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Research Article

Micromorphological description of vernacular cob process and comparison with rammed earth

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Abstract Past builders have developed very low-embodied energy construction techniques optimizing the use of local building materials. These techniques are a source of inspiration for modern sustainable building. Unfortunately, this know-how was orally transmitted and was lost as earth construction fell into disuse during the 20th century in European countries. The absence of written documents makes necessary to use an archaeological approach in order to rediscover these construction strategies. Micromorphological analysis of thin sections collected in earth building walls was used for the first time to describe cob construction technique and highlighted several typical pedofeatures allowing to clearly identifying this process. Finally, a first comparison of the cob and rammed earth micromorphological features permitted to identify two key factors to distinguish these two techniques, the manufacturing state (solid or plastic) and the organization of the material in the wall.

1. Introduction

The need to save resources and energy for housing has led to a renewed interest in construction using locally sourced and low embodied energy building materials. Raw (unfired and unstable) earth is part of those materials (Floissac et al., 2009; Habert et al., 2010; Habert et al., 2012; Morel et al., 2001). The construction strategies developed

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by past builders are dictated by the quality and amount of locally available construction materials. These resource constraints, combined with inhabitant needs, engender local constructive cultures and change over time to adopt to society evolutions (Akinwumi, 2014; Fodde, 2009; Jaquin et al., 2008; Hamard et al., 2016a). The late 19th and early 20th-century heritage buildings in the Western European countries are the outcome of such evolutions. Local constructive cultures are a source of inspiration for modern sustainable building design (Ferrigni et al., 2005).

The cob technique is popular in Western France. This process involves the production of earth elements in plastic state, which are applied wet and stacked to build a monolithic and load-bearing or freestanding wall (Hamard et al., 2016a). The cob building process involves four steps: (1) raw material supply and preparation, (2) mixing, (3) implementation, and (4) wall rectification and drying (Hamard et al., 2016a). In the past, masons employed a large diversity of strategies at each stage of the cob process, and cob processes had hundreds of variations (Hamard et al., 2016a).

Rammed earth is described as the manufacturing of earth, that is, slightly wet and tamped in a formwork using a wood rammer. Earth is placed by layers of 10—15 cm inside a shuttering. Each layer is spread by foot and then tamped using a rammer with a pointed edge. After compaction, the rammed earth layers are 6—10 cm-thick. Once all layers inside a shuttering are compacted, the formwork is moved horizontally to proceed with the construction of the wall. After completing a level, which is called a "lift," the shuttering is moved vertically for a new lift (Hamard et al., 2016b).

A large part of the diversity of the know-how transmitted orally for centuries in European countries was lost as earth construction fell into disuse during the 20th century (Watson and McCabe, 2011; Hamard et al., 2016a). The information that survived was derived from the testimonies of past builders. Nevertheless, these testimonies are only a small sample of traditional earth building knowledge. The absence of written documents necessitates the use of an archaeological approach to rediscover these construction strategies and optimize the use of local building materials.

From an architectural and historical point of view, this knowledge enables us to follow the evolution and spread of earth construction processes. From a technical perspective, this knowledge can provide precious information for heritage maintenance and help rediscover the solutions employed by past builders to overcome obstacles that are still relevant, such as the influence of soil, geography, geology, and climate on construction process choices. The knowledge gained will help promote the use of locally available materials to boost the circular economy of the building sector.

Given the absence of suitable methodologies, the goal of this work is to explore a rational methodology based on the micromorphology analysis of samples collected in earth heritage buildings to rediscover traditional earth construction processes. Micromorphology is derived from pedology (Fedoroff, 1979). For archaeological building materials, micromorphology studies give access to features resulting from mechanisms that can reveal the elementary steps of the construction process (Wattez, 2003; Gé et al., 1993; Cammas, 2003). These studies help identify the building construction techniques used by Neolithic (Wattez, 2003) to Roman or even 17th-century buildings (Cammas, 2003).

The same methodology, based on the micromorphological analysis of thin sections, has been successfully used by the authors for rammed earth (Hamard et al., 2016b). In this work, this methodology is extended to the cob. This work also presents some of the results obtained in the context of a PhD thesis (Hamard, 2017). This paper aims to address the relevance of this approach to identify the micromorphological features resulting from the cob process. The results are then compared with rammed earth to propose the micromorphological criteria for earth building process identification. Rammed earth and cob are both monolithic wall building techniques. Distinguishing one process from the other is sometimes difficult, especially in the archaeological context. Under these circumstances, whether micromorphological analysis is suitable for distinguishing which cob technique was employed in a heritage building is interesting to know.

2. Materials and methods

2.1. Study area

The partial destruction of a barn located in the locality of La Poterne in the city of Saint-Gilles (Brittany, France) (Fig. 1) enabled us to collect cob specimens from a cob wall. The cob barn is a single-story floor building that is 3 m high, 20 m long, and 8 m wide. Its general orientation is north—south. Three different construction phases can be distinguished. The first one is evident in the Napoleonian land register (early 19th century). The two other phases date back to the beginning of the 20th century. This type of building, which is made of several extensions, is typical of the architectural heritage of Brittany. Specimens were collected from the south-facing wall made during the second phase. The barn is located on a plateau bounded in north—west and south—west by the Mares Noires river and on the south—east by a dry valley. The soil of the plateau developed on the Pleistocene loess, lying on the Brioverian alternations of silts, clays, and gravels (Outin and Thomas, 1999; BRGM, n.d.) (Fig. 1). According to the soil map of Brittany (Lemercier et al., 2015), the soil of the La Poterne locality comes from shales or silts and is characterized by low argilluviation and variable waterlogging rates (soil map unit 12025; Lemercier et al., 2015). The topographical position (plateau) and the bedrock composition (loess) allow identification of the soil type of the locality as a Neoluvisol, according to French soil classification (Baize and Girard, 2008). This finding corresponds to Luvic Cambisol in the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014).

2.2. Sample production

Three construction stages are recognizable in the cob barn (Fig. 2). For accessibility, the samples were collected in the middle part of the barn. Before demolition, several portions of approximately 50 cm × 50 cm × 20 cm of the same

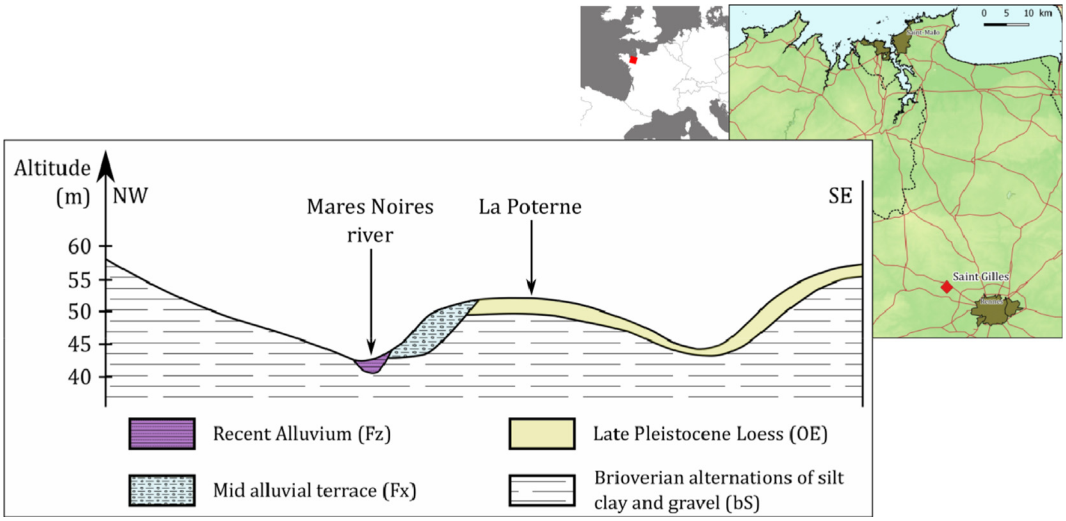

Fig. 1 Location map of Saint Gilles (Brittany, France) and geological cross-section of the locality of "La Poterne" in Saint Gilles.

lift of the wall facing west were cut using a rock chainsaw and brought back to the laboratory (Fig. 2). From those portions of the wall, smaller undisturbed samples were collected for earth identification and thin-section manufacturing. For identification, the particle size distribution was determined following French standards NF P 94 056 and NF P 94 057 (AFNOR, 1996, 1992), and the methylene blue value was according to French standard NF P 94 068 (AFNOR, 1998).

The specimens for thin-section production were cut using a table saw. These samples were air dried before drying them in an oven at 45 °C. This temperature minimizes the changes in the mineral structure of the clay and the organic matter of the material. According to the

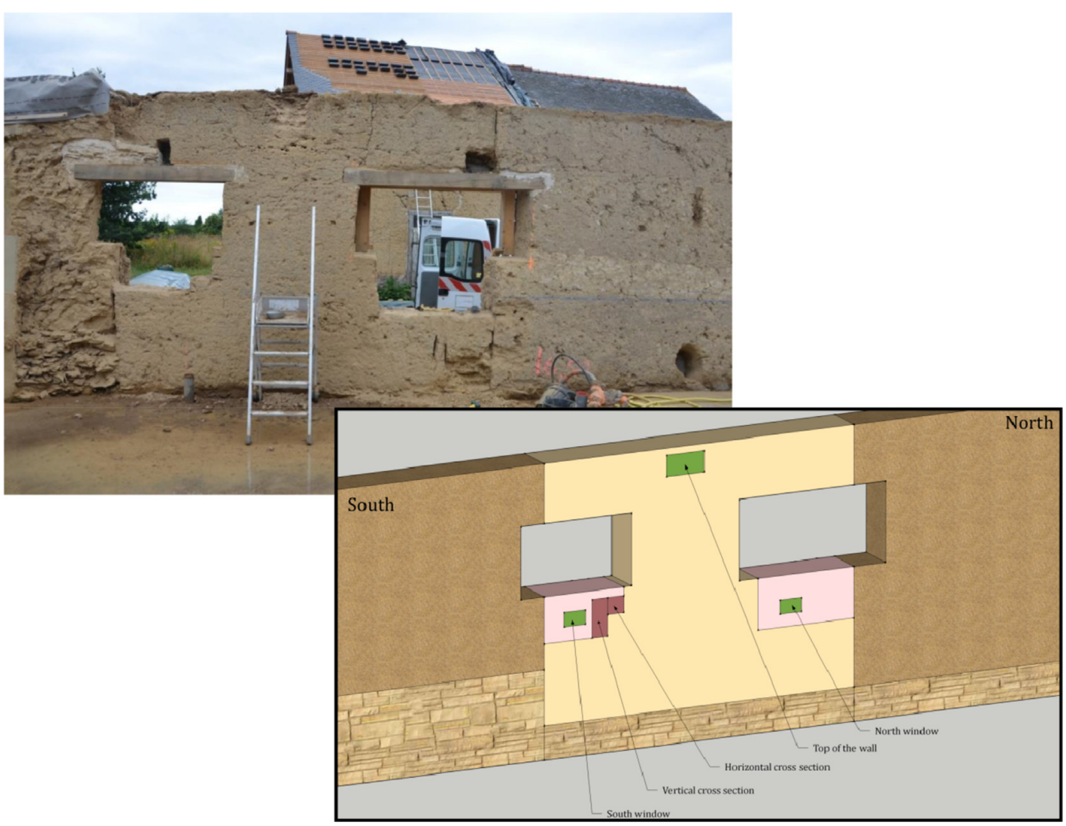

Fig. 2 View of the three different construction stages (North, middle and South) identified in the wall, seen from the inside of the building. Sampling concerned the middle stage (yellow): pink parts were collected, with particular samples for thin sections (red) and material identification (green).

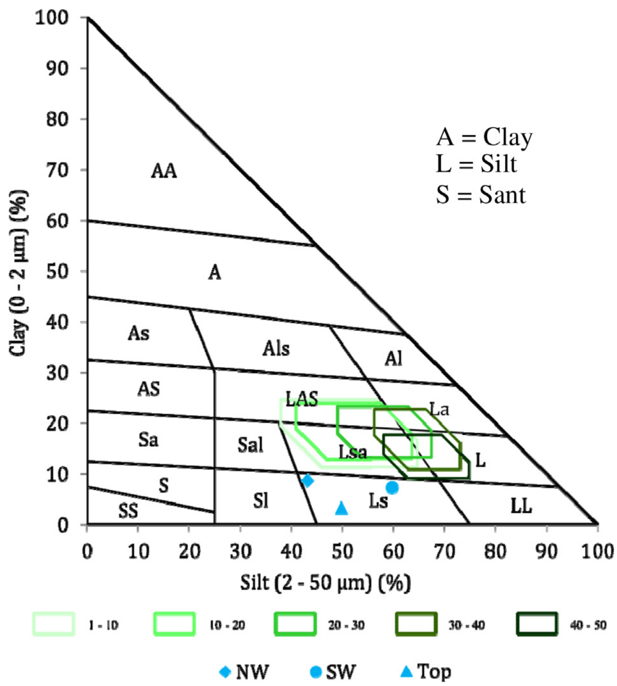

Fig. 3 Texture of material collected in north window (NW), south window (SW) and top of the wall (Top) compared with texture of cob frequency classes (1%–10% to 40%–50% of building heritage) after (Hamard et al., 2018).

protocol proposed by Guilloré (1985), the samples were soaked with synthetic resin. After polymerization for one or two months, a slab of the sample was cut. This slab was temporarily glued to a glass slide. The unattached face of the slab was levelled, ground, and glued definitively on another glass slide. The temporary glass slide was removed, and the specimen was grounded to 25 µm. This value is the reference thickness for micromorphological and geological analyses and for which the transparent observation of the thin section is possible under plane polarized light, crossed polarized light, oblique incident light, and ultraviolet fluorescence (Stoops, 2003). Finally, a thin glass slide was glued on the second face to protect the thin section.

2.3. Analysis

A cubic wall specimen was cut, and its faces were water-sprayed to highlight the macrostructural organization of the cob wall by the naked eye.

Thin section descriptions were performed according to Bullock et al. (1985) and Stoops (2003) with the help of Mackenzie and Guilford (1980) and Delvigne (1998) for petrographical description. The abundance of components was evaluated with abundance charts and description terms (Bullock et al., 1985; Stoops et al., 2010). The specific description terms defined in a previous study (Bullock et al., 1985; Stoops, 2003) and used in the description section of this paper are italicized in the text. These references provide a system of analysis and description of soil thin-sections. The indicators selected for the analysis were as follows: (1) groundmass, referring to the coarse and/or fine material that forms the base material of a thin section; (2) microstructure, referring to the spatial arrangement of mineral and organic particles and of voids; (3) fabric, referring to the arrangement of the fine fraction and the preferential orientations of coarse material; (4) inclusions, referring to sporadic allochthonous elements; and (5) limits, referring to soil discontinuities. To limit biases related to observer interpretation, the micromorphological description was made by two different observers in two different laboratories. The micromorphological description presented here is the result of this double checking.

3. Results

3.1. Texture and macroscale characteristics

The texture of materials collected in the north and south windows and at top of the wall (Fig. 2) is presented in Fig. 3 (Hamard et al., 2018). Clay, silt, sand, gravel content, methylene blue value, and methylene blue activity were calculated according to Lautrin (1989), and the results are presented in Table 1.

The cob implementation technique employed to build the middle part of the cob barn (Fig. 2) was not clearly visible on-site. Macrostructural analysis revealed horizontally organized fiber layers (Fig. 4), delineating clods of earth. Nonetheless, fiber layers were obvious and sometimes discontinuous.

Pictures of the thin sections were used to draw horizontal and vertical schematic cross-sections (Fig. 5). The horizontal cross-section is perpendicular to the faces of the wall, whereas the vertical cross-section is parallel to the face of the wall. The fibers are visible throughout the cross-sections but more specifically concentrated along the sub-horizontal planes (fibers in the yellow color in Fig. 5). The soil aggregates are horizontally flattened and parallel to the fiber planes. Vertically oriented voids are clearly visible throughout the horizontal cross-section but less visible in the vertical cross-section (Fig. 5).

Table 1 Identification of material collected in north window (NW), south window (SW) and on top of the wall (Top).

Material	Clay (0–2 µm) (%)	Silt (2–50 µm) (%)	Sand (50 µm - 2 mm) (%)	Coarse Elements (> 2 mm) (%)	Methylene Blue Value (g/100g)	Methylene Blue Activity
NW	7	33	37	24	0.91	14
SW	7	54	30	9	0.78	12
Top	3	47	44	6	0.69	22

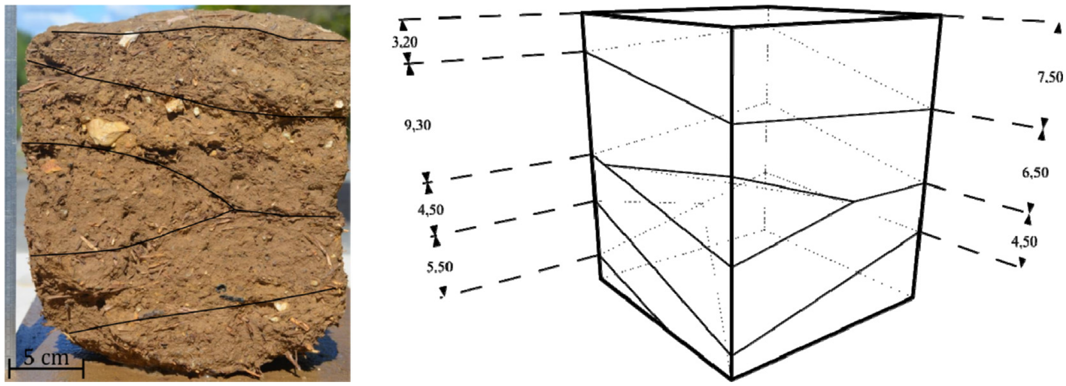

Fig. 4 Cob clods limits of a wall portion underlined on a picture (on left) and depicted on a 3-dimension schematic diagram (on right, dimensions in cm).

3.2. Micromorphological characteristics

A detailed micromorphological description, which was adapted from the micromorphological description tables proposed by Bullock et al. (1985) and Stoops (2003), is presented in Table 2. Specific description terms are italicized. The microstructure of the cob material is *apedal*, with *dominant vughy* and *frequent vesicular* microstructures. In the *vughy* microstructure, voids are dominated by *round vughs* with concave and convex walls and randomly oriented or subhorizontally elongated (Fig. 6). *Vesicle voids* are visible in the *vesicular* microstructure (Fig. 6). Vertical *planar voids* partially accommodated with a pointed edge (Fig. 6) are visible across the thin sections, more especially in the horizontal cross-section.

The groundmass has a $c/f_{10\mu m}$ ratio of 7/3, with a *porphyric* distribution pattern. The coarse material was made of (1) mineral grains: *dominant angular* quartz silts and sands, *rare subangular* silt micas, and *rare sub angular* silt feldspar; (2) rock fragments: *rare subrounded* quartzite gravels and *rare subrounded* sandstone-schists gravels; (3) organic components: *few* well-preserved pluricentimetres straw stem *residues* (Fig. 7a) and *rare* inframillimetres plant *organ fragments*; (4) *rare* soil aggregates containing *subrounded* quartzite gravels; (5) *very rare* bones; and (6) *very rare* ceramics. The fine material was made of *yellowish-brown speckled* clay.

Textural, impregnative, and amorphous pedofeatures were observed in the earth material. The textural pedofeatures are as follows: (1) *occasional non-laminated coatings* of voids (Fig. 7b) or straw stems (Fig. 7c), most of the time in normal position relative to wall gravity, with a material dominated by 5—100 μm of *angular* quartz, sometimes covered with a layer of fine material and sometimes associated with groundmass fragments (Fig. 7b); (2) *occasional non-laminated impure clay intercalations* inside groundmass (Fig. 7d); and (3) *occasional plurimillimetres* clay-depleted zone inside groundmass (Fig. 7e). The impregnative amorphous pedofeatures are as follows: (1) *occasional moderate to strong* Fe-Mn *coatings* and *hypo-coatings* of voids (Fig. 7f); (2) *occasional moderate to strong* Fe-Mn and *hypo-coatings* of plant fragments (Fig. 7g); (3) *occasional moderate to strong* Fe-Mn impregnations of groundmass (Fig. 7h); and *rare plurimillimetres typic* nodules with *sharp* or *gradual* boundaries.

Thin section analysis distinguished two main fabrics: Fabric 1 is the most represented, with a *randomly* distributed sand fraction inside a silty-clayey fine material, and Fabric 2, a *banded fabric* with local sand particles, stems, *intercalations*, and clay-depleted area is sub-horizontally organized (Fig. 8a—c). However, this organization is sometimes oblique (Fig. 8d). These limits are located in or near straw stem concentration areas (Fig. 5) and are not continuous along the thin sections. These limits are also associated with broken straw stem residues (Fig. 8a, c, and 8d) and with sheared (Fig. 8e, f), deformed (Fig. 8g), or rounded (Fig. 8h) soil aggregates.

4. Discussion

4.1. Excavation area location

Angular quartz, micas, feldspar, and sandstone schists most likely come from the alteration in the Brioverian formation, whereas subrounded quartzite gravels, associated with soil aggregates, are most likely derived from an old alluvial deposit.

Anthropogenic remains (i.e. bones and ceramics) are very few in earth material, suggesting a non-superficial origin. Groundmass, the base material of the thin section, which excludes fiber addition, has few plant residues (such as fine roots or herbaceous fragments) and exhibits low finely organic components with a high degree of comminution. These observations confirm that the material source is non-superficial.

The material collected in the north window has a high gravel content (Fig. 3 and Table 1), whereas the material collected at the top of the wall has a lower clay content than the other materials. The methylene blue values of the three materials are quite similar. These differences are deemed compatible with the horizontal and vertical natural variations inside a unique excavation site but might indicate several soil horizons or several depths. These differences highlight that the excavated soil was not homogenized prior to cob mixing.

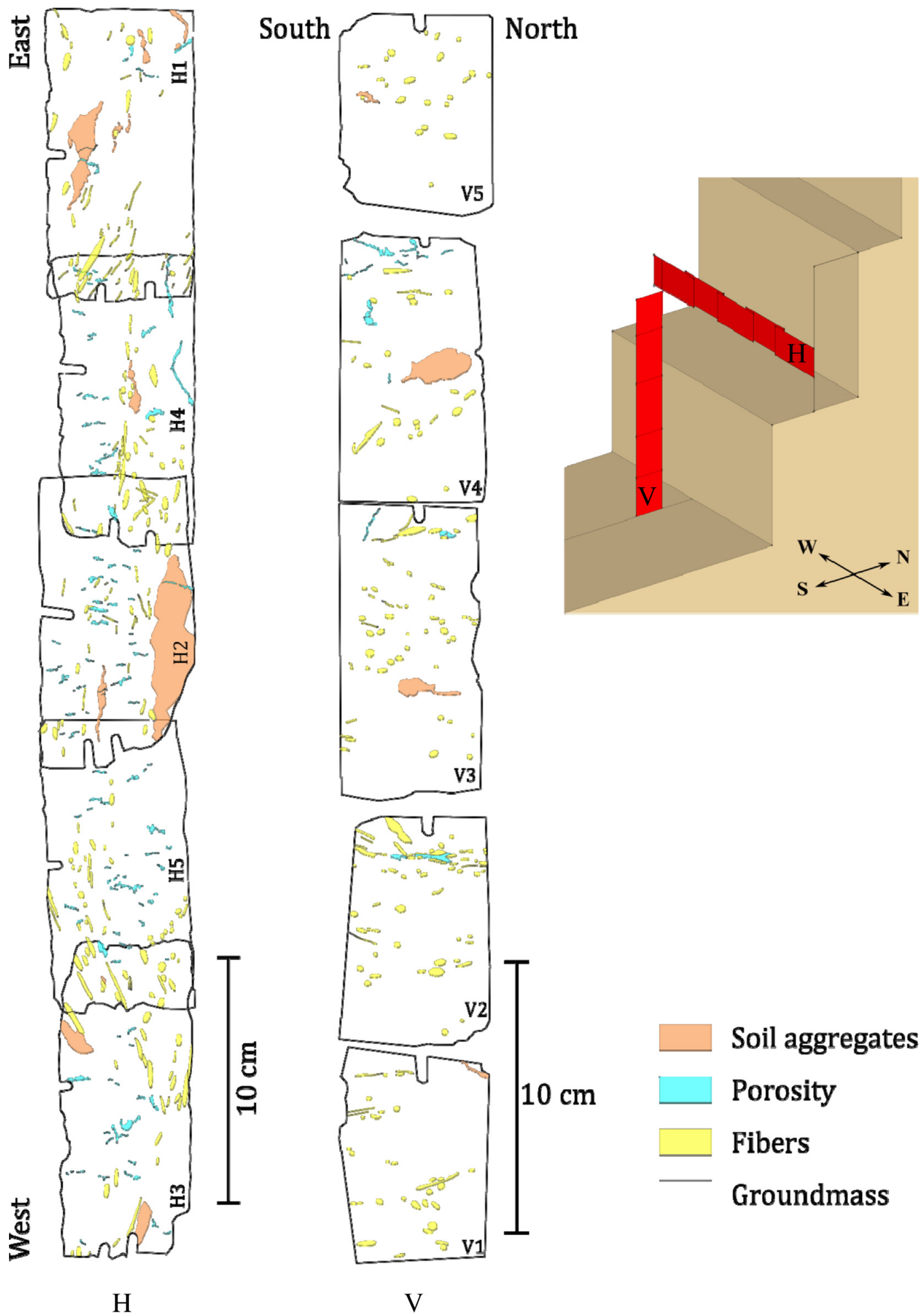

Fig. 5 Horizontal (H) and Vertical (V) cross-section highlighting thin sections macrostructure.

4.2. Fiber addition

The straw stems observed in the thin sections correspond to the straw fibers observed by the naked eye. Their vegetal cells are clearly visible and have a high birefringence (Fig. 7a), indicating slight aging. The aging/decomposition of organic matter in soils is caused by bacteria in water (Canseco, 1996). Once implemented in a wall and dry, organic matter incorporated in an earthen wall is subjected less to decomposition than in surficial horizons. The slight aging of straw stems suggests the intentional addition of fibers in the cob mixture, and ageing may have occurred

Table 2 Micromorphological description, after (Bullock et al., 1985; Stoops, 2003).

Microstructure	Total porosity by volume (%)			10–20			
	Aggregates type			Apedal			
	Microstructure type			Vughy			Vesicular
	Total proportion (%)			50–70			<5
	Void type			Vughs	Planar	Vughs	Vesicles
	Size of voids (mm)			0.5–3	1–20	0.5–2	0.5–1
	Relative proportion (%)			30–50	30–50	15–30	15–30
	Orientation pattern			Random	Vertical	Horizontal	Random
Mineral and/or organic components	General	Coarse/fine limit (μm)		10			
		c/f ratio		7/3			
		Sorting		Poorly sorted			
		Related distribution		Porphyric			
	Coarse components	Proportion mineral (%)		>70			
		Proportion organic (%)		5–15			
		Mineral grains	Main types	Quartz	Mica	Feldspar	
			Size	20 μm – 2 mm	20 μm – 100 μm	10 μm – 30 μm	
			Sorting	Poorly sorted	Well sorted	–	
			Shape	Angular	Subangular	Subangular	
			Total proportion (%)	>70	5–15	<5	
			Degree of alteration	Weak	Moderatly weak	Moderatly weak	
		Rock fragments	Main types	Quartzite	Sandstone schists		
			Size (mm)	3–30	1–25		
			Sorting	Moderately sorted	Moderately sorted		
			Shape	Subrounded	Subrounded		
			Total proportion (%)	<5	<5		
			Degree of alteration	Moderatly weak	Moderatly weak		
		Organic components	Main types	Organ residues (stem)	Plant residue		
			Size	1–50 mm	0.5–1 mm		
			Shape	Acicular	–		
			Total proportion (%)	5–15	<5		
			Communition	Whole organs	Organ fragments		
			Preservation	Good	Moderate		
		Other	Main types	Soil aggregates	Bones	Ceramic	
			Total proportion (%)	<5	<5	<5	
	Fine material	Proportion mineral		>70%			
		Proportion organic		<5%			
		Main colour		Yellowish brown			
		b-fabric		Speckled			
		Limpidity		Speckled			

(*continued on next page*)

Table 2 *(continued)*

Pedofeatures					
Textural pedofeatures	Type	Coating	Intercalations	Clay depletion
	Size	0.5–5 mm	2–20 µm	1–5 mm
	Lamination	Non-laminated	Non-laminated	Non-laminated
	Texture	Silt and clay	Impure clay	Silt
	Colour	Yellowish brown	Yellowish brown	Grey
	Related to	Stem and voids	Groundmass	Groundmass
	Abundance	Occasional	Occasionnal	Occasionnal
Impregnative pedofeatures	Type	Hypo-coating	Int/ext hypo-coatings	Impregnation
	Nature	Fe-Mn	Fe-Mn	Fe-Mn
	Related to	Voids	Plant fragments	Groundmass
	Size	0.5–10 mm	100 µm – 10 mm	100 µm – 5 mm
	Degree of impregnation	Moderate - Strong	Moderate - Strong	Moderate - Strong
	Oblique incident light colour	Red	Red	Red
	Abundance	Occasionnal	Occasionnal	Occasionnal
Amorphous pedofeatures	Type	Nodules		
	Abundance	Rare	Rare	
	Size	100 µm – 5 mm	100 µm – 5 mm	
	Nature	Typic	Typic	
	Boundary	Sharp	Gradual	
	Relative proportion (%)	30–50	30–50	

during the drying of the cob wall. Fiber abundance and their organization in the layers (Figs. 4 and 5) also indicate the intentional fiber addition by past builders.

4.3. Clod limits

The limits of clods are visible at the macroscale (Fig. 4) and underlined by fiber layers. These limits are still visible to the naked eye upon observation of thin sections (Fig. 5) but are less obvious under microscope observation. At the microscale, the clod limits are better depicted as a transition zone, underlined by the subhorizontal fiber concentration associated with subhorizontal vughs and quartz alignments (Fig. 8a, b, c) and sometimes with vesicles (Fig. 6).

4.4. Mixing

Several pedofeatures highlight the kneading action of earth material at the plastic state with straw fiber addition: (1) subhorizontal voids located beneath the fiber or quartzite (Fig. 6), (2) straw fibers filled with earth (Fig. 7c), (3) in-situ fragmentation of straw fibers (Fig. 8c), (4) sheared and horizontally flattened soil aggregates (Fig. 8e, f), (5) straw fibers forced inside soil aggregates (Fig. 8g), and (6) rounded soil aggregate (Fig. 8h). These features are in line with the traditional cob mixture preparation prior to implementation, which usually involves treading, by men or animal, of the earth at the plastic state together with fibers (Hamard et al., 2016a). Nonetheless, given that these pedofeatures are predominantly in a normal position relative to the wall gravity, they can also be attributed to the compaction of clods inside the wall during the implementation or drying phase. As clods are implemented subhorizontally, the distinction between the compaction pedofeatures linked to the treading of the cob mixture and those linked to the clod compaction inside the wall at the time of implementation is difficult to make. Thus, the earth did not have sufficient time to dry and fossilize the mixing features before implementation, and these two steps follow each other quickly.

Quartz particles are not evenly distributed in groundmass, and the straw fibers are mainly located at the clod limits. The blending action of cob mixing is highly limited. In this case, cob mixing is dominated by kneading, which forces straw fibers inside the surface of the earth material and allows the water ingress to achieve the homogeneous consistency of the cob mixture. The characteristics of the studied wall indicate that the construction technique employed here can be identified as a local constructive technique of Brittany called "*caillibotis*" (case (b) in (Hamard et al., 2016a)). Thus, a description of the technique employed for cob wall construction can be proposed. A layer of fiber was spread on the ground, followed by a layer of earth and another layer of fiber. The entire ground was wetted and trod by foot. The fibers penetrated the faces of the cob mixture layer and were then cut into squares. These squares or clods were piled horizontally inside the wall. However, the irregular shape and size of the clods in the studied wall suggest a flexible way of implementation.

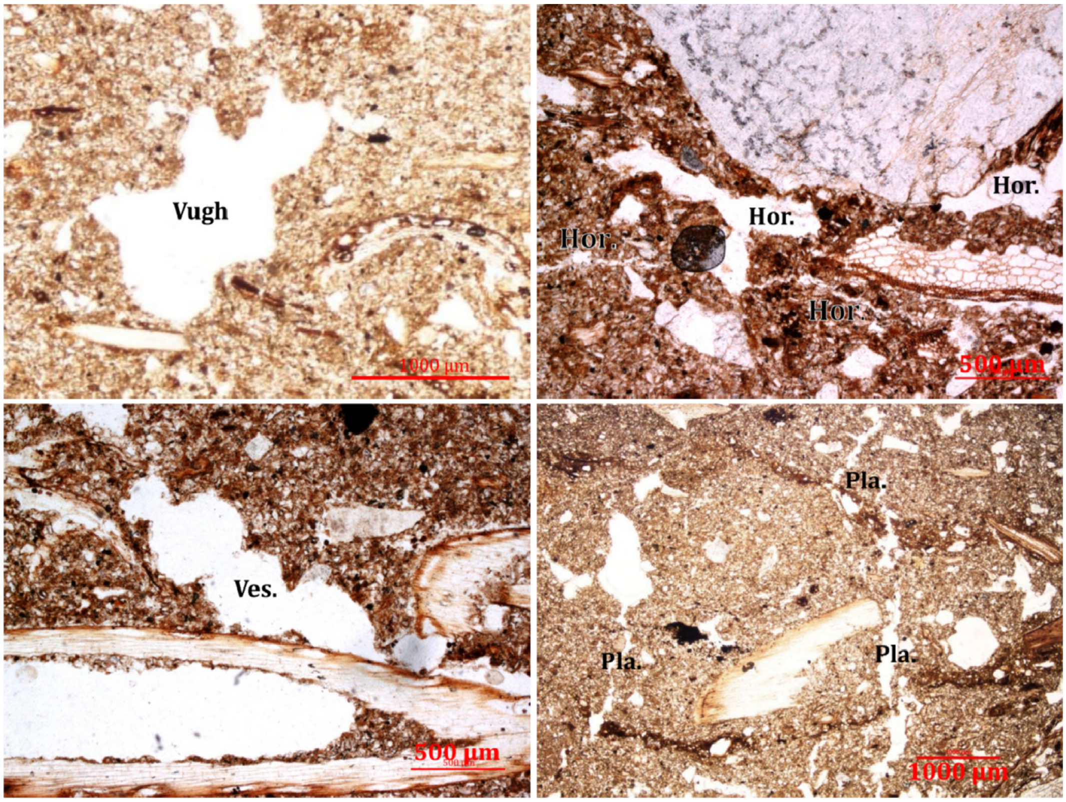

Fig. 6 Microscope pictures of voids type: Vugh = random vughs; Hor. = sub horizontal vughs; Ves. = vesicles; Pla. = vertical planar voids.

4.5. Clay depletion and intercalation

Clay depletions are visible in some areas inside groundmass (Fig. 7e), in the material inside some fibers (Fig. 7c), or in the material inside some voids (Fig. 7b). During kneading and/or clod implementation, the compaction of the material at the plastic state leads to excess water flow. The water flow preferentially circulates inside high porosity areas, such as voids and fibers or discontinuities of earth, and leaches clays and sometimes fine silts, depending on the speed flow.

4.6. Impregnations

Fe and Mn oxides occur when the soil is saturated with stagnant oxygen-depleted water for several days in the presence of sufficient organic matter and microorganisms and at a temperature above 5 °C (Lindbo et al., 2010). The straw fibers added in the cob mixture are affected by Fe/Mn impregnations (Fig. 7g). The implementation of clods of cob is made right after the cob mixture treading or, at most, 1 day after kneading (Hamard et al., 2016a). According to the literature, this period is insufficient to generate impregnative pedofeatures. Therefore, impregnations observed in the thin sections developed at the beginning of the drying of the wall, at least for those affecting the straw fibers.

The broken impregnations, clay-depleted deposits in the voids included in impregnation, and impregnated plant residue perpendicular to the general orientation of the earth material observed in the thin sections prove that a part of the impregnations occurred before wall drying. These impregnations could be inherited from the initial soil and could be related to an intentional rotting of the soil before construction, thereby reducing the organic matter content; if the organic matter was added, then these impregnations could be for stabilization. No intentional fine organic matter addition in the groundmass for stabilization purpose was highlighted in the thin section observation. The small vegetal residue content of the groundmass and the Fe/Mn impregnations of the groundmass were attributed to an intentional rooting of the soil prior to construction or be inherited from the initial soil, which is subjected to variable waterlogging rates (Lemercier et al., 2015).

4.7. Shrinkage

The vertical planar voids intersect all the pedofeature types observed in the thin section and are visible across all thin sections, more specifically across the horizontal cross-section (Fig. 5). These vertical voids are interpreted as shrinkage cracks. Notably, the shrinkage is more pronounced in the direction perpendicular to the face of the wall than in the direction parallel to the face of the wall, because less restraint exists in the direction perpendicular to the face.

5. Comparison between cob and rammed earth

The typical micromorphological features associated with rammed earth were described in a previous study (Hamard et al., 2016b). Table 3 presents a comparison of the

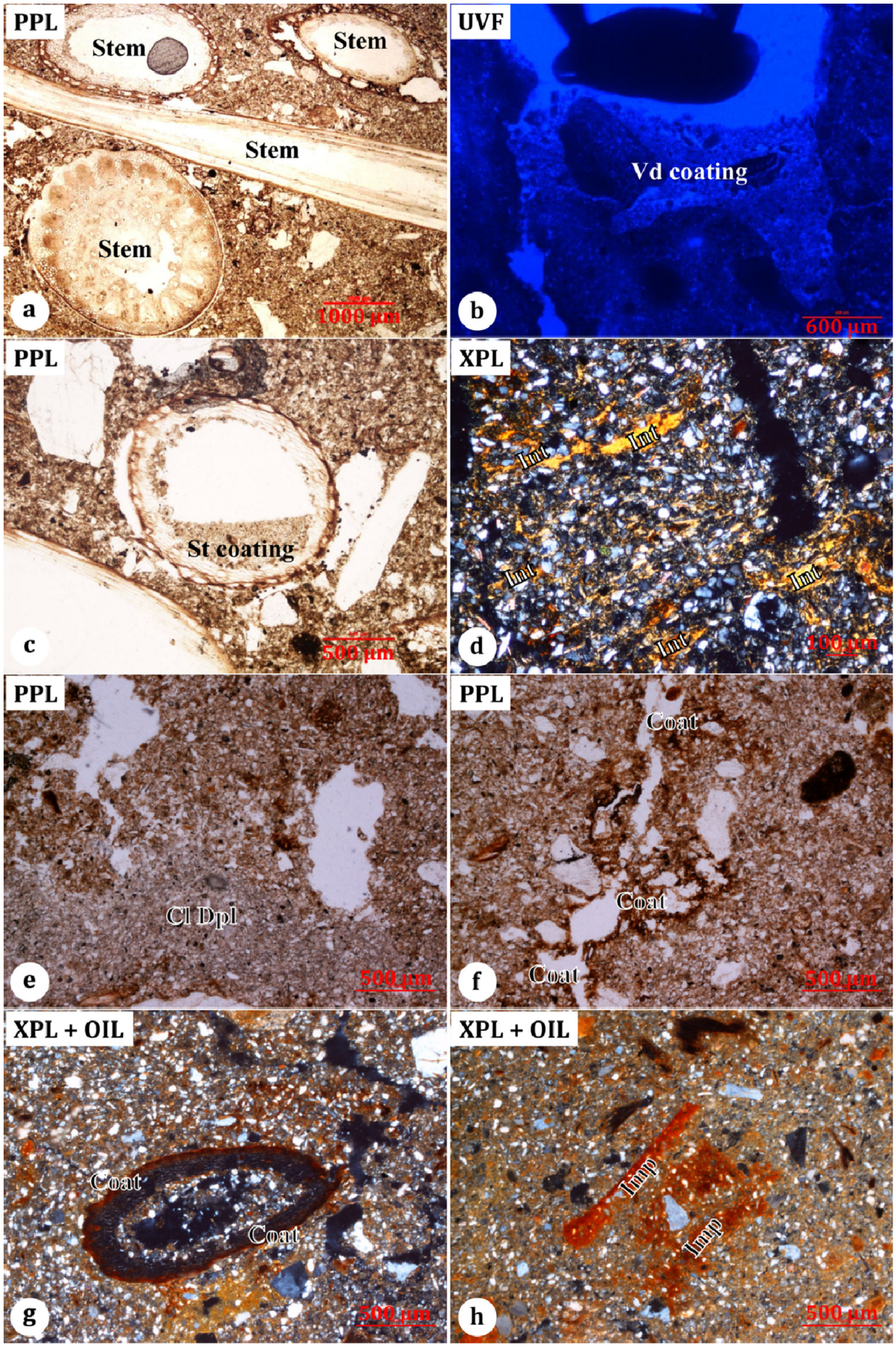

Fig. 7 Microscope picture of (a): straw stem residues (Stem); (b): silty void coating (Vd coating); (c): silty coating in the section of a straw stem (St coating); (d): clay intercalations (Int); (e): clay depletion at the lower part of the photo (Cl Dpl) highlighting a banded fabric; (f): voids coating and hypo-coatings (Coat); (g): straw stem hypo-coatings (Coat); (h): Fe groundmass impregnations (Imp).

micromorphological features related to the rammed earth farm of Cras-sur-Reyssouze (Hamard et al., 2016b) and the cob barn of Saint Gilles at different process stages. Rammed earth vernacular construction techniques show little variations, and rammed earth can be regarded as a standardized process to a certain extent. The features highlighted for the rammed earth farm in Table 3 can be used as a basis for assessing the micromorphological characteristics

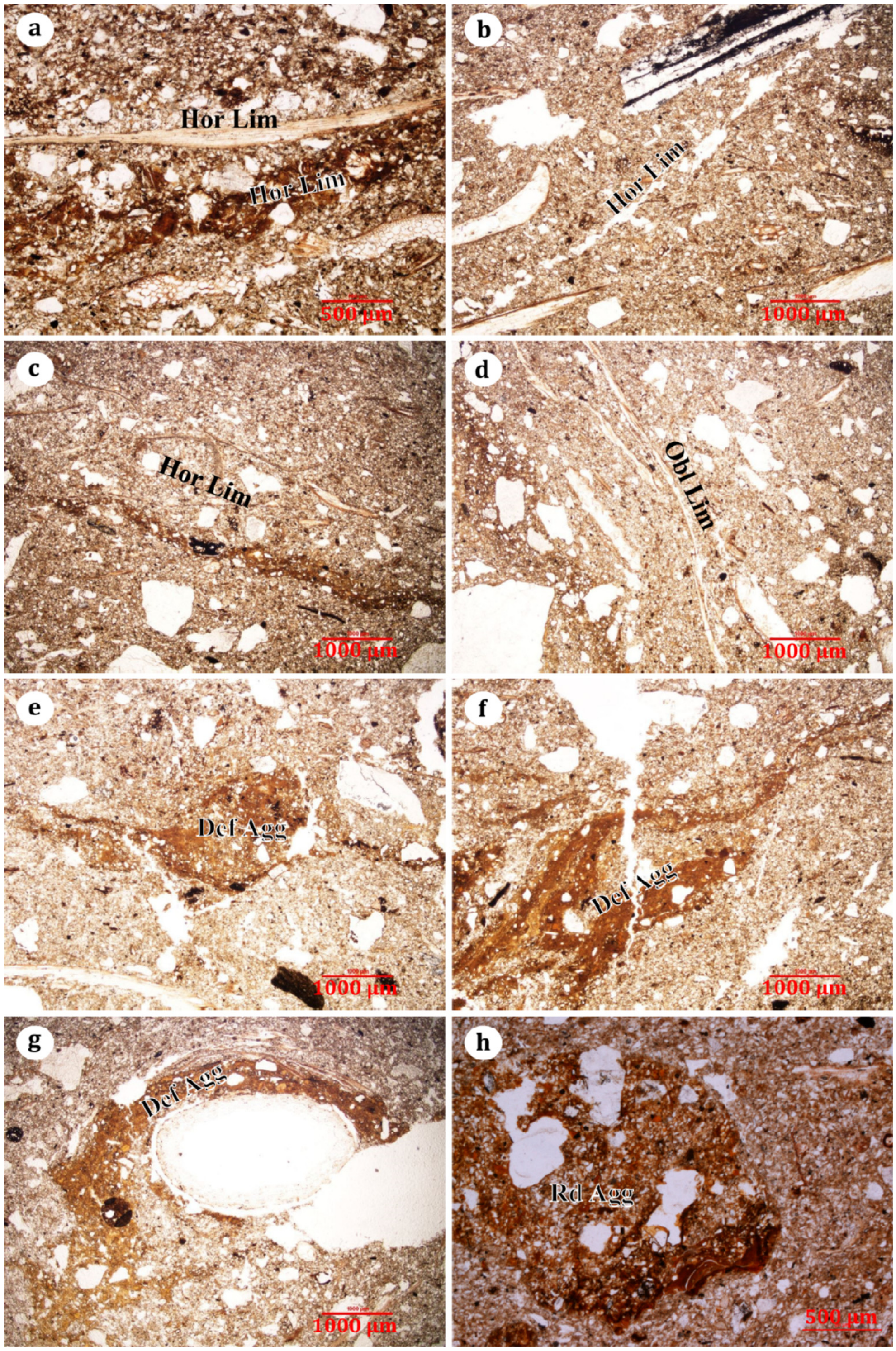

Fig. 8 Fabric pedofeatures: subhorizontal limits (Hor Lim)(a, b and c) and oblique limit (Obl Lim)(d) underlined by sand alignments straw stems and voids parallel to the limits, deformed soil aggregates (Def Agg)(e, f and g) and round aggregate (Rd Agg)(h). All pictures are taken in PPL.

of rammed earth. However, this is not the case for the cob barn. The cob process shows large variations (Hamard et al., 2016a), and the features proposed in Table 3 for the cob farm only concern the "*caillibotis*" technique. Nonetheless, two major differences between the cob and rammed earth processes have an impact on micromorphological features, namely, their manufacturing state (solid or plastic) and the organization of the material in the wall. Rammed earth is implemented at the solid state and the material deforms in a brittle manner, whereas cob is implemented at the plastic state and the material deforms in a ductile manner. The type of deformation, plastic

Table 3 Micromorphological features allowing distinguishing a rammed earth building (Hamard et al., 2016a) and the cob barn of Saint-Gilles, at different process stages (W_m = water content of manufacturing stage).

Process stage	Rammed Earth	Cob *"caillibotis" technique*
W_m	Voids with rough and irregular walls indicates a solid state	Vesicles, clay depletion and intercalations indicating a plastic state
Mixing		Plastic deformations of soil aggregates, straw fibres filled with earth, clay depletion and intercalations indicating a kneading action
Limits	Layers are underlined by obvious and continuous limits outlined by sand alignments, subhorizontally elongated voids and a contrast between an above high and a below low porosity	Clods limits underlined by fibre layers by naked eye and, at microscale, by a transition zone associated with subhorizontal fibres concentrations, flattened voids and sand alignments
Compaction	Inside rammed earth layers, ramming process generates overlapping discontinuous limits, horizontally oriented associated with a shortening, oblique shear lines, sometimes combined together to create corner shape figures	
Drying		Drying is associated with in situ Fe-Mn impregnations indicating ancient short waterlogging, affecting mostly fibres, and with vertical shrinkage cracks, more pronounced in the direction perpendicular than parallel to the face of the wall

or brittle, is one of the key micromorphological parameters that can distinguish rammed earth (brittle) from cob (plastic). Inside lifts, rammed earth is compacted into layers, whereas cob clods are stacked one upon the other. Unlike the cob, the rammed earth wall exhibits a regular and continuous layered structure. This structure is another key parameter that distinguishes rammed earth from cob.

6. Conclusion

This first micromorphological analysis of the cob material highlights the following: (1) a unique excavation site was used, and the material was not homogenized prior to implementation; (2) intentional fiber addition; (3) micromorphological description of cob clod limits; (4) the clear kneading action at the plastic state attributed to cob mixture trampling; (5) limited or absence of blending action; (6) water flow responsible for clay-depleted and intercalation areas, attributed to cob mixture trampling and possibly to the compaction of cob clods during implementation in the wall; (7) impregnations of Fe and Mn oxides attested during wall drying and hypothetically during the intentional rotting of the material prior to mixing; and (8) the more pronounced shrinkage of the wall perpendicularly than horizontally to its face.

In addition to micromorphological analysis, macroscale observations were essential in understanding the general organization of clods. For the cob wall study, similar to other earth construction techniques, microscale and macroscale descriptions are both required. Combining these two observation scales allowed the identification of "*caillibotis*" as the construction technique employed for this building. This result is in line with the type of techniques employed at the beginning of the 20th century in the Rennes basin (Bardel and Maillard, 2010).

Finally, a comparison of the micromorphological features of cob and rammed earth enabled the identification of typical microscopic features corresponding to the two key factors, thereby allowing the identification of these two processes: the manufacturing state (solid or plastic) and the organization of the material in the wall. Micromorphology is a powerful tool of discriminating and rediscovering earth building techniques and their variations. From an architectural and historical point of view, this knowledge can enable us to follow the evolution and spread of earth construction processes. From a technical perspective, this knowledge would provide precious information for heritage maintenance and help rediscover the solutions employed by past builders to overcome obstacles that are still relevant. This work will help promote the use of locally available materials to boost the circular economy of the building sector.

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