Examples of *bousillage* made with Spanish moss, golden broom, and *Posidonia oceanica* (credit: author, 2025).

Current relevance of the historic construction technique of *Bousillage* using Spanish moss, golden broom, and *Posidonia oceanica*

Ana Patricia Minguito García

Universidad Politécnica de Madrid, Department of Architectural Composition, Spain.
Email: ap.minguito@upm.es

Abstract: *Bousillage* is a traditional construction technique used to build vertical and horizontal enclosures in tropical, West European, and Mediterranean regions. It uses a timbered structure called *colombage* and a fibrous filler made from natural waste. This research paper confirms the current practice of this ancient technique by analyzing its structural, hydrothermal and environmental peculiarities through the examination of three persistent solutions that use golden broom, Spanish moss, and *Posidonia oceanica* as binders. The methodology begins with a theoretical framework that confirms the technique's historical roots according to context. Then, field and hygrothermal data is collected for each vegetal binder type. The main objective is to test the initial hypothesis that *bousillage* is a symbiotic construction method which creates a balance between nature and anthropocentrism in the local ecosystem—regardless of the plant waste used or the climatic context in which it is developed. The research results clarify that this environmental balance is achieved when waste discarded by nature is used as an active component in thermal building improvements. This benefits both the fauna and flora species, as well as anthropized neighborhoods. In conclusion, reviving this traditional technique in accordance with the current ecological situation, creates necessary anthroponatural interdependence for the long-term survival of the ecosystem.

Keywords: bioinsulation; framework; binder; filler; environment; balance.

Received: 27/06/2025; **Accepted:** 04/11/2025; **Available online:** 21/11/2025; **Published:** 31/12/2025.

Cite as: Minguito García, A.P. (2025). 'Current relevance of the historic construction technique of *Bousillage* using Spanish moss, golden broom, and *Posidonia oceanica*'. *VITRUVIO - International Journal of Architectural Technology and Sustainability*, *10*(2), e24209. https://doi.org/10.4995/vitruvio-ijats.2025.24209

1. Introduction

Bousillage is an ancient construction technique used in European and American cultures. It combines wood, mud, and plant waste from different ecosystems as a binding fiber to create thermal mass. Traditionally, the strength and insulation of building were increased by adding animal hair, lime residues from oyster shells, straw or hay. However, collecting and incorporating these materials became too labor-intensive to justify their systematic use, even though they substantially improve the thermal insulation of typical earthen walls (Parlato et al., 2022; Jové-Sandoval et al., 2023) (see Table 3).

The term "*bousillage*" first appeared in the French settlements of the Gulf of Mexico's in the early 17th century, as documented in the 1611 French-English dictionary (Blokker and Knight, 2009).[1] Though this technique took root in northern France and spread to the colonies, it was developed primarily in the Asturian mountain pastures for the past five centuries. (Graña Carcía and López Álvarez, 2007, pp. 213-215). There, it shaped the traditional image of shepherds' thatched-roof huts commonly known as *teitos*, which were made of golden broom (GB) (Figure 1). Centuries later, the *bousillage* technique arrived at the Acadian outposts in Nova Scotia, Canada. Here, people began using straw and hay as insulation fillers. This trend traveled along the U.S. East Coast to the Upper Mississippi Valley, where grass from swamps and marshes was used instead. Over time, the technique evolved to include an endemic epiphytic-bromeliad called Spanish moss (SM),[2] as a binder in Louisiana's architectural heritage (Mulcahy et al., 2016) (Figure 2). Returning to the Iberian Peninsula, the *bousillage* travelled across the Mediterranean coast and arrived at the Pitiusas archipelago (Ibiza and Formentera). In keeping with the idea of local reuse, *Posidonia oceanica* (PO) serves here as a binder (Figure 3).

Using these resources expelled from the nature as "secondhand" bioinsulating materials, helps restore the ecosystem balance in those areas with long periods of instability. Thus, a positive ecological footprint can be projected in the construction sector, one of the most disadvantaged fields of anthropization.

2. Historical framework

The technique's strength lies in its ability to adapt its construction methodology according to available resources in the surrounding. By maintaining only a common wooden structural framework, fillers from tropical forests, pastures or coastal dunes, can be used.

Pastoral colonization of the Asturian mountains dates back to the Neolithic period, reaching its peak in the 12th century, where *teitos* made of rye straw and GB became the typical structure for rural development in the Somiedo area and in the Ancares and Cabrera regions of León (Álvarez González, 2001; Graña Carcía and López Álvarez, 2007, pp. 92-155). The technique spread to southern France, where it became significant in Ardèche and Lozère since the 17th century (Menéndez, 2008). There, straw and animal hair were used to insulate roofs.

Although the exploration of North America began in the 16th century, the French did not establish a permanent settlement until the early 1600s. Imitating that construction method common in France at the time, the settlers took advantage of the local forests to extract wood for a hollow structural frame. They initially filled it only with mud to build the first colonies. However, in 1699, Jesuit priest Paul du Ru recorded that the indigenous people of the American Southeast's coastal region already used SM fibers to cover cracks in domestic buildings made with oak posts. This extraordinary record demonstrates two facts: firstly, it shows that the French were aware of this alternative practice; and secondly, that they applied this Native American knowledge correctly to improve their own mud constructions. Consequently, SM began to be used as a binder to fill the wooden framework (Reyna et al., 2022).

From then on, this improved indigenous recipe capable of withstanding hurricanes, became the standard construction method for French colonial, Creole, and Acadian buildings along the Gulf Coast (Fricker et al., 1998). In fact, it peaked in popularity in Louisiana, where over 100 well-documented *bousillage* constructions from the early 18th to the late 19th century still stand today (Blokker and Knight, 2013) (Figure 4).

This advancement in the *bousillage* traveled back to France, where animal hair and straw started to be mixed with mud in order to create sturdier enclosures. From there, the technique spread through the Pyrenees in the opposite direction to the mountain pastures of Asturias. Here, the roofs' *teitado* technique got also used to build walls, under the name of *cebatu*. This variant replaced the traditional stone walls of Pyrenean huts with an interwoven structure of hazel rods filled only by GB fibers. Over time, clay was added to increase strength and thermal mass (Wang et al., 2006) (see Table 3).

This trend also influenced the traditional construction on the Pitiusas Islands, making use of available Mediterranean resources (García-Andreu et al., 2008). From the 14th to the 19th century, PO became a potential material for covering fishermen's shelters to increase their insulation (Oliver et al., 2017). Note that PO is never mixed

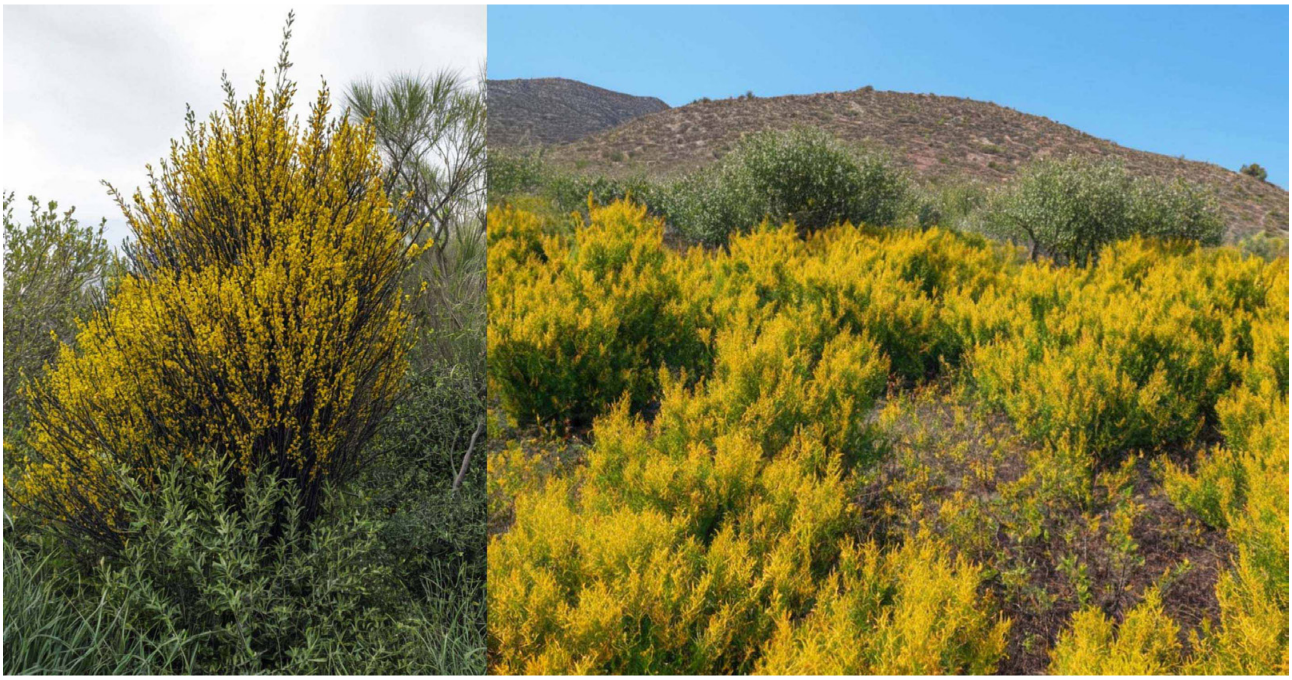

Figure 1 | GB on the border between Asturias and Galicia (credit: author, 2024).

Figure 2 | Oak trees covered by SM in Audubon Park, New Orleans (credit: author, 2023).

Figure 3 | Accumulation of PO along the coast of Menorca (credit: author, 2025).

with mud. Instead, it is compacted upon insertion into the timber substructure to achieve greater thermal behavior (Hamdaoui et al., 2018; Carmona et al., 2018).

Although these three types of *bousillage* fell out of favor when cheaper, easier-to-use materials became available, recent initiatives are gradually reviving the original construction method. The goal is to reestablish the symbiotic relationship that the technique fosters.

3. Relevance and contribution

This paper defends the hypothesis that the *bousillage* of SM, GB and PO creates an unusual environmental balance between nature and humans, taking advantage of local plant excess as an active component in building insulation. The objective is to evaluate its beneficial impact, based on the dynamic that no external agent alien to the ecosystem's original functioning is introduced; rather, natural dynamics are understood to adapt the construction process accordingly. Thus, the technique can be used anywhere, considering only different plant waste produced by each ecosystem to fill the timber framework. This finding lends credence to the notion of tangible circularity in the construction process, but in reverse order. Natural resources are no longer used in place of artificially manufactured ones, in order to reduce the carbon footprint. Conversely, waste produced by nature that disrupts the proper functioning of the ecosystem is used, not only to reduce the ecological impact but even to turn it into a positive one. Additionally, this comparative study highlights the maintenance of these three *bousillage* variants, since their hygrothermal performance achieves competitive market values—surpassing other current bioinsulations and matching those of artificial ones.

To consolidate this hypothesis, the three vegetal resources most used as binders in the history of *bousillage* are analyzed. Photographic reports from field visits to Louisiana, Asturias and the Mediterranean coast, as well as data research from specialized scientific sources are compiled to create analytical drawings that evaluate how the technique transforms itself to generate a positive impact to its respective environment. The results presented below show that, despite originating from different climates, those plant binders are reused according to common principles of circularity. In other words, the positive anthroponatural impact is produced by the implementation of the technique itself, regardless of the fibrous waste.

In addition, clarifying this *bousillage*'s contribution can promote its further development in other geographical contexts with similar conditions. And it could also serve as a reference point for reviving other traditional construction systems that are symbiotic to the environment.

4. Discussion of results

SM, GB, and PO exhibit sustainability dynamics that significantly impact three stages: their role as atmospheric regulators, their reutilization process that benefits nature by managing its waste, and their ability to achieve high hygrothermal behavior.

4.1. A unified environmental approach

In the American tropics, SM seeds are blown by the wind into cracks in oak tree bark, where they germinate. Then, they produce tiny tendrils that anchor it to the tree as it grows. These tendrils serve as a microhabitat for rat snakes, bats, and jumping spiders. The epiphytic-bromeliad produces its own food by capturing moisture and nutrients released from the dead cells of host trees. For this reason, it tends to develop on the bare branches of mature or slow-growing oak trees, which serve as scaffolding. Although SM does not appear to harm trees, it can accelerate their death by blocking sunlight from reaching their leaves (Figure 5).

In addition, its populations are highly vulnerable to changes in air composition. Indeed, the decline of SM in specific areas is indicative of elevated atmospheric acidity levels, which exceed the permissible limit of 0.05 µg/m^3 (Suriel, 2010; Sun et al., 2021). If harmful particles are released, the plant becomes dormant until conditions improve (Larson et al., 2004). Once the polluted episode ends, the plant reactivates and substantially increases its growth rate by 120% as a defense tool, becoming so thick that it hardly damages the tree's health—even fragmenting its branches. At this point, the SM begins to act as a parasite, posing a direct threat to the survival of the oak ecosystem. On the other hand, a natural benefit arises when humans control the plant's expansion by collecting samples from fatigued trees, as well as fallen remains caused by overloading.

Figure 4 | Original and current state of Beau Bassin House, built between 1765 and 1890 in Vermilion, Lafayette (credit: author, 2023).

GB is a characteristic plant of Asturias's meadows, but it is also a potentially invasive species. Their roots have nodules that convert nitrogen from the air into soil nutrients improving the quality of pastureland for livestock by 50-100 kgN/ha per year (Martínez-Cordeiro et al., 2014; Pérez-Fernández et al., 2016; Domínguez et al., 2018). However, excessive use of this fertilizer can damage crops due to the excessive release of polyphenols, which can be phytotoxic. Their rapid spread also threatens the survival of other local species such as exacerbated trees or rye straw, becoming meadows inaccessible to local wildlife. Along with the rural exodus and the Cantabrian deforestation caused by fire—which average 275 ha per year—the invasion of the GB has become a pressing problem.

Due to a decline in cultivated rye straw, the remaining pastures in Asturias only generate basic feed for livestock. There is no straw available for use as roofing material, as was done in the past. Consequently, GB has gradually replaced it, helping to mitigate the fire risk associated with

Figure 5 | Bare oak branches with a dense cover that hinders transpiration in the marshes of Avery Island, south Louisiana (credit: author, 2023).

its rapid growth. However, GB thatching is much more complex due to its irregular morphology. For this reason, the practice is declining in favor of using it in vertical enclosures, following the *cebatu* variation of *bousillage*.

Lastly, PO meadows play a fundamental role in the biological, geomorphological, and ecological regulatory processes of the Mediterranean Sea. They essentially act as CO_2 sinks and provide food for over 1500 species of fauna and flora (Concu and Pani, 2023). They also promote photosynthesis by fixing sediment, with a 20.3% reduction in hydrodynamic suspension and an 11.7% increase in deposition speed (Astudillo-Gutierrez et al., 2024).

In autumn, PO meadows undergo a process of natural exfoliation. The leaves turn dark and fall off, creating vegetal covers along the coast that act as a natural breakwater, stabilizing sandy substrates. However, the continuous influx of storms in recent years has created a surplus that the coast itself is finding increasingly difficult to manage. Since mollusks and crustaceans, such as *puu*, cannot use the leaves as a habitat due to their lack of seabed roots, the metabolic webs are altered. One way to address the surplus that disturbs the biological balance is to bury small quantities in order to enrich the soil of beaches and dunes. However, if the accumulation of dead PO exceeds 875 m^3/m of coastline, removal is necessary.[3]

In all three cases, the initial commensal relationship—in which the plant benefits the ecosystem—transforms into parasitism. Reading the dynamics of the environment and responding to its needs, means acting with ecological responsibility. It is not just a matter of removing the excess of SM that overwhelms trees, the uncontrollable proliferation of GB that destroys the meadows fertility, or the PO that collapses the coast. The challenge lies in reintroducing each vegetal waste into the local ecological and economic cycle by adapting cultural customs to climatic needs.

4.2. Same construction system

The *bousillage* technique is based on a combination of two elements: a wooden frame and a fiber binder. Using one plant or another does not substantially interfere with the construction process, although the pretreatments, mixtures, and assembly do impart certain peculiarities (Figure 6).

The first step is collecting the raw plant material that serves as the binder. This waste is treated using various processes before being incorporated into the wooden substructure.

Analysis of samples from old buildings in Vermilione, a town south of Lafayette, Louisiana (Figure 7), reveals the presence of untreated epiphyte outer bark (Figure 8). This suggests that the fibers were incorporated into the mud while still green; that is, they were collected directly from the ground after falling or from overburdened tree branches. While they do not require curing, cleaning is mandatory to eliminate chiggers and red bugs, which can decompose the structure.

Other studies reveal traces of a dark gray epiphyte, which results from the natural drying of SM (Blokker and Knight, 2009). This suggests that the fibers originate from residues that have accumulated over long periods of time under the tree canopy or from samples that were dried in the open air after cleaning.

The third option is to exhaustively cure the epiphyte by composting it.[4] SM used to be buried in a pit for 5 months to release excess water into the arid Louisiana soil and achieve optimal strength. Once the gray covering of the bromeliad dries completely, it falls off, revealing long, strong black filaments (Figure 9). After curing, unwanted materials, such as twigs, sand, leaves, and other debris, are removed using simple vibrating or sieving techniques.

According to the Breaux manuscript,[5] the cured strands of SM are then gently separated and placed in alternating layers with clay at the bottom of a hole, basin or *tâche*. Specialized workers called *tâcherons* or *tacherettes* mix the components by using a process similar to grape treading, until the consistency resembles mortar.

One of the most challenging aspects of the *bousillage* technique is to determinate the correct proportions that ensure enclosures optimal hygrothermal performance. Usually, vegetal fibers act as the solute, and the mud—which is made from a mixture of sand, clay, and water—acts as the solvent. If the mixture contains more than 20% water, it will not compact; and if it is too dry, the enclosure may crack (Blokker and Knight, 2009). Once the mixture

Table 1 | Two samples of insulation compositions made from SM mixed with mud (credit: author, 2025).

Volume	λ = 0.06 W/mK	λ = 0.146 W/mK
Fibers	83.46 %	45.69 %
Clay	3.24 %	10.99 %
Sand	7.57 %	24.85 %
Water	5.73 %	18.81 %

Table 2 | Two samples of insulation compositions made from GB mixed with mud (credit: author, 2025).

Volume	λ = 0.09 W/mK	λ = 0.11 W/mK
Fibers	88.80 %	79.40 %
Clay	2.55 %	4.04 %
Sand	5.94 %	9.43 %
Water	2.72 %	7.14 %

has the right consistency (Table 1) (Kain et al., 2021), a small portion is compacted by hand into a "*bousillage* loaf" or *torchis,* measuring 30-60 cm long, 10-20 cm wide, and 5-8 cm deep. These loaves are then placed between the holes of the timbered substructure (Blokker and Knight, 2013).

The GB must be cut at a specific time. Traditionally, it is collected in August, when high temperatures allow for 30% drier fibers (Menéndez, 2008). After harvesting, the material is separated into piles and sifted to remove impurities. Due to their biocidal nature susceptibility to decomposition in their raw state, fibers must be completely dried before being used as insulation. Otherwise, they can break and rot, harboring microorganisms that destroy the timber structure and cancel the thermal resistance. Once dry, thatchers called here *teiteros* or *teitadores* group the GB into bundles and place them on roofs. Alternatively, it can be compacted and inserted directly into the vertical enclosure's profile. Another option is to introduce the fibers as a binder for the mud used to fill walls. The appropriate proportions of the mixture are also achieved through a manual treading (Table 2) (Gaujena et al., 2020).[6]

Using PO as a binder offers a wider range of possibilities for manufacturing. It should be noted that the variant most used in traditional Balearic architecture incorporated dried PO directly, without mixing it with clay (Tugores and Morata, 2017).[7] The drying process is more complex due to the wet vegetal residue. When the leaves are collected, they are shaken or sieved to remove as much sand as possible so as not to alter the beaches composition (Hamdaoui et al., 2018). Then,

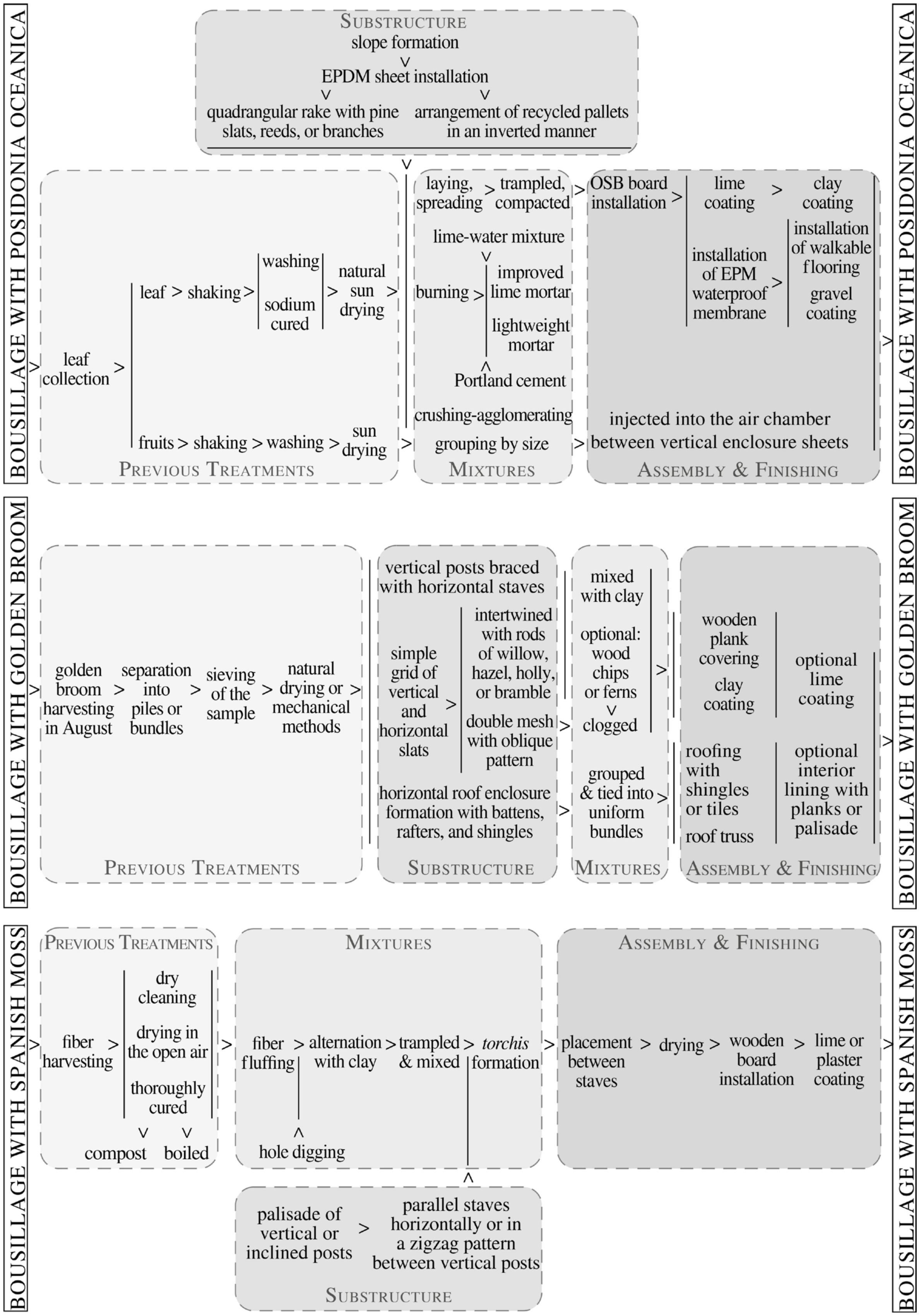

Figure 6 | Comparison of the construction sequence of the *bousillage* technique if SM, GB or PO is used as a binder for the insulating fill (credit: author, 2025).

Figure 7 | Interior walls made by *bousillage* of SM in the village of Vermilione (credit: author, 2023).

Figure 8 | X-ray of the wooden substructure with the insulating fill of mud and SM in Vermilione (credit: author, 2023).

Figure 9 | Samples of cured and dried SM fibers, with the respective mud mixtures for *bousillage* (credit: author, 2023)

they are washed with plain or distilled water to remove residue. In some cases, to eliminate salt crystals and improve the fibers' durability, the leaves are cured with a 2-6% sodium hydroxide solution (Concu and Pani, 2023). Finally, to completely dry the sheets, the material is spread in 5-10 mm thick layers and left out in the sun for a full day (Oliver et al., 2017). Once dry, leaves are confined within the wooden substructure

Table 3 | A comparison of thermal transmittance and density of natural and artificial insulations. * Indicates that auxiliar structure is required (credit: author, 2025).

Material	λ (W/mK)	ρ (kg/m³)
Adobe	0.40-1.00	600-1,900
Straw / hay*	0.04-0.08	60-200
Straw + mud*	0.05-0.15	50-450
Animal hair*	0.038-0.045	200-400
Animal hair + mud*	0.12-0.35	700-1,300
Oyster shells + mud*	0.20-0.60	300-600
Mortar	0.50-0.72	1000-1860
Sandstone	1.3-1.6	2300-2700
Limestone	1.1-1.5	2300-2700
Granite	2.0-2.8	2300-2700
SM*	0.036-0.046	40-140
SM + mud*	0.047-0.146	50-200
PO (leaves)*	0.041-0.055	170-215
PO (spheres)*	0.043	150-190
GB*	0.05-0.09	120-300
GB + mud*	0.09-0.11	120-300
Cork (panels)*	0.036-0.045	90-150
Hemp*	0.055-0.065	130-190
EPS	0.032-0.038	12-35
XPS	0.034-0.035	28-45
Mineral wool*	0.031-0.042	30-150
PU*	0.035-0.038	30-60

until the appropriate density is obtained—between 170-215 kg/m³ (Carmona et al., 2018). Nowadays, PO is also incinerated to reduce its volume and produce mortar. The Fraunhofer Institute for Building Physics in Munich has also patented a method of using shredded PO waste to manufacture wood-like agglomerates (García-Andreu et al., 2008)—as seen in the 14 multi-family dwellings built in Formentera by the IBAVI.

As a last resort, the fibrous fruit spheres of PO (Figure 10), can be used as insulating capsules by blowing them into wooden frameworks. Sea salt acts as a preservative and biocide, making these spheres rot-proof, non-flammable and capable of trapping air in their micro-structural cavities (Saval et al., 2014). This means that they do not require chemical treatments or additional curing in order to function properly as insulation. Note that using PO leaves or spheres as filler provides nearly the same hygrothermal insulation capacity, though the wall density is lower in the latter case (Table 3) (Hamdaoui et al., 2018; Carmona et al., 2018).

Figure 10 | Leaves and fruits of PO in Menorca (credit: author, 2025).

Mixing SM or GB fibers with mud improves the ductility, compression, and flexural behavior of the enclosure compared to traditional mortar paste (Allègue et al., 2014), stone walls or with other bioinsulations, such as cork or hemp (Silvestre et al., 2016; Gaujena et al., 2020) (see Table 3). In general terms, the mixture provides 20% greater thermal mass than conventional insulations, acting as a better natural passive heater and hygrothermal regulator.

The other main component of *bousillage* technique is the structural framework that holds the filling in place. In the studied contexts of Louisiana, Asturias, and the Pitiusas, wood is the only locally available, sustainable material that can be reused for this purpose. Its layout traditionally differs depending on the type of plant waste. GB can be used for any kind of enclosure, while SM is inserted in vertical structures, and PO is placed on floors or roofs.

The name given to the *bousillage* timbered substructure is *colombage*. It involves vertical posts spaced 61-91 cm, and staves placed at intervals of 10-20 cm to support the infill material (Figure 11) (Fricker et al., 1998). The staves are trapezoidal in cross-section, 2–5 cm thick, and wedge-shaped ends to fit in a staggered pattern at the posts without nails (Blokker and Knight, 2009). In the GB *cebatu*, hazel twigs are woven into the posts instead of staves (Figure 12). The gaps in the colombage are filled from the bottom up (Figures 13-14). The wall takes shape as the "*bousillage* loaves" are tightly packed

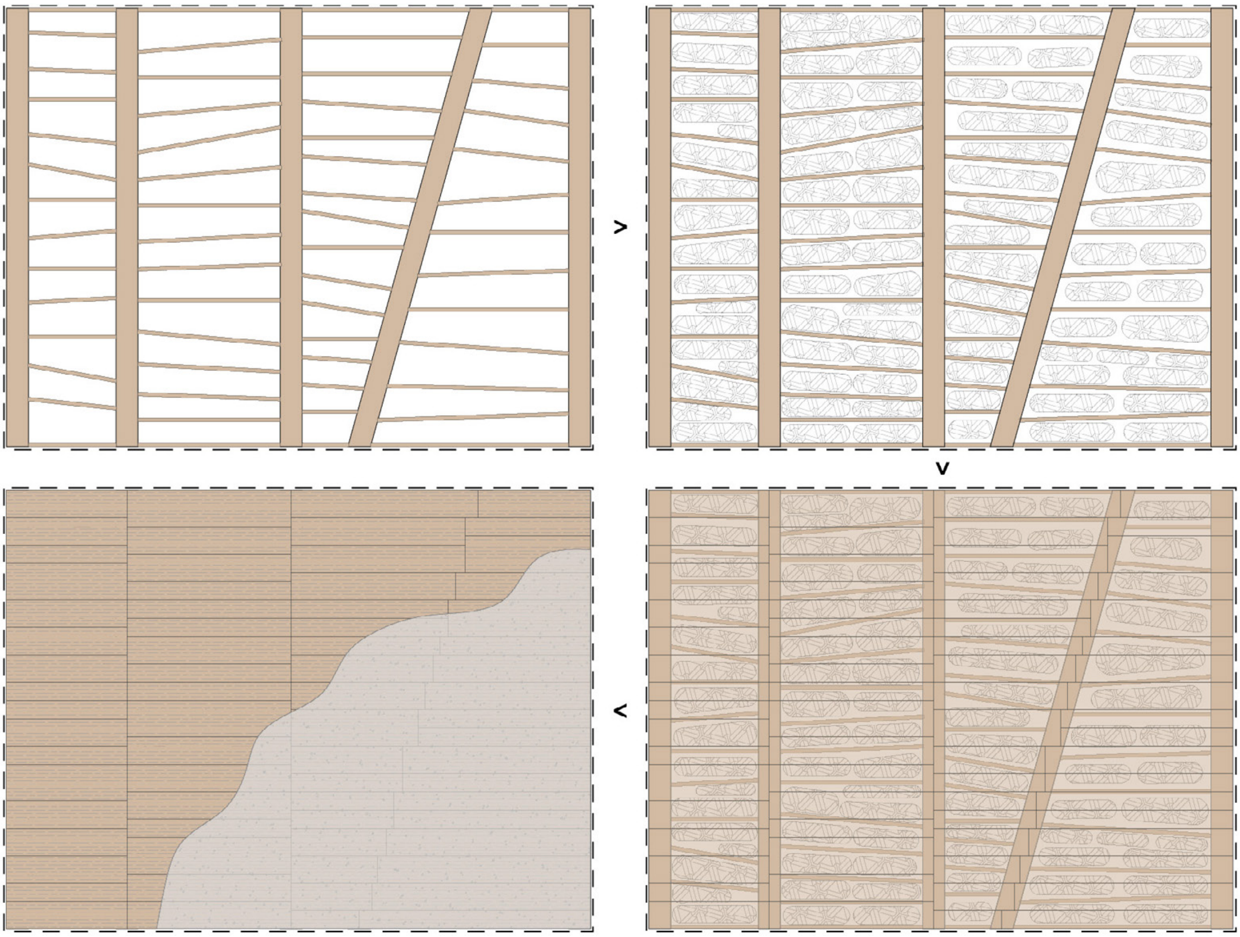

Figure 11 | Construction sequence of a vertical *bousillage* with SM: *colombage* of wooden posts and staves; placement of *torchis*; closure with wooden boards; and coating with plaster or lime (credit: author, 2025).

together. Each wall must dry completely for 2-4 months. Then, wooden boards are placed on both sides to form a kind of "box", that is protected by lime plaster, reaching a thickness of 50 cm.

Conversely, the *bousillage* technique for horizontal enclosures simplifies the *colombage* structure. Only a 2×2 m^2 framework made of pine wood, reeds, or branches is needed. If it is configured using pallets (Oliver et al., 2017), dismantling the structure is unnecessary, as they can be placed upside down to receive the infill material (Figure 15).

Dry PO is usually spread at a rate of 20 kg/m^2 to achieve a total thickness of 16 cm. The plant fibers are compacted by foot until it reaches an average density of 185 kg/m^3. Once completed, the enclosure is covered with wooden boards, such as OSB-III. The roof is finished with a 20 cm layer of lime plaster and a 10 cm of clay (Figure 16). The lime absorbs water from leaks, while the vegetable filling insulates and allows air vapor to pass in both directions, maintaining the interior hygrothermal balance (Table 4) (Oliver et al., 2017); Giada et al., 2019).[8]

Table 4 | Moisture absorption or EMC percentages of the envelope according to the type of fiber and the ambient humidity (credit: author, 2025).

Humidity	50%	95%
SM (0.04 W/mK, 50 kg/m^3)	8-15%	20-40%
SM + mud (0.12 W/mK, 125 kg/m^3)	10-25%	30-60%
PO (0.044 W/mK, 185 kg/^{m3})	7-12%	18-28%
GB (0.07 W/mK, 125 kg/m^3)	7-14%	18-35%
GB + mud (0.10 W/mK, 210 kg/m^3)	10-30%	30-60%

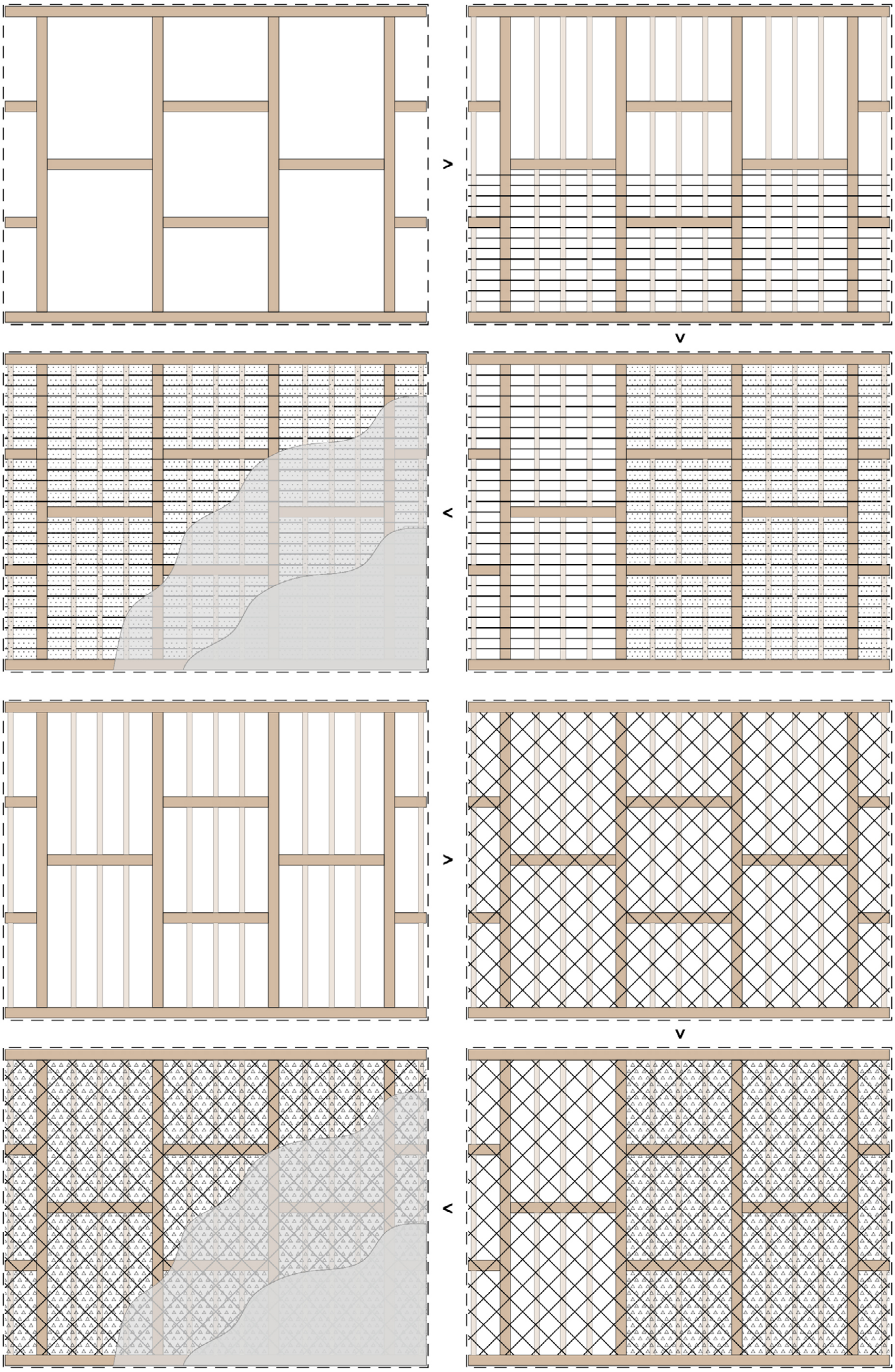

Figure 12 | Alternatives for constructing a vertical *bousillage* with GB: *colombage* of wooden posts and, eventually, staves; two variations of interwoven hazel twigs; placement of the mixture of mud and fibers; and coating with wooden boards, plaster or lime (credit: author, 2025).

Figure 13 | Analytical diagram of an enclosure made with mud and SM: vertical or diagonal wooden posts (1) and transverse staves (2) to assemble the *colombage* structure, and *torchis* (3) as insulating filler (credit: author, 2025).

Figure 14 | Vertical GB enclosure made by a timbered frame (1), wooden posts (2), hazel twigs interwoven (3), plant fibers mixed with mud (4), and clay coating (5) (credit: author, 2025).

Figure 15 | Analytical diagrams of a roof enclosure: structure of recycled pallets or wooden slats (1), filling with PO (2), after forming slopes (3) and waterproofing (4) (credit: author, 2025).

Both vertical and horizontal arrangements have a layered composition, all with the common goal of forming a "*bousillage* box". Therefore, it is reasonable to assume that these boxes made on site can also be industrialized. This would initiate an alternative prefabrication process, speed up roof construction and open new prospects.

5. Conclusions for future dynamics

This review of the *bousillage* technique in three contrasting climatic contexts reveals that due to its positive ecological footprint, this practice can be further developed today. The key to its success lies in introducing this construction dynamic as an additional element within the ecosystem's web of relationships. At the same time, the conditions of home comfort can be improved by collecting waste that nature discards.

The comparative study concluded that SM *bousillage* achieves the best thermal performance without the need for mud (0.04 W/mK). However, mixing is

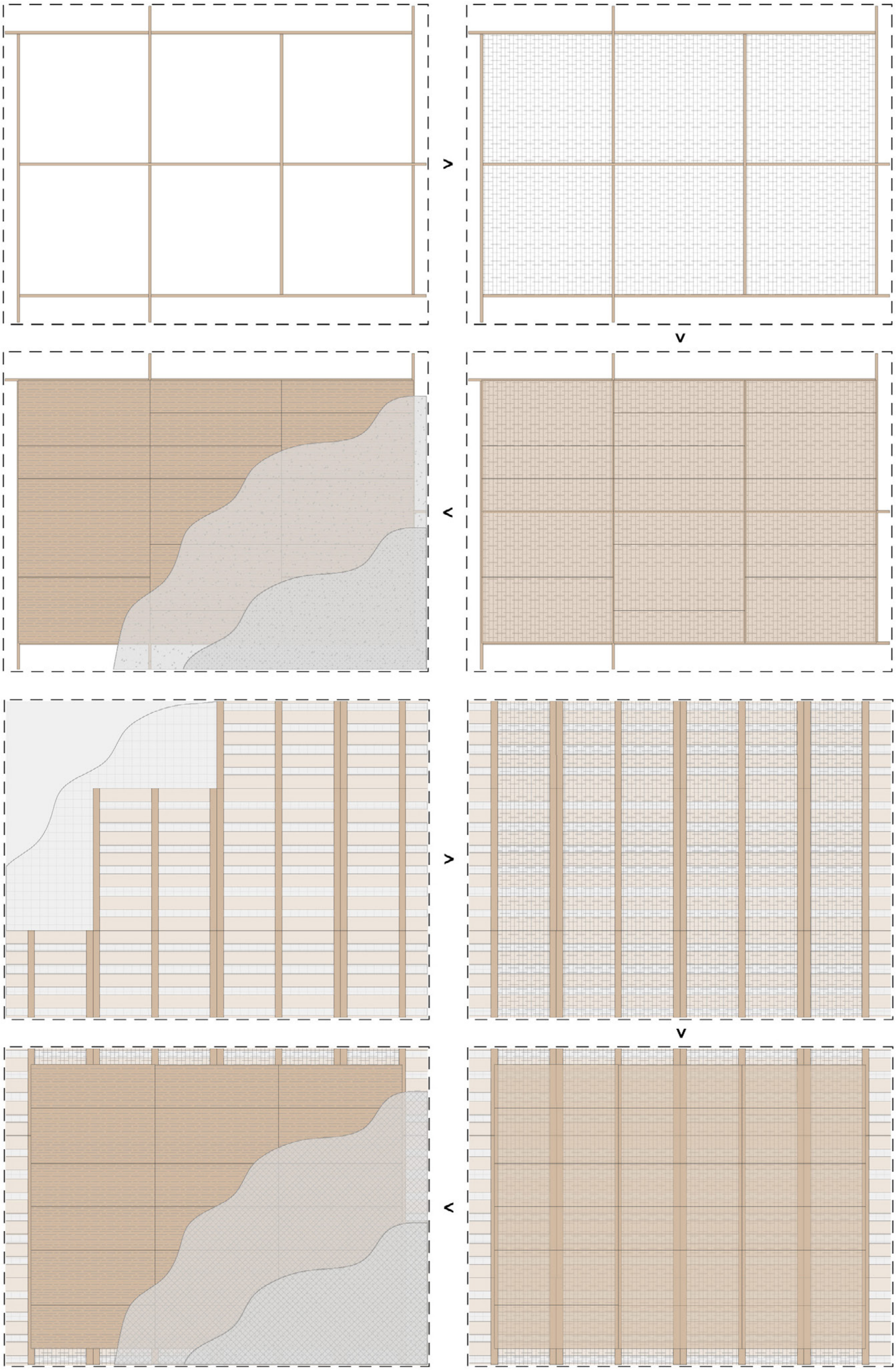

Figure 16 | Alternatives for constructing a roof using PO: square colombage or inverted pallets on a waterproof sheet after forming slopes; placement of fibers; closure of the “bousillage box” with wooden boards; coating with lime and clay or geotextile and gravel (credit: author, 2025).

recommended to facilitate assembly and improve hygrothermal behavior (from 9.5 % to 23 % of absorption). It also increases the enclosure's durability by 5.6 times (Mclaughlin et al., 2016), since it reduces open porosity, controls moisture permeability and limits access by insects and fungi that accelerate biodegradation. It is also worth noting the similar values achieved in roof insulation with pressed PO, whether using dry leaves or fruit spheres (average rate of 0.044 W/ mK). In this case, it is not mixed with clay to reduce the roof's weight further.

Both cases coincide with the thermal transmittance values obtained from enclosures made of agglomerated cork panels (0.042 W/mK). These numbers are also close to the average thermal performance of artificial mineral wool or PU (0.037 W/mK). While they differ from the insulation values achieved by synthetic EPS and XPS panels (0.035 W/mK), using natural fibers from local ecosystem waste produces a carbon footprint of only 0.30-1 $kgCO_2e/m^2$—compared to 1.7-2 $kgCO_2e/m^2$ for conventional materials (Ye et al., 2025). Although the GB *bousillage*'s hydrothermal resistance values are not particularly impressive, the conclusion remains the same in all three cases: restoring ecosystem balance is more worthwhile than investing in a distant chemical industry.

Nevertheless, it is important to be aware of the limitations of the technique. The *bousillage* is developed because there is a surplus of waste that is no longer needed by the ecosystem to thrive. If this surplus does not exist, the technique fails as a sustainable construction process. Continuing to use the material would not give new life to waste but rather consume the natural resources that stabilize the ecosystem. Consequently, metabolic rhythms would be altered, creating a new negative impact. Therefore, the *bousillage* must align with the rhythms of nature's surplus production. Extraction should cease when there is no excess, requiring thorough construction planning that can adapt to it. Finally, new specific legislation is also needed to regulate the removal of plant fibers from their natural context, based on determining when they no longer qualify as waste.[9]

In conclusion, a small paradigm shift could lead to a model of responsible architecture that addresses environmental concerns and cultural traditions. Incorporating the environmental variable into anthropocentric construction processes can positively improve landscape quality and building comfort conditions through a simple one-time action.

Acknowledgments

This work was carried out within the framework of the 'Programa Propio I+D+I' of the Universidad Politécnica de Madrid (UPM).

Notes

1 Reference to the book *A Dictionarie of the French and English Tongues* written by Randle Cotgrave in 1611. Here, *bousillage* appears linked to the verb *bousillé* or *bouzillé*, which literally means to smear or "fill with manure."

2 Its long, curly, gray strands resemble the traditional image of "old men's beards." In an attempt to mock the Spanish during the dispute over the occupation of Louisiana, French settlers named the species "Spanish moss."

3 In April 2020, the "Consell Insular de Formentera" registered that 5,000 m^3 of PO and 11.48 tons of commercial pallets were collected from Formentera's beaches. Using both materials in construction projects creates a win-win situation: discarded natural resources and anthropogenic waste are given a second life.

4 According to experts Blokker and Knight, while curing was likely not part of early *bousillage*, it emerged alongside industrial mechanization in the late 19th century, due to its ability to enhance strength (Blokker, 2009). Contemporary restoration methods recommend boiling the vegetal fibers to substantially improve performance in a 118% (Holliday, 2009).

5 Acadian historical narrative written between 1840-1901 that details the traditional manufacturing process of *bousillage* using SM.

6 Since there are no empirical studies assessing the hygrothermal behavior of GB insulation, values obtained from hemp fiber studies are used as references, which are then weighed according to the Maxwell–Eucken model.

7 According to historians Tugores and Morata, dried PO was used in La Sapiència's coffered ceilings, which were built in Palma in the 14th century, in order to protect the structure from moisture and wood-eating insects.

8 Today, this assembly is reinforced by placing the substructure on top of a layer of concrete covered by an EPDM sheet. Additionally, the final lime-clay finish is replaced with a geotextile attached to the waterproof sheet to secure the enclosure. Stone slabs are typically used on accessible roofs and recycled gravel on inaccessible ones.

9 Initiatives such as "Respect Your Capital", "Beached PO from Problem to Resource," "Sea-Matter" and "Life Reusing PO" are worth mentioning. SM *bousillage* has a growing support network funded by universities of Florida and Texas, as well as private companies that continue to innovate the traditional method by restoring historic buildings in Louisiana.

References

Allègue, L., Zidi, M., & Sghaier, S. (2014). Mechanical properties of *Posidonia oceanica* fibers reinforced cement. *Journal of Composite Materials, 49*(5), 509-517. https://doi.org/10.1177/0021998314521254

Álvarez González, M. (2001). *El teito de escoba en Somiedo*. Colegio Oficial de Aparejadores y Arquitectos Técnicos del Principado de Asturias, Oviedo, España.

Astudillo-Gutierrez, C., Cáceres, I., Gracia, V., Sierra, J.P., & Sánchez-Arcilla, A. (2024). Study of Velocity Changes Induced by Posidonia oceanica Surrogate and Sediment Transport Implications. *Journal of Marine Science and Engineering, 12*(4), 569. https://doi.org/10.3390/jmse12040569

Blokker, L.E., & Knight, H.A. (2009). *Louisiana's Bousillage Tradition: Investigation of Past Techniques for Future Practice*. The James Marston Fitch Charitable Foundation [WWW document]. URL https://fitchfoundation.org/wp-content/uploads/2017/05/FITCH_Blokker-Knight_final_web.pdf (accessed 18 mayo 2023)

Blokker, L.E. (2009). Building with Bousillage: Perpetuation of a Construction Tradition in Louisiana. *ARRIS: Journal of the Southeast Chapter of the Society of Architectural Historians 20*, 44-63. https://doi.org/10.1353/arr.2009.0003

Blokker, L.E., & Knight, H.A. (2013). Louisiana Bousillage: The Migration and Evolution of a French Building Technique in North America. *Construction History, 28*, 27-48.

Carmona, C., Horrach, G., Oliver, C., Forteza, F.J., & Muñoz, J. (2018). *Posidonia oceanica* as thermal insulation. *Revista de la construcción, 17*(2), 250-257. https://doi.org/10.7764/RDLC.17.2.250

Concu, G., & Pani, L. (2023). Recycling of Beached *Posidonia oceanica* in the Construction Sector. Computational Science and Its Applications – *ICCSA 2023 Workshops* 14110, 391–403. https://doi.org/10.1007/978-3-031-37123-3_28

Domínguez, J., Gómez-Brandón, M., Martínez-Cordeiro, H., & Lores, M. (2018). Bioconversion of Scotch broom into a high-quality organic fertiliser: Vermicomposting as a sustainable option. *Waste Management & Research, 36*(11), 1092–1099. https://doi.org/10.1177/0734242X18797176

Fricker, J., Fricker, D., & Duncan, P.L. (1998). *Louisiana Architecture: A Handbook on Styles*. University of Louisiana at Lafayette Press, USA.

García-Andreu, C., Saval, J.M., Frías, M., & Chinchón, S. (2008). Caracterización de las cenizas de Posidonia oceánica para su utilización como material de construcción. *Ingeniería Civil, 149*, 131-140.

Gaujena, B., Agapovs, V., Borodinecs, A., & Strelets, K. (2020). Analysis of Thermal Parameters of Hemp Fiber Insulation. *Energies, 13*(23), 6385. https://doi.org/10.3390/en13236385

Giada, G., Caponetto, R., & Nocera, F. (2019). Hygrothermal properties of raw earth materials: A literature review. *Sustainability, 11*, 5342. https://doi.org/10.3390/su11195342

Graña García, A., & López Álvarez, J. (2007). *Los teitos en Asturias. Un estudio sobre la arquitectura con cubierta vegetal* (Serie Mayor 1). Red de Museos Etnográficos de Asturias.

Hamdaoui, O., Ibos, L., Mazioud, A., Safi, M., & Limam, O. (2018). Thermophysical characterization of *Posidonia oceanica* marine fibers intended to be used as an insulation material in Mediterranean buildings. *Construction and Building Materials, 180*(20), 68–76. https://doi.org/10.1016/j.conbuildmat.2018.05.195

Holliday, K. (2009). Whose city hall is it? Architecture and identity in New Orleans. *Journal of Urban Design, 14*(3), 279–308. https://doi.org/10.1080/13574800903056499

Jové-Sandoval, F., García-Baños, E.M., & Barbero-Barrera, M.M. (2023). Characterisation and thermal improvement of adobe walls from earth-straw lightweight panels. *MRS Advances, 9*, 71–77. https://doi.org/10.1557/s43580-023-00630-1

Kain, G., Morandini, M., Stamminger, A., Granig, T., Tudor, E. M., Schnabel, T., & Petutschnigg, A. (2021). Production and physical–mechanical characterization of peat moss (*Sphagnum*) insulation panels. *Materials, 14*(21), 6601. https://doi.org/10.3390/ma14216601

Larson, B. C., Frank, J. H., Main, M. B., & Allen, G. M. (2004). Florida's native bromeliads (CIR 1466). *Wildlife Ecology and Conservation* Department Publications. https://doi.org/10.32473/edis-uw205-2004

Martínez-Cordeiro, H., Pájaro Varela, M., García-Jares, C., Lores, M., & Domínguez, J. (2014). Conversión acelerada de retama negra (*Cytisus scoparius*) en un biofertilizante de calidad mediante vermicompostaje. *Recursos Rurais, 10*, 23–31.

Mclaughlin, C., Adderley, W. P., Kennedy, C., & Alick, L. (2016). Management of Louisiana's historic bousillage buildings. In T. Joffroy, H. Guillard, & C. Sadozaï (Eds.), *Terra Lyon 2016*. CRAterre.

Menéndez, C.O. (2008). *Teitos. Cubiertas vegetales de Europa Occidental: de Asturias a Islandia*. Colegio Oficial de Aparejadores y Arquitectos Técnicos del Principado de Asturias, Oviedo, España.

Mulcahy, K. V., Naquin, T. C., & Harper, J. N. (2016). Cajun Louisiana: Culture as a way of life. *The Journal of Arts Management, Law and Society, 49*(1), 14–29. https://doi.org/10.1080/10632921.2018.1461723

Oliver, C., Martín, A., & Moyá, J. (2017). *Life Reusing Posidonia*. Institut Balear de l'Habitatge (IBAVI), Palma, Islas Baleares, España.

Parlato, M. C. M., Cuomo, M., & Porto, S. M. C. (2022). Natural fibers reinforcement for earthen building components: Mechanical performances of a low quality sheep wool. *Construction and Building Materials, 326*, 126855. https://doi.org/10.1016/j.conbuildmat.2022.126855

Pérez-Fernández, M., Calvo-Magro, E., & Valentine, A. (2016). Benefits of the symbiotic association of shrubby legumes for the rehabilitation of degraded soils under Mediterranean climatic conditions. *Land Degradation & Development, 27*, 395–405. https://doi.org/10.1002/ldr.2457

Reyna, C., Gómez-Soberón, J. M., & Rojas-Valencia, M. N. (2022). Let's talk about construction traditions in Louisiana that tap into earthen architecture. In *Earth USA Conference in Santa Fe*. New Mexico, USA.

Saval, J. M., Lapuente, R., Navarro, V., & Tenza-Abril, A. J. (2014). Fire-resistance, physical, and mechanical characterization of particleboard containing Oceanic Posidonia waste. *Materiales de Construcción, 64*(314), e019. https://doi.org/10.3989/mc.2014.01413

Silvestre, J. D., Pargana, N., Brito, J., Pinheiro, M. D., & Durao, V. (2016). Insulation cork boards—Environmental life cycle assessment of an organic construction material. *Materials, 9*(5), 394. https://doi.org/10.3390/ma9050394

Sun, X., Li, P., & Zheng, G. (2021). Biomarker responses of Spanish moss *Tillandsia usneoides* to atmospheric Hg and hormesis in this species. *Frontiers in Plant Science, 12*, 625799. https://doi.org/10.3389/fpls.2021.625799

Suriel, R.L. (2010). Spanish Moss: Not Just Hanging in There. *Science Activities, 47*, 133–140. https://doi.org/10.1080/00368121003739398.

Tugores, F., & Morata, J. (2017). *Pintures murals a l'àmbit civil a Mallorca (s. XIII - XV). 146 casos i una classificació*. Universitat de les Illes Balears.

Wang, J., Carson, J. K., North, M. F., & Cleland, D. J. (2006). A new approach to modelling the effective thermal conductivity of heterogeneous materials. *International Journal of Heat and Mass Transfer, 49*(17–18), 3075–3083. https://doi.org/10.1016/j.ijheatmasstransfer.2006.02.007

Ye, F., Wei, H., Xiao, Y., Berardi, U., Quaranta, G., & Demartina, C. (2025). Bio-based insulation materials in sustainable constructions: A review of environmental, thermal and acoustic insulation, durability, and mechanical performances. *Renewable and Sustainable Energy Reviews, 223*, 115872. https://doi.org/10.1016/j.rser.2025.115872