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Compatibility between Sustainability and Conservation in Earthen Architecture: Initial Analysis of Restoration Interventions and Contemporary Applications in Spain

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Abstract

The rehabilitation of traditional earthen architecture in Spain currently faces the challenge of reconciling heritage values with sustainability objectives such as energy efficiency, emission reduction, and cost-effectiveness, increasingly applied across the construction sector. Earthen architecture represents significant cultural heritage, offering an opportunity to promote traditional bioclimatic strategies and circular economy practices adapted to the demands posed by climate change. Within the context of the "Earth4Future" research project, which aims to evaluate the rehabilitation of traditional buildings and contemporary earthen construction, this study focuses on identifying intervention dynamics documented in 70 traditional buildings and contemporary applications in 15 newly constructed buildings. A statistical analysis has been conducted on the types of interventions, the compatibility of materials and techniques used, and the primary motivations driving these interventions. The analysis of the contemporary applications examines the type of technique employed in relation to traditional methods and the mechanisms applied for quality control, energy improvement, or cost reduction. The paper ultimately aims to identify patterns of good practices, evaluate the synergies between tradition and innovation, and lay the groundwork for sustainable intervention guidelines.

Keywords: *traditional techniques; intervention strategies; earthen construction; sustainable design*

1. Introduction

Earthen construction is found in a large part of the Spanish territory, and a considerable part of the population continues to live in these buildings (Correia et al., 2011; Houben & Guillaud, 1994; Maldonado & Vela Cossío, 2011; Mileto et al., 2017). Its conservation as heritage is undeniable, considering its intrinsic value and the risk of loss which threatens all of Spanish traditional architecture (IPCE, 2014).

However, this conservation should also take into account the current context of climate change and the need for energy efficiency, reduction of emissions, and economic profitability (United Nations Environment Programme, 2023; Von Der Leyen, 2019). The constructive use of earth also presents a series of environmental advantages which have encouraged its application in contemporary architecture, mostly at bioclimatic, economic, and energy level.

In this context, the project "*Earth 4 Future: Sustainable reuse of earthen architecture and its lessons for contemporary architecture*" (PID2022-139154OB-I00) seeks to provide a global approach to the use of earth in interventions in both traditional and contemporary buildings. It is thus proposed to study aspects such as compatibility of interventions with heritage value, energy efficiency, life cycle, and construction costs.

2. Objectives and methodology

This text focuses on the study of the compatibility of these interventions with the heritage value of this type of architecture, by analysing dynamics relating to intervention in 70 traditional buildings and to application in 15 modern buildings throughout Spain (Fig. 1).

The cases of interventions in traditional buildings have been identified in research projects carried out previously (Mileto et al., 2017, 2022), while the modern buildings have been selected following an extensive bibliographical review of publications.

Two fiche models with general data on buildings (geographical, climate, and architectural data) and specific information on the form of intervention in existing elements and on the form of construction in new buildings have been proposed for this study (Fig. 2). This has allowed the statistical analysis of different aspects, enabling conclusions to be drawn on the compatibility and application of these techniques.

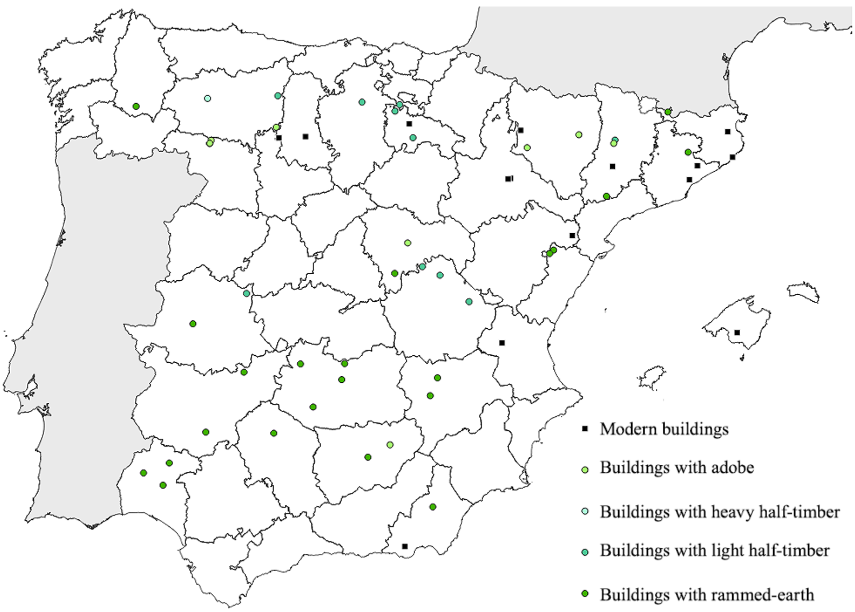

Fig. 1 – *Distribution of case studies* (Hueto-Escobar, 2025).

The study of the interventions has focused on the analysis of different aspects in 385 constructive elements such as walls, openings, roofs, and renders. However, interventions in plinths, floors and ceilings, partition walls and paving have also been documented, while the process of obtaining valid conclusions on these elements has been conditioned by difficult access and lack of visibility.

The study has focused on an initial reflection, distinguishing between planned interventions seeking to propose multiple cohesive actions and spontaneous interventions with no prior criteria established. Equally, the degree of compatibility of techniques and materials has been analysed to establish whether they differ from the original ones.

Moreover, the general objective of the intervention was analysed based on the work's initial criterion, result, or motivation and the type of intervention based on the physical action carried out. Within the objectives, distinctions have been made between aesthetic updates, aimed at adapting to current standards and tastes; recurring maintenance or tasks, to prevent or anticipate occasional and limited repairs in response to the appearance of lesions; restorations taking into consideration the heritage value of the element; rehabilitations seeking to improve the features of the element or to include new functions; expansions which entail a volumetric increase of the buildings; and intentional demolitions of part of the building.

Finally, when assessing the type of intervention, factors considered include the consolidation of existing elements; reintegration of missing parts using similar solutions; reconstruction of elements with similar ones; replacement of elements with different ones; and demolition adding other elements which did not exist previously.

In terms of the contemporary forms of application of these techniques, an analysis has been made of the material, volumetric, compositional, and aesthetic relationship of these buildings with regard to local tradition. This has helped ascertain whether they replicate local tradition or import traditions from other areas; whether they reinterpret local tradition or tradition from other areas; or whether they opt for a modern solution.

Equally, an analysis was carried out to identify the constructive elements in which earth was most frequently used and the particular techniques applied.

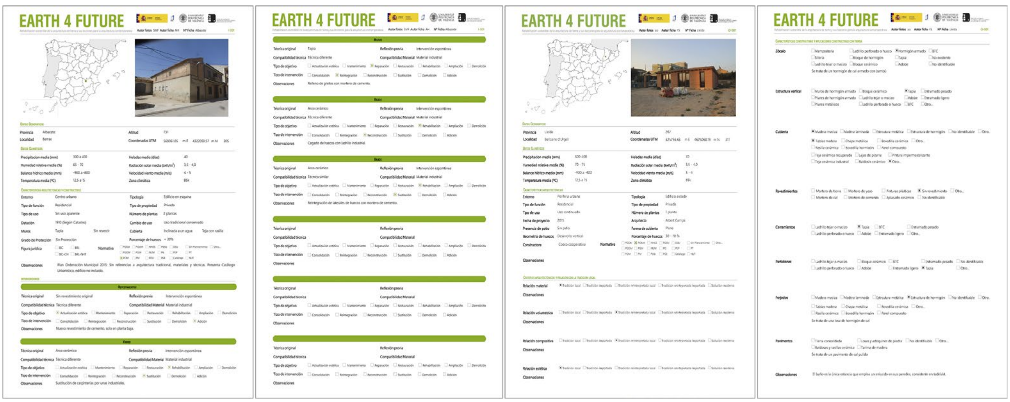

Fig. 2 – *Study fiches for interventions in traditional buildings and application in contemporary buildings.*

3. Earthen intervention dynamics

In general (Table 1), the interventions identified answer to a spontaneous dynamic in 63.6% of cases and to prior planning in 36.4% of cases. When examining the degree of compatibility with pre-existing techniques and materials, there is a predominant use of different techniques in 61.8% of cases and industrial materials in 82.1% of cases. In fact, the use of similar traditional materials falls to 14.8%, and different traditional materials are used in 3.1% of cases. Among the general objectives driving these interventions (Table 2), it is worth noting repairs (36.9%) and rehabilitations (33.2%). In contrast, there is a significant drop in more respectful interventions such as maintenance (6.0%) and restorations (8.8%). As regards the types of intervention (Table 3), there is a predominance of substitutions (34.3%), reintegrations (24.9%), and additions of elements (26.8%). However, there is a considerable reduction in more respectful actions such as consolidations (2.9%) and reconstructions (11.2%).

Load-bearing walls are the constructive element (33.5%, Table 1) displaying the most frequent interventions. Among the different traditional

Table 1 – *General analysis of prior planning, technical compatibility and material compatibility.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Walls	129 33.5%	102 79.1%	27 20.9%	93 72.1%	36 27.9%	13 10.1%	4 3.1%	112 86.8%
Openings	96 24.9%	71 74.0%	25 26.0%	75 78.1%	21 21.9%	12 12.5%	1 2.1%	82 85.4%
Roofs	77 20.0%	27 35.1%	50 64.9%	31 40.3%	46 59.7%	17 22.1%	1 1.3%	59 76.6%
Claddings	54 14.0%	26 48.1%	28 51.9%	24 44.4%	30 55.6%	10 18.5%	2 3.7%	42 77.8%
Plinth	21 5.5%	17 81.0%	4 19.0%	12 57.1%	9 42.9%	3 14.3%	2 9.5%	16 76.2%
Slabs	5 1.3%	2 40.0%	3 60.0%	3 60.0%	2 40.0%	1 20.0%	0 0.0%	4 80.0%
Partitions	2 0.5%	0 0.0%	2 100%	0 0.0%	2 100%	1 50.0%	0 0.0%	1 50.0%
Pavings	1 0.3%	0 0.0%	1 100%	0 0.0%	1 100%	1 100%	0 0.0%	0 0.0%
Total	385 100%	245 63.6%	140 36.4%	238 61.8%	147 38.2%	57 14.8%	12 3.1%	316 82.1%

Table 2 – *Analysis of the general objectives of the interventions documented.*

	Total	Walls	Openings	Roofs	Claddings	Plinths	Slabs	Partitions	Floors
Update	39 10.1%	2 1.6%	3 3.1%	0 0.0%	33 61.1%	1 4.8%	0 0.0%	0 0.0%	0 0.0%
Maintenance	23 6.0%	1 0.8%	3 3.1%	16 20.8%	3 5.6%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Repair	142 36.9%	61 47.3%	24 25.0%	22 28.6%	16 29.6%	17 81.0%	2 40.0%	0 0.0%	0 0.0%
Restoration	34 8.8%	7 5.4%	2 2.1%	15 19.5%	6 11.1%	3 14.3%	0 0.0%	0 0.0%	1 100%
Rehabilitation	128 33.2%	38 29.5%	67 69.8%	21 27.3%	0 0.0%	0 0.0%	0 0.0%	2 100%	0 0.0%
Extension	30 7.8%	21 16.3%	2 2.1%	4 5.2%	0 0.0%	0 0.0%	3 60.0%	0 0.0%	0 0.0%
Demolition	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Total	385 100%	129 33.5%	96 24.9%	77 20.0%	54 14.0%	21 5.5%	5 1.3%	2 0.5%	1 0.3%

Table 3 – *Analysis of types of interventions documented.*

	Total	Walls	Openings	Roofs	Claddings	Plinths	Slabs	Partitions	Floors
Consolidation	11 2.9%	5 3.9%	0 0.0%	1 1.3%	1 1.9%	3 14.3%	0 0.0%	0 0.0%	1 100%
Reintegration	96 24.9%	44 34.1%	16 16.7%	11 14.3%	7 13.0%	17 81.0%	1 20.0%	0 0.0%	0 0.0%
Reconstruction	43 11.2%	7 5.4%	5 5.2%	18 23.4%	10 18.5%	0 0.0%	1 20.0%	1 50.0%	1 100%
Replacement	132 34.3%	32 24.8%	52 54.2%	24 31.2%	19 35.2%	1 4.8%	3 60.0%	1 50.0%	0 0.0%
Demolition	14 3.6%	4 3.1%	9 9.4%	1 1.3%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Addition	103 26.8%	44 34.1%	18 18.8%	23 29.9%	17 31.5%	0 0.0%	1 20.0%	0 0.0%	0 0.0%
Total	385 100%	129 33.5%	96 24.9%	77 20.0%	54 14.0%	21 5.5%	5 1.3%	2 0.5%	1 0.3%

Table 4 – *Detailed analysis of interventions on walls: planning and technical and material compatibility.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Rammed earth	66 51.2%	56 84.8%	10 15.2%	54 81.8%	12 18.2%	5 7.6%	1 1.5%	60 90.9%
Adobe	32 24.8%	22 68.8%	10 31.3%	18 56.3%	14 43.8%	5 15.6%	3 9.4%	24 75.0%
Heavy half-timber	19 14.7%	14 73.7%	5 26.3%	13 68.4%	6 31.6%	1 5.3%	0 0.0%	18 94.7%
Light half-timber	1 0.8%	1 100%	0 0.0%	0 0.0%	1 100%	0 0.0%	0 0.0%	1 100%
Masonry	7 5.4%	5 71.4%	2 28.6%	5 71.4%	2 28.6%	2 28.6%	0 0.0%	5 71.4%
Brick	1 0.8%	1 100%	0 0.0%	1 100%	0 0.0%	0 0.0%	0 0.0%	1 100%
Replaced	1 0.8%	1 100%	0 0.0%	1 100%	0 0.0%	0 0.0%	0 0.0%	1 100%
Unidentified	2 1.6%	2 100%	0 0.0%	1 50.0%	1 50.0%	0 0.0%	0 0.0%	2 100%
Total	129 100%	102 79.1%	27 20.9%	238 61.8%	147 38.2%	57 14.8%	12 3.1%	316 82.1%

Table 5 – *Detailed analysis of interventions on openings: planning and technical and material compatibility.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Squared timber	30 31.3%	24 80.0%	6 20.0%	18 60.0%	12 40.0%	8 26.7%	1 3.3%	21 70.0%
Rounded log lintel	3 3.1%	22 66.7%	2 33.3%	0 0.0%	3 100%	2 66.7%	0 0.0%	1 33.3%
Stone lintel	5 5.2%	4 80.0%	5 20.0%	4 80.0%	1 20.0%	1 20.0%	0 0.0%	4 80.0%
Ceramic arch	8 8.3%	6 75.0%	2 25.0%	7 87.5%	1 12.5%	0 0.0%	0 0.0%	8 100%
Replaced	17 17.7%	9 52.9%	8 47.1%	17 100%	0 0.0%	0 0.0%	0 0.0%	17 100%
Unidentified	33 34.4%	26 78.8%	7 21.2%	29 87.9%	4 12.1%	1 3.0%	1 3.0%	31 94.0%
Total	96 100%	71 74.0%	25 26.0%	75 78.1%	21 21.9%	12 12.5%	2 2.1%	82 85.4%

Table 6 – *Detailed analysis of interventions on roofs: planning and technical and material compatiblity.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Roof tile & timber	35 45.5%	16 45.7%	19 54.3%	15 42.9%	20 57.1%	9 25.7%	0 0.0%	26 74.3%
Roof tile & thin tile	14 18.2%	6 42.9%	8 57.1%	5 35.7%	9 64.3%	2 14.3%	0 0.0%	12 85.7%
Roof tile & reed	1 1.3%	0 0.0%	1 100%	0 0.0%	1 100%	1 100%	0 0.0%	0 0.0%
Roof tile & moulding	1 1.3%	0 0.0%	1 100%	0 0.0%	1 100%	0 0.0%	0 0.0%	1 100%
Plant & reed	3 3.9%	0 0.0%	3 100%	0 0.0%	3 100%	2 66.7%	1 33.3%	0 0.0%
Replaced	18 23.4%	5 27.8%	13 72.2%	9 50.0%	9 50.0%	2 11.1%	0 0.0%	16 88.9%
Unidentified	5 6.5%	0 0.0%	5 100%	2 40.0%	3 60.0%	1 20.0%	0 0.0%	4 80.0%
Total	96 100%	27 35.1	50 64.9	31 40.3	46 59.7%	17 22.1%	1 1.3%	59 76.6%

Table 7 – *Detailed analysis of interventions on renders: planning and technical and material compatibility.*

	Cases	Spontaneous	Planned	Different technique	Similar technique	Similar traditional material	Different traditional material	Industrial material
Lime mortar	20 37.0%	6 30.0%	14 70.0%	4 20.0%	16 80.0%	6 30.0%	1 5.0%	13 65.0%
Earth mortar	6 11.1%	6 100%	0 0.0%	4 66.7%	2 33.3%	0 0.0%	0 0.0%	6 100%
Gypsum mortar	1 1.9%	1 100%	0 0.0%	0 0.0%	1 100%	0 0.0%	0 0.0%	1 100%
No render	15 27.8%	8 53.3%	7 46.7%	12 80.0%	3 20.0%	1 6.7%	1 6.70	13 86.7%
Replaced	9 16.7%	4 44.4%	5 55.6%	2 22.2%	7 77.8%	2 22.2%	0 0.0%	7 77.8%
Unidentified	3 5.6%	1 33.3%	2 66.7%	2 66.7%	1 33.3%	1 33.3%	0 0.0%	2 66.7%
Total	54 100%	26 48.1%	28 51.9%	24 44.4%	30 55.6%	10 18.5%	2 3.7%	42 77.8%

techniques which can be used to build these walls (Table 4), rammed earth is the technique with most frequent interventions (51.2%), followed by adobe (24.8%) and heavyweight half-timbered walls (14.7%). In general, spontaneous interventions predominate although planned interventions are slightly more frequent in adobe walls and considerably less so in rammed earth walls (Fig. 3). In terms of technical and material compatibility there is a predominance of different techniques and industrial materials. However, adobe and half-timbered walls often undergo interventions with similar techniques incorporating industrial materials such as industrial brick.

Openings are the second most frequent element (24.9%, Table 1) requiring intervention, probably to improve energy efficiency. Although it is often impossible to identify the type of lintel, there is a high percentage of interventions in squared lintels (31.3%, Table 5). As in the rest of constructive elements, there is a clear predominance of spontaneous interventions, with different techniques and industrial materials. In this regard, the replacement of joinery with PVC or aluminium doors and windows, as well as the expansion of openings in entrances to buildings (Fig. 4) and the installation of unsuitable elements such as blinds and railings are of particular note.

Fig. 3 – *Rammed earth wall intervened with industrial brick* (Vegas & Mileto, 2016).

Fig. 4 – *Adobe wall where the entrance has been enlarged* (Vegas & Mileto, 2016).

Roofs (20.0%, Table 1) are in third place in terms of frequency of intervention. Among the traditional techniques with interventions (Table 6) it is particularly worth noting roofs with roof tiles and timber (45.5%) and roofs with roof tiles and thin ceramic tiles (18.2%). However, it is also worth highlighting the high number of cases where the roof has been completely replaced (23.4%). In this case, there is a relatively higher frequency of planned interventions using similar techniques. Likewise, although the percentage of industrial materials is also higher, the frequency with which similar traditional materials is used is significantly higher than for the rest of the elements. Among the interventions documented those that stand out most are complete and partial reconstructions using similar techniques but using cement mortar, as well as structural replacements with concrete and metal elements. However, it is also worth emphasizing the high number of interventions which include insulation material and gutters.

Table 8 – *Analysis of compatibility with local tradition at a material, volumetric, aesthetic, and comoposition level.*

	Material		Volume		Aesthetic		Composition	
Local tradition	5	33.3%	6	20.0%	4	26.7%	5	33.3%
Local reinterpreted tradition	8	53.3%	6	53.3%	5	33.3%	5	33.3%
Imported tradition	2	13.3%	1	6.7%	0	0%	0	0.0%
Imported reinterpreted tradition	0	0.0%	8	6.7%	2	13.3%	1	6.7%
Modern solution	0	0.0%	4	13.3%	4	26.7%	4	26.7%

Claddings (14.0%, Table 1) occupy the fourth position in terms of the frequency of intervention. Among these (Table 7) it is worth highlighting interventions in lime mortar renders (37.0%) and earth mortar renders (11.1%). As seen with the roofs, the frequency with which interventions are planned and similar techniques are used is relatively greater. However, there is a great predominance of the use of industrial materials such as cement mortar and plastic paints. These generally require the partial or complete replacement of existing render or the application of new render with the materials mentioned.

4. Earthen contemporary construction

Although the bibliographical review has covered the whole of Spain, it should first be noted that many of the examples identified are concentrated in the northeast of the country, particularly in Catalonia where 5 of the 15 cases documented are found. Equally, although the oldest project dates back to 2001, most were completed between 2010 and 2023. In terms of the compatibility of these new materials and local constructive tradition (Table 8), this is seen slightly more frequently in the aspects analysed which involve a degree of reinterpretation of local tradition or a direct replication of local tradition. However, in terms of the aesthetic and composition of openings the percentage of cases displaying modern language is relatively higher.

The use of earth in construction in contemporary residential buildings focuses on load-bearing walls, enclosures and partitions. Although in load-bearing walls there is a predominant use of rammed earth (7 cases), it is worth highlighting the greater use of compressed earth blocks or CEBs (6 cases) over that of adobes (2 cases) or heavyweight half-timber (2 cases). Both the CEBs and the rammed earth walls used show a degree of industrialization, given the use of cement in the case of the former and the use of pre-manufactured rammed earth blocks in the latter.

Equally, in enclosures with no structural function, rammed earth (5 cases) and CEBs (6 cases) have mostly been reported, although other examples can be found with heavyweight half-timber (2 cases) and adobe (1 case). In the case of partitions the use of CEBs (5 cases) is also frequently encountered, although there are also some documented examples of heavyweight half-timber (2 cases). However, the presence of other industrial techniques such as brick (2 cases) should also be noted.

While the use of industrial reinforced concrete (2 cases) and ceramic blocks (1 case) can be seen in some buildings for the execution of plinths and foundations, there is some concern for structural and material compatibility as reinforced lime concrete (5 cases) is used with different reinforcements solutions such as steel rods or bamboo.

In roof and floor structures it is common to use solid timber in correlation with traditional solutions, while vaults are also observed in a few cases.

5. Conclusions

The analysis conducted, based on 385 interventions documented in 70 historic residential buildings built with earth, shows a general tendency towards spontaneous interventions and the use of industrial materials, reflecting the risk to the conservation of this type of heritage. It is clearly revealed that load-bearing walls are the elements displaying the most interventions, followed by openings, roofs, and renders. A significant use of industrial materials is found in all cases, particularly when earthen elements are replaced with brick, concrete, or PVC, affecting technical and material compatibility with original structures.

Although the number of interventions which resort to similar traditional methods is limited, the use of these techniques in contemporary residential projects shows that these solutions are viable and to some degree compliant with current requirements. The analysis carried out on 15 contemporary buildings in Spain has highlighted the use as load-bearing walls, enclosures, and partitions. In this respect, the solutions documented show a degree of industrialization which offers better control of the properties of the material and a reduction in financial costs.

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