%	3	20.0%	2	6.3%
1800–2200 mm	2	0.5%	1	0.2%	3	2.1%	4	26.7%	1	3.1%
	409		562		142		15		32	

Table 11. Correlation between annual average rainfall and the documented half-timbered walls, based on the presence and extent of the renderings.

Annual Rainfall	Infill rendering		Structure and infill rendering		Without rendering	
100–200 mm	0	0.0%	0	0.0%	0	0.0%
200–300 mm	0	0.0%	0	0.0%	0	0.0%
300–400 mm	3	1.3%	4	1.1%	8	1.4%
400–500 mm	13	5.8%	96	26.4%	72	12.6%
500–600 mm	26	11.6%	44	12.1%	78	13.6%
600–700 mm	73	32.6%	62	17.1%	119	20.8%
700–800 mm	14	6.3%	35	9.6%	68	11.9%
800–1000 mm	22	9.8%	40	11.0%	80	14.0%
1000–1400 mm	54	24.1%	81	22.3%	119	20.8%
1400–1800 mm	13	5.8%	1	0.3%	24	4.2%
1800–2200 mm	6	2.7%	0	0.0%	5	0.9%
	224		363		573	

Table 12. Correlation between annual mean rainfall and the documented half-timbered walls, classified by typological variant.

Annual Rainfall	Continuous Wall		Discontinuous walls	
100–200 mm	0	0.0%	0	0.0%
200–300 mm	0	0.0%	0	0.0%
300–400 mm	13	1.4%	2	0.8%
400–500 mm	157	17.1%	24	9.9%
500–600 mm	139	15.1%	9	3.7%
600–700 mm	211	23.0%	43	17.8%
700–800 mm	88	9.6%	29	12.0%
800–1000 mm	110	12.0%	32	13.2%
1000–1400 mm	166	18.1%	88	36.4%
1400–1800 mm	29	3.2%	9	3.7%
1800–2200 mm	5	0.5%	6	2.5%
	918		242	

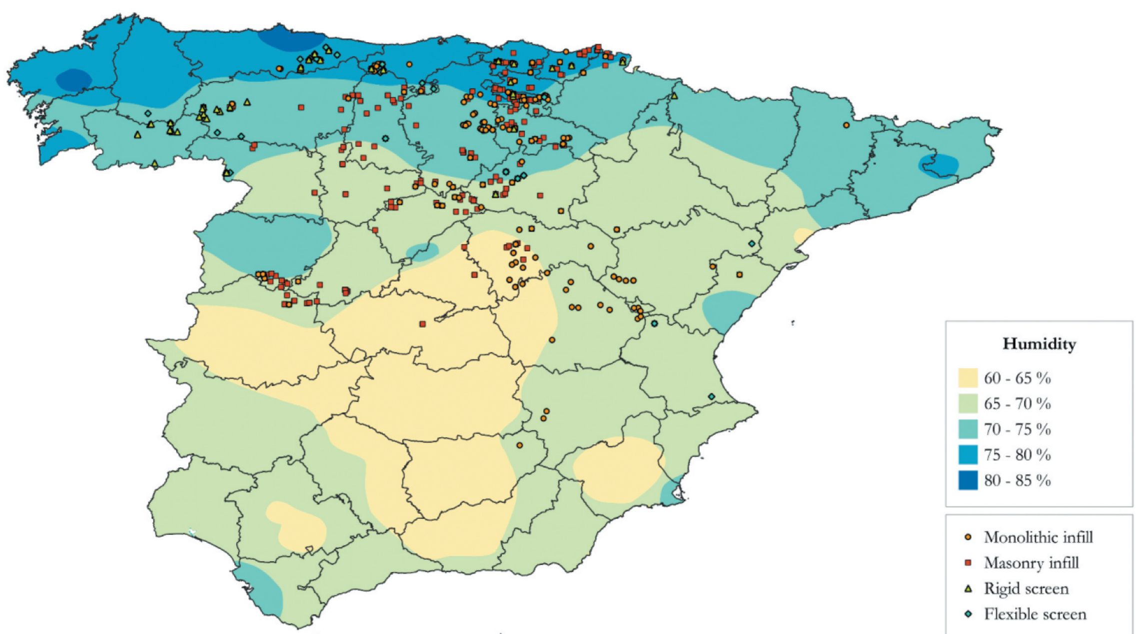

Figure 15. Humidity and half-timbered walls, classified by material variant. Source: Authors, based on Atlas Nacional de España (Instituto Geográfico Nacional 2004).

In general, all the material variants are distributed into annual relative humidity ranges of between 70 and 75% (Figure 15), with 49% of monolithic infills, 36.3% of brick infills, 58.5% of rigid screens, and 41.3% of flexible screens (Table 13). However, it is observed that screens tend to be used in areas with higher humidity, and 37.8% of rigid screens and 49.2% of flexible screens are found in areas with a relative humidity of between 75 and 80%. In this regard, the screens provide better ventilation of interior spaces, either by incorporating laths set apart or with the execution of non-rendered wattle-and-daub and are ideal for enclosing interior spaces used for storage and drying foodstuffs. In contrast, monolithic infill and brick infill decrease in proportion to the increase in relative humidity of the place.

Table 13. Correlation between humidity and documented half-timbered walls, classified by material variant.

Humidity	All techniques		Monolithic infill		Masonry infill		Rigid screen		Flexible screen	
60–65%	63	5.4%	37	9.4%	26	3.9%	0	0.0%	0	0.0%
65–70%	353	30.4%	101	25.7%	254	37.6%	3	3.7%	6	9.5%
70–75%	492	42.4%	196	49.9%	245	36.3%	48	58.5%	26	41.3%
75–80%	252	21.7%	59	15.0%	150	22.2%	31	37.8%	31	49.2%
80–85%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	1160		393		675		82		63	

4.8. Water balance

Areas with an excess or deficit of water can be defined through the correlation between rainfall and evapotranspiration, a concept which covers the processes of water evaporation from the soil, transpiration of plants and the soil's absorption capacity (Instituto Geográfico Nacional 2019, 102). The water balance of a place can be linked to the humidity of the soil and the possible influence of absorption through capillarity in the degradation processes observed in half-timbered walls. In general these are found rather homogeneously in areas with negative water balances, with a lower accumulation of water in the soil which may have affected the walls studied (Figure 16).

However, the presence of half-timbered walls over plinths or walls in more resistant materials is more commonly found (Hueto Escobar et al. 2020), and therefore, the frequency of damp stains and erosion due to capillary water absorption is relatively infrequent (Hueto Escobar et al. 2022). Analysis of the dimensions of these plinths or lower walls shows that those with smaller dimensions are not used as frequently in areas with damp terrain or positive water balances. In fact, 34.6% of plinths under 50 cm and 38.6% of plinths between 50 and 100 cm high are located in areas with a positive water balance, compared to 50.8% of plinths between 100 and 150 cm, and 45.1% of plinths between 150 and 200 cm (Table 14). In the case of bigger lower walls, their existence is mostly associated with the presence of ground floors and the use of half-timbered walls on the upper floors, although they are also an element which protects from humidity through capillarity.

4.9. Mean temperature

The distribution of temperatures throughout Spain is highly irregular due mostly to the country's vast size, which results in greater thermal amplitudes inland and

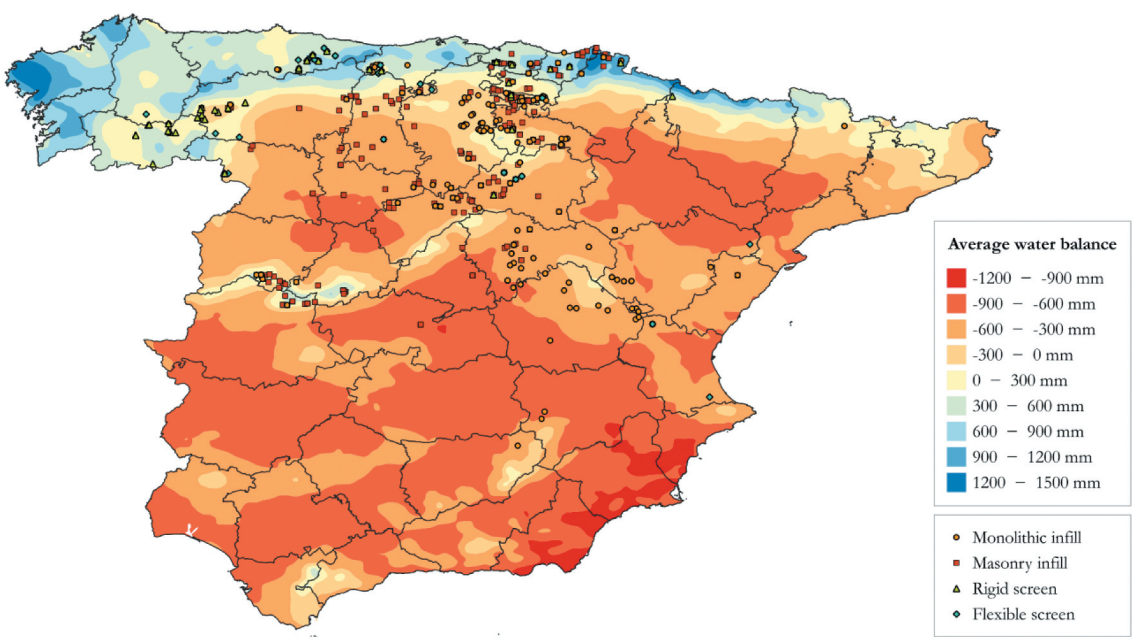

Figure 16. Water balance and half-timbered walls, classified by material variant. Source: Authors, based on Atlas Nacional de España (Instituto Geográfico Nacional 2004).

Table 14. Correlation between water balance and the documented half-timbered walls, based on dimensions of plinths or lower walls.

Water balance	< 50 cm		50–100 cm		100–150 cm		150–200 cm		200–250 cm		250–300 cm		> 300 cm	
−1200 to −900 mm	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
−900 to −600 mm	1	3.8%	7	15.9%	0	0.0%	0	0.0%	8	2.6%	5	3.2%	5	2.1%
−600 to — 300 mm	8	30.8%	11	25.0%	9	14.3%	42	17.9%	77	25.5%	40	25.8%	58	24.0%
−300 to 0 mm	8	30.8%	9	20.5%	22	34.9%	87	37.0%	115	38.1%	49	31.6%	91	37.6%
0 to +300 mm	7	26.9%	15	34.1%	23	36.5%	62	26.4%	48	15.9%	35	22.6%	43	17.8%
+300 to + 600 mm	2	7.7%	2	4.5%	5	7.9%	19	8.1%	32	10.6%	16	10.3%	28	11.6%
+600 to +900 mm	0	0.0%	0	0.0%	4	6.3%	25	10.6%	12	4.0%	6	3.9%	7	2.9%
+900 to +1200 mm	0	0.0%	0	0.0%	0	0.0%	0	0.0%	8	2.6%	2	1.3%	3	1.2%
+1200 to +1500 mm	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2	0.7%	2	1.3%	0	0.0%
	26		44		63		235		302		155		235	

softer ones in coastal areas, along with the distribution and altitude of mountainous systems (Instituto Geográfico Nacional 2019, 93). As most of the cases studied are located inland in areas with a considerable average altitude and relatively cold climates, their capacity for insulation is a determining factor in the use and distribution of different variants (Figure 17). In this respect, heavier infills display greater thermal inertia due to their mass and are found mostly in colder areas with annual mean temperatures between 10 and 12.5°C. This is the specific case of 65% of monolithic infills and 70% of brick infills (Table 15). The use of screens is concentrated in this temperature range, with 52% of cases with rigid screens and 67% of cases with flexible screens. However, a tendency to use rigid variants in slightly warmer areas can be seen, with 41% of cases found in locations with average temperatures between 12.5 and 15°C. This may be due to the fact that many of the rigid screen variants are made up of a single element, either timber laths or simple lath-and-daub, with a lower thermal inertia than flexible screens and double rigid screens where a greater use of rendering, infill and plant fibres results in a slight improvement to thermal insulation.

4.10. Solar radiation

In warm climates, traditional architecture tends to seek the warmth of the sun in the colder seasons and solar protection in the warmer seasons (Correia, Dipasquale, and Mecca 2014). In general, half-timbered walls are concentrated in the areas with least solar radiation in Spain (Figure 18), also coinciding with areas with lower temperatures and higher levels of humidity. In these areas, solar radiation mostly becomes advantageous and is used to heat buildings. The configuration of half-timbered walls using a timber frame which mostly fulfils a structural function allows the configuration of large openings taking advantage of solar incidence to heat the interior of buildings. Equally, greater thermal

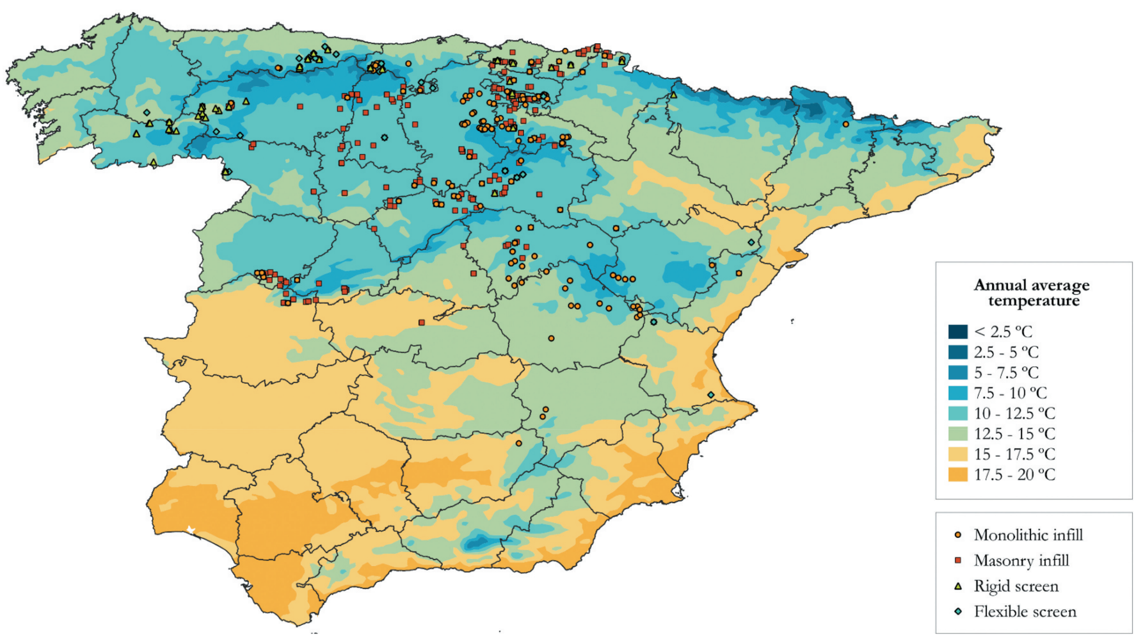

Figure 17. Annual mean temperatures and half-timbered walls, classified by material variant. Source: Authors based on Atlas Nacional de España (Instituto Geográfico Nacional 2004).

Table 15. Correlation between annual mean temperatures and documented half-timbered walls, classified by material variant.

Mean Temperature	All techniques		Monolithic infill		Masonry infill		Rigid screen		Flexible screen	
< 2.5°C	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2.5–5°C	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
5–7.5°C	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
7.5–10°C	116	10.0%	72	18.3%	29	4.3%	5	6.1%	14	22.2%
10–12.5°C	778	67.1%	255	64.9%	473	70.1%	43	52.4%	42	66.7%
12.5–15°C	260	22.4%	66	16.8%	168	24.9%	34	41.5%	6	9.5%
15–17.5°C	6	0.5%	0	0.0%	5	0.7%	0	0.0%	1	1.6%
17.5–20°C	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
> 20°C	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	1160		393		675		82		63	

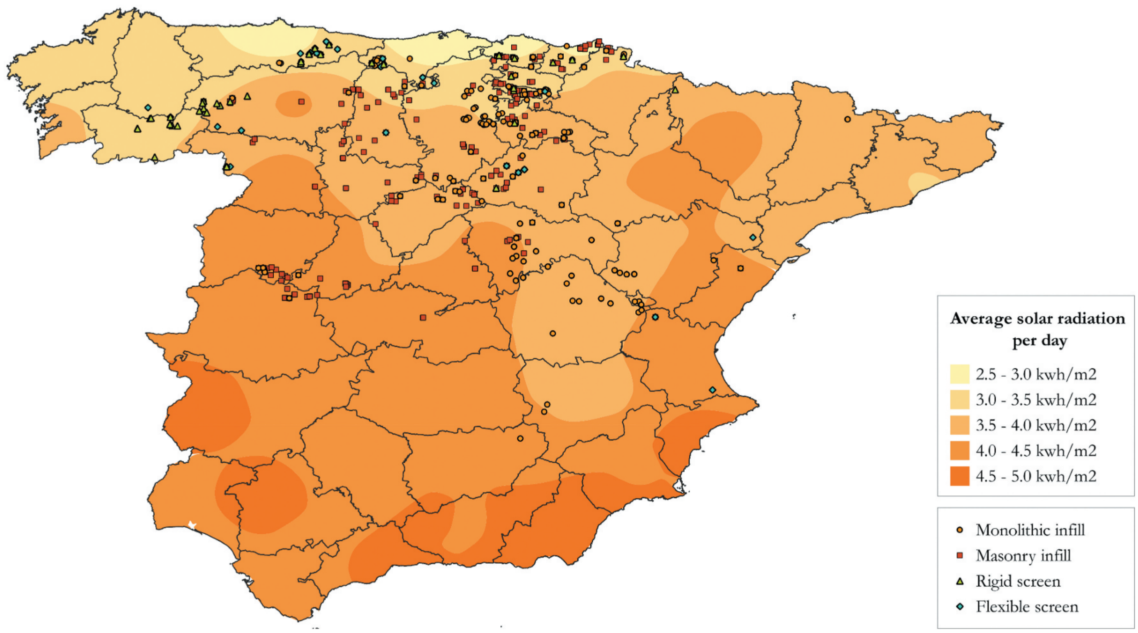

Figure 18. Solar radiation and half-timbered walls, classified by material variant. Source: Authors, based on Atlas Nacional de España (Instituto Geográfico Nacional 2004).

Table 16. Correlation between solar radiation and the half-timbered walls documented, classified by material variant.

Solar radiation	All techniques		Monolithic infill		Masonry infill		Rigid screen		Flexible screen	
2.5–3.0 kwh/m^2	32	2.8%	5	1.3%	28	4.1%	3	3.7%	1	1.6%
3.0–3.5 kwh/m^2	398	34.3%	128	32.6%	198	29.3%	59	72.0%	36	57.1%
3.5–4.0 kwh/m^2	511	44.1%	197	50.1%	289	42.8%	20	24.4%	24	38.1%
4.0–4.5 kwh/m^2	219	18.9%	63	16.0%	160	23.7%	0	0.0%	2	3.2%
4.5–5.0 kwh/m^2	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	1160		393		675		82		63	

inertia than other techniques allows these walls to capture solar incidence and transmit it to the interior, heating it. Specifically, 50.1% of monolithic infills and 42.8% of brick infills are concentrated in areas with an average solar radiation of 3.5–4.0 kwh/m^2 (Table 16). Although this type of variant displays greater thermal inertia than screens these walls are still relatively thin, coinciding with the squared-off timber, and transmit the heat absorbed to the interior (Mileto et al. 2019).

The frequency with which the half-timbered walls develop lesions relating to solar radiation, especially chromatic alteration and the dehydration of timber, is considerable (Hueto Escobar et al. 2021). As well as protecting from other atmospheric agents, rendering also provides protection from solar radiation. A tendency to protect the wall in areas with greater solar radiation can be observed. Specifically, 21.2% of the walls with complete rendering are located in areas with solar radiation of 4–4.5 kwh/m^2, compared to 13.8% and 17.6% of cases with rendering of infill and the non-rendered cases located in these ranges respectively (Table 17). In contrast, the percentage of walls without rendering increases as annual mean solar radiation decreases, until reaching 40.5% of cases with solar radiation of 3–3.5 kwh/m^2.

Equally, the presence of discontinuous walls with overhangs, arcades or porticos contribute to the creation of shaded spaces which improve environmental comfort in warm regions or seasons. Just as a tendency was observed in the use of this type of wall in rainy regions, there is also a tendency to use them more frequently in areas with high solar radiation. Specifically, 25.2% of discontinuous walls are found in regions with an annual mean solar radiation of 4–4.5 kwh/m^2, compared to 17.2% of continuous walls (Table 18).

5. Conclusions

The cross-analysis between the detailed information on 1160 half-timbered walls throughout Spain and the different themed maps analysed has provided conclusions on the factors favouring the use of these techniques in

Table 17. Correlation between solar radiation and the documented half-timbered walls, depending on the presence and extent of rendering.

Solar radiation	Infill rendering		Structure and infill rendering		Without rendering	
2.5–3.0 kwh/m^2	8	3.6%	4	1.1%	30	5.2%
3.0–3.5 kwh/m^2	76	33.9%	90	24.8%	232	40.5%
3.5–4.0 kwh/m^2	109	48.7%	192	52.9%	210	36.6%
4.0–4.5 kwh/m^2	31	13.8%	77	21.2%	101	17.6%
4.5–5.0 kwh/m^2	0	0.0%	0	0.0%	0	0.0%
	224		363		573	

Table 18. Correlation between solar radiation and documented half-timbered walls, classified by typological variant.

Solar radiation	Continuous Wall		Discontinuous walls	
2.5–3.0 kwh/m^2	27	2.9%	5	2.1%
3.0–3.5 kwh/m^2	293	31.9%	105	43.4%
3.5–4.0 kwh/m^2	440	47.9%	71	29.3%
4.0–4.5 kwh/m^2	158	17.2%	61	25.2%
4.5–5.0 kwh/m^2	0	0.0%	0	0.0%
	918		242	

specific regions. It also valorizes the different strategies developed to adapt to the individual conditions of place. In general, half-timbered walls are characteristic of mountain areas close to vegetation formations at an altitude of 500 −1000 masl, although a tendency is observed towards the use of heavy infill at higher altitudes and lightweight screens at lower altitudes. The presence of rivers is not as determining a factor as the proximity of vegetation formations used to source optimal timber for construction, although the use of this type of wall has spread to other areas through river trade of materials. However, proximity to water is a slightly conditioning factor for the development of certain variants which require the use of water as is the case of earth infill, or those which require vegetation associated with riverbanks, as is the case of wattle-and-daub. It is possible to observe a certain tendency to use half-timbered walls in areas near hardwood forests, more durable and resistant than conifer timber. The presence of different types of lithological domains also conditions the type of infill used, with masonry infill preferred in siliceous and calcareous domains given their greater resistance. However, earth infills are in use beyond clayey areas as earth is an economical material that is easy to work and available in many areas, while the quality of construction can be improved through different processes and additives. Climate, as a concept covering rainfall, humidity, water balance of the ground, solar radiation and other points, is a determining factor in the different strategies developed by the builders of half-timbered walls to improve durability. These strategies could be summed up as the use of larger eaves in areas with higher annual rainfall; the presence of plinths or ground floors increasing in height in proportion with the water balance and the humidity in the ground; the presence of rendering protecting walls from rainfall and solar incidence; while also allowing timber to breathe when necessary, and even taking advantage of overhangs, arcades and galleries as areas protected from extreme rain or sun. All these lessons in sustainability in terms of adaptation to surroundings, to geographical conditions, to the needs of a community, and the incorporation of strategies aimed at prolonging the useful life of buildings can be extrapolated to modern architecture and form part of the cultural value of traditional architecture.

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