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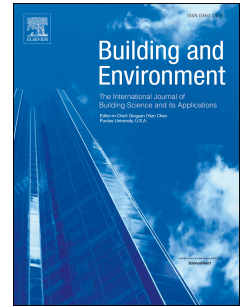
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**Cob, a vernacular earth construction process in the context of modern sustainable building**

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**Abstract**

The will of reducing environmental and social impact of building industry has led to a renewed interest in earth construction. Most of earth construction literature dealt with rammed earth or adobe techniques, but very little with cob. Yet, cob participates in the diversity of vernacular earth construction processes that value local materials and is an alternative to rammed earth and adobe in specific geographical conditions. Conservation of cob heritage also requires a better knowledge of this vernacular construction process. This bibliographical analysis gathered extensive data on cob process and summarized the different cob process variations, attempting to take into account their diversity. This analysis allowed us to provide novel data on cob process, and more specifically, (1) a clear definition of cob with regard to other earth construction processes, (2) a first summarized description of cob process that clearly distinguished its variations, (3) a list of fibres traditionally employed, (4) values and, if possible, average and standard deviation for fibre length, fibre content, manufacture water content, drying times, lift heights and wall thicknesses, (5) a summary of the strategies to manage shrinkage cracks, (6) a criterion on the quality of implementation and/or earth for cob, based on slenderness ration of lifts and (7) a discussion on the evolution of cob process with regard to societal evolutions.

**Highlights**

- A clear definition of cob is proposed.
- A first summarized description of cob process is proposed.
- First order of magnitude of characteristics of cob process is proposed.
- A summarization of the strategies of management of shrinkage is proposed.
- A criterion on the quality of implementation and/or earth for cob is proposed.

**Key Words:** cob; vernacular; earth construction; process; sustainable building.

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## 32 1 Introduction

33 Cob is part of vernacular earth construction techniques. It consists in stacking clods, made of a mix of plastic  
34 earth, in order to build a monolithic wall. As other earth construction techniques, cob encountered a renewed  
35 interest for its low environmental impact in comparison to conventional construction materials [1–4].

36 Indeed, the building sector is one of the largest consumer of natural resources [2,3,5–8]. It also generates large  
37 amounts of waste [5,6] and produces greenhouse gases that participate to climate change [6–10]. Embodied  
38 energy together with operating energy of the building sector represent approximately 40 % of global energy use  
39 [5,6,8,9].

40 Until 2000s, operating energy only was considered because of its dominant share in the total life cycle. Since, the  
41 use of more efficient equipment and insulations modified the balance between embodied energy and operating  
42 energy so that the proportion of embodied energy increased [6,8,11]. In order to pursue energy saving effort, the  
43 next challenge of the building sector will be the reduction of embodied energy [8]. This involves good  
44 maintenance of heritage and the use of construction materials with low embodied energy [12,13].

45 Improving durability of cob heritage will save as much energy as it would be required for new constructions  
46 [14]. Still existing cob building heritage is estimated to 50 000 in Germany [15], 40 000 in Devon (UK) [16,17],  
47 30 000 in Ille-et-Vilaine (France) [18] and 20 000 in Manche (France) [19]. In European Union, cob heritage  
48 thus represent, at least, 200 000 buildings. Those buildings date back to the first half of 20<sup>th</sup> century, the 19<sup>th</sup>, 18<sup>th</sup>  
49 century and are even older [9,15,18,20–39], which prove their high durability (Figure 1). This longevity is only  
50 possible if properly maintained by skilled craftsmen [9,30,40–44]. Unfortunately, this expertise is lost in the  
51 Western countries [1,4,17,42,45–47] and inappropriate maintenance is a serious threat to cob heritage [16,41,44].  
52 Hence, there is a need to describe and understand cob construction process in order to propose suitable  
53 maintenance solutions in order to increase buildings lifetime.

54 Former builders mainly had animal energy and unprocessed local materials for construction purpose. Centuries  
55 after centuries, they optimized the use of available natural resources, according to geographical context and  
56 societal evolutions, and developed local constructive cultures [1,42,48]. As a consequence, embodied energy of  
57 earth construction is very low in comparison to other materials conventionally used in construction  
58 [1,2,9,10,16,46,49–53]. For example, embodied energy of a wall made of earth is about 20 times less than that  
59 made of hollow cinder blocks [9,10]. Earth construction offer other benefits: better social impact [5], low  
60 greenhouse gas emissions [6,9,10,46,49,54], high thermal mass [1,19,30,49,52,55–63], good indoor air quality  
61 [1,7,9,10,49,51,54,64–67] and reversible clay binding allowing a complete and low-energy recycling  
62 [10,16,31,49,50,52–54]. As these local constructive cultures are a source of inspiration for anti-seismic

63 constructions [48], they can be used to propose future energy-efficient building solutions. Earth building heritage  
64 is therefore a precious testimony of low-environmental impact construction.

65 The aim of this paper is to propose a clear definition of cob with regard to other earth construction techniques,  
66 analyse cob bibliographic data in order to provide a description of vernacular cob construction process and an  
67 explanation of the key factors of the process.

68 Among the 133 references used to describe local cob construction techniques, 77 % concerned France and  
69 United Kingdom (Table 1). This bibliography is an overlook to vernacular cob construction techniques around  
70 the world, with a focus on France and United Kingdom.

71 In this paper, soil names the material in its natural context and earth names the material extracted for  
72 construction purpose.

## 73 2 Cob definition

### 74 2.1 The place of cob in the family of earth construction techniques

75 To provide a definition of cob it is necessary to understand what makes this earth construction technique  
76 different from the other ones. Thus, before proposing a definition for cob, the classification of vernacular earth  
77 construction techniques is to be considered.

78 Some earth construction process classifications were proposed in the literature but no general agreement exists  
79 [9,17,36,68–72]. Among those classifications, those based on the distinction between wet methods and  
80 dry/compaction methods [9,17,71] are judged more appropriate for classification purpose. For wet processes,  
81 earth mixture is placed at plastic state and mechanical strength of the material is provided through drying  
82 shrinkage densification (adobe, cob). For dry processes, earth mixture is placed at optimum Proctor water  
83 content and mechanical strength is provided through compaction densification (Compressed Earth Block and  
84 rammed earth). A second distinction is made according to the implementation of the earth in the wall, through  
85 masonry units (Compressed Earth Block and adobe) or direct monolithic wall realization (cob and rammed  
86 earth).

87 These classifications are adapted and supplemented with non-load bearing techniques (wattle and daub and  
88 plasters) and a classification is proposed in Figure 2. This classification is based on three criteria: (1) water  
89 content of mixture (dry-compression densification / wet-shrinkage densification), (2) implementation type (dry  
90 masonry units built with a mortar / direct implementation of earth mixture at manufacture water content in order  
91 to build a monolithic wall / infilling of a wooden structure / overlying of walls) and (3) structural role of the  
92 earth element (load-bearing and free-standing walls / non-load bearing walls).

93 Using this classification, it is possible to propose a definition for cob. This definition should be wide enough to  
94 comprise all process variations, but precise enough to differentiate cob process from other earth construction  
95 techniques. The following four key characteristics are proposed to define cob process: (1) realization of earth  
96 elements in a plastic state, (2) implemented wet, in order to build a (3) monolithic and (4) load bearing or  
97 freestanding wall.

## 98 2.2 Cob name

99 A large variety of vernacular names for earth construction techniques (Table 2) fall under the definition of cob  
100 process. Nowadays, these names tend to disappear in favour of the universal term, “cob”. This allows a better  
101 international communication between researchers, engineers and professionals of earth construction, but it erases  
102 the nuances between local techniques and cause equivalence problems.

103 Indeed, those names sometimes describe similar techniques and sometimes describe different variations of cob  
104 process. As an example, *bauge* in Brittany (France) and *mâsse* in Normandy (France) describe the same  
105 technique (see case a, section 3.3.1), as well as *caillibotis* in Brittany and *gazon* in Normandy also describe the  
106 same technique (see case b, section 3.3.1). The term *bauge* has imposed on the entire francophone area instead of  
107 regional terms to name this technique [73]. But the word *bauge*, in its strict meaning, refers to the earth, fibre  
108 and water mixture that was traditionally employed in Brittany for earth construction [26,74–77]. Although this  
109 term refers to the mixture obtained, it necessarily refers to its associated process. Nevertheless, using the term  
110 *bauge* to name *mâsse* constructions of Normandy is a misnomer and using the term *bauge* to name *caillibotis* or  
111 *gazon* technique is confusing.

112 To avoid this confusion, it should be specified when *bauge* is used in a strict sense (*bauge s.s.*) to differentiate it  
113 from its acceptance as a general term. The same difficulty exists for the internationally accepted term cob [4].

114 Some authors [36,68,69] proposed to name this technique “piled earth”, since it better described this construction  
115 process. Nevertheless, it failed, for the moment, to impose instead of the term cob. As for *bauge*, it should be  
116 specified when cob is used in a strict sense (cob s.s., the vernacular technique used by former builders in Devon  
117 [16]) to differentiate it from its acceptance as a general term, cob.

## 118 3 Cob process

119 A summary of cob construction process is proposed in Figure 3, using the engineering process description: an  
120 *engineering process* is divided into a succession of *elementary steps*. Based on literature information, cob  
121 process is divided into 4 elementary steps: (1) raw material supply and preparation, (2) mixing, (3)  
122 implementation and (4) rectification and drying.



## 123 3.1 Material supply

## 124 3.1.1 Earth

125 *Earth source selection*

126 For former builders, the first step of the cob building process was the identification of earth material source.

127 Thanks to the legacy of previous builders and their own experience, they had a specific knowledge of the way to  
128 choose earth for cob construction [9,22,78]. Since this knowledge was orally transmitted, and used senses such

129 as touch, sight, smell, taste and hearing, it required a long learning alongside a master [78,79]. This knowledge is  
130 nowadays lost in the West, but it is possible to try to rediscover and translate it by mean of geotechnical analysis.

131 Some authors have characterized earth materials collected inside or next to old cob walls [44,52,80–87]. Results  
132 are too small and incomplete to summarize them. However, vernacular cob earth textures were defined in the

133 literature as loam [15,20,21], clay [22,31–34,88–94], silt [31,82,93,95] or clayey-silt [31,35,93,96] soils.

134 Silts, sands and gravels were identified as the granular skeleton that provides strength to the material

135 [14,17,84,86,97]. Well-graded soils were preferred since their packing structure allowed good space filling

136 properties that increased cob density, and therefore its mechanical strength [14,17,84]. Clay was identified as the

137 binder that brings cohesion to the material [84]. If clay content was too low, cob material crumbled [84,97,98].

138 Nevertheless, clay content also governs the drying shrinkage of the cob mixture. If clay content was too high,

139 large shrinkage cracks weakened the material [84,97,98]. As for earth plasters [99], there is an optimum clay

140 content for cob, thought to be around 20 % [9,16,81]. Thus, suitability of soil for cob construction depended on

141 clay content and particle size distribution. This is why some authors proposed earth-grading envelope to attest of

142 their suitability for cob construction [9,16,19,47,55,81,100,101]. However, most of the grading curves of earth

143 collected in old cob buildings did not fit inside those grading envelopes [44,80,86,102]. Consequently, these

144 grading envelopes failed to give full account of former cob masons knowledge.

145 Authors agreed with the fact that cob earth material was locally sourced. This was evidenced by the similarity

146 between available soils next to heritage cob buildings and the earth used in their walls

147 [10,31,38,85,86,93,95,102,103]. But more precisely, locally sourced earth materials meant that they could have

148 been dig from the foundations of the building [98], a pond next to the new building or in a field surrounding the

149 building [22,26,33,35,74,76,77,88,90,92,93,98,104–106], inside and immediately around the building during the

150 construction [26,35,94], a field around the building [35,74,77,84,88,104,105], the cellar of the building [98,107],

151 an earth quarry, located on the same municipality [95], a ditch cleaning [108] or a hollow way [74,77,109].

152 Another practice that appears to have been quite common, but difficult to attest, is the reuse of the earth of old

153 cob walls [110,111]. It is then possible to precise what “local earth” meant for vernacular cob construction. It

154 was an earth excavated on-site or, tenth [33] or hundredth [76] of meters or, at most, a few kilometres away from  
155 the site [95].

#### 156 *Earth excavation and transportation*

157 Topsoil is rich in organic matter that decompose after implementation and created mechanical weaknesses inside  
158 earth walls [52,112–114]. It was therefore considered as unsuitable for cob construction  
159 [9,32,33,35,40,52,74,77,78,91,97,98,107,108,110,115–117] and it was cleared off before the excavation was  
160 carried out [40,74,77,107]. Sometimes topsoil was removed the year before the construction took place, in order  
161 to break down the subsoil under the effect of winter moistening and freezing to ease the excavation process  
162 [107]. The excavation was done by the owner and relatives [32,74,76,78,84,88,104,118–120] by hand, thanks to,  
163 for example, a mattock [34].

164 Because the most suitable earth for construction was found just below the topsoil, excavation concerned a large  
165 surface area and a thin layer of soil [35,98]. When not excavated on-site, earth was transported to the site by  
166 animal-drawn tumbrel and stored [74,104,105,121,122]. For a 20 m<sup>3</sup> earth lift, this corresponded to 10 tumbrel  
167 travels [88].

168 A unique source of material was sometimes not enough to complete the walls of the building [81]. As an  
169 example, when the earth excavated from the foundations of the building was not enough, another local material  
170 source was exploited (dug from a pong, a field, a hollow way...) depending on needs and opportunities. The use  
171 of different earth sources was highlighted by the variations of colour and texture from a lift to another [24].

172 A first option was to realize the material supply at once, and all material sources could have been mixed together  
173 [107]. A second option was to realize the material supply separately for each lift [88]. Indeed, the amount of  
174 earth necessary to realize one lift was estimated to 20 m<sup>3</sup>, which corresponded to several working days of hard  
175 labour for the working team [88].

176 Sometimes the poor earth quality required to temper it thanks to another material [108,110,120,121,123]. Thus  
177 another earth material source or aggregates could have been employed as an earth grading corrector  
178 [107,108,110,120].

#### 179 *Earth preparation*

180 Sometimes, earth was brought on-site the year before the construction took place, so that weathering effect broke  
181 it down in order to facilitate the screening (if required) and the mixing of the material [10,22,108,124] and to let  
182 the organic matter to decompose [108]. If rainfalls were not sufficient, the earth was wetted during winter [108].  
183 More generally, earth was stored close to the construction site some weeks before the construction took place  
184 [88,105,110]. The preparation of the earth, prior to mixing, could involve one or a combination of the 4

185 following actions: (1) earth was got rid of large rocks [14,16,35,47,74,77,81,85,90,98,104,105,115,123,125,126],  
186 maximum particle size diameters is in the region of 50 mm (Table 3); (2) earth was loosened [16] thanks to a hoe  
187 [35,77,104,115], a mattock [126] or a spade [126], in order to break clods of earth; (3) earth was soaked days  
188 before mixing to make it more workable and to homogenize water content [34,35,47,64,74,77,88,98,104,105];  
189 (4) earth was trodden by men [105] or by animals [88,124] to prepare soaked earth prior to mixing.

### 190 3.1.2 Water

191 As there was no water supply network at the time of their construction, cob buildings were more likely located  
192 near water sources [4,23,122]. Water was taken from the well of the farm, from a pond created by the excavation  
193 of the earth material [88,108] or from a ditch close to the construction [108,110]. In Brittany, the cob wall  
194 construction had to be completed before July, because, as water became scarce in summer, its use was restricted  
195 to farm activities [74,104]. In Devon, water supply seemed to have been a less critical problem since cob  
196 building took place in late spring and during the summer months, because these periods were favourable for  
197 walls drying [14,19].

### 198 3.1.3 Fibres

199 Although un-fibered cob was mentioned [9,14,34,84,107,118,127], cob technique was generally associated with  
200 natural fibre addition. Most commonly cited fibre employed for cob is straw (Table 4). According to Petitjean  
201 [74], during the 19<sup>th</sup> Century, evolution of agricultural practices generated straw excess, fostering its use at the  
202 expense of fibres used before. Actually, large varieties of fibres were used in vernacular cob construction (Table  
203 4). Since fibres were locally sourced [19,33], this diversity reflects the adaptations of the vernacular cob  
204 construction process by former builders to resources available in their nearby environment. Authors both referred  
205 to cut, or chopped, and uncut fibres (Table 3). Two modes for fibre length can be identified (Table 3): (1) small  
206 fibres (10-20 cm), fibres length being about equal to the size of a cob lump, (2) long fibres (40-60 cm), fibres  
207 length being about equal to the width of the wall.

208 The role of fibres inside cob walls was to (1) facilitate the mixing [14,100,107], (2) assist handling  
209 [9,10,16,22,26,31,84,100,117,118], (3) accelerate the drying process [9,14,19,26,35,100,107], (4) distribute  
210 shrinkage cracks throughout the wall mass [9,14,16,19,22,24,26,34,49,52,100,107,128,129], (5) enhance  
211 cohesion and shear resistance of the wall [9,14–16,19,26,31,49,100,129,130], (6) improve weathering resistance  
212 [10,100,130], (7) reinforce bond between lifts [108,117] and (8) wall angles [94,108].

213 Some authors [14,15,19] stated that fibres contributed to the thermal insulation of the wall. Yet, Keefe [9] argued  
214 that thermal conductivity reduction of a cob wall was significant only if a large amount of fibres was added to  
215 the mixture (about 25 % by mass). Fibre content of cob was generally between 1 to 2 % by mass (Table 3). In

216 this case, thermal contribution of fibres seemed very limited. Anyway, the most important function of fibre is  
217 thought to be the distribution of shrinkage cracks [9,14,24,107].

#### 218 3.1.4 Stabilizer

219 Fibres can be regarded as a stabilizer. As most of vernacular cob was fibered, it might not necessitate further  
220 stabilizer addition. As a consequence the use of cement or lime as a stabilizer in cob mixture seemed to have  
221 been rarely employed [16,79,84,107,125]. Keefe [9] considered hydraulic binder stabilization with a critical eye.  
222 According to him, under temperate climate, it should be possible to construct strong, durable buildings without  
223 recourse to stabilization. Moreover, he stated that during this process, the soil undergoes a fundamental and  
224 irreversible chemical change so that it is no longer recyclable, becoming, in effect, a sort of "brown concrete"  
225 [9].

226 The use of natural stabilizers was mentioned in the literature: animal dung, small pieces of straw, chalk, vegetal  
227 oils, white of egg, cow urine, ashes, milk, blood, buttermilk, casein [16,41,84,94,107,131]. Too little information  
228 are available about stabilization in cob literature, thus, the use of stabilizer is not detailed in this paper.

#### 229 3.2 Mixing

230 When raw materials (earth, water and, if required, fibres and supplementary earth or aggregates) were supplied  
231 on site and prepared as described in section 3.1, they were ready to be mixed together to form the cob mixture.  
232 Mixing took place on a flat and if possible hard [16,123] and impervious [126] surface. This surface was  
233 sometimes pre-wetted [16,126] and sometimes covered by a bed of fibres [16]. Earth was spread on this surface  
234 and arranged in the shape of a flat circular heap (1 to 6 m diameter) next to the wall under construction  
235 [102,115,123,125], or in a continuous pile of earth (0.5 to 1.8 m large) all around the future building, alongside  
236 the walls under construction [74,77,88,104,105]. More rarely the mixing was done in a rough trough [125].  
237 Earth was spread to form a layer some centimetres thick [74,104,105] to 10 cm thick [16,115,116]. Fibres (when  
238 required) were evenly distributed on the earth [10,16,74,77,88,90,102,104,105,115,116,125,126] and the whole  
239 was trodden by men [9,10,16,20,21,24,32–35,47,51,74–  
240 77,83,84,89,90,98,104,105,107,108,110,115,116,118,121,125,126,128,131–133] or by animals [16,31–  
241 33,35,47,74,77,83,104,107,128,132], generally horses [21,35,87,88,102,123,124] or oxen  
242 [21,35,102,108,110,121]. During mixing, more fibres (when required) were gradually added [75,102,121,123]  
243 and water content was corrected, based on guesstimate of the cob masons [9,10,14,16,34,102,116,123,126].  
244 Manufacture water content of the cob mixture should bring it into a workable mix [16,47,85,87], i.e. into a  
245 plastic state [10,31,35,88,97,128,134,135]. Manufacture water content are in the region of 20 % (Table 3), which

246 is in agreement with a plastic state. Average fibre content range from 1.4 to 1.7 % by mass (Table 3). This is in  
247 agreement with the optimum fibre content around 1% proposed by Danso et al. [130].  
248 In order to ease the mixing, some authors referred to the use of forks [107,108,121,123], picks [102,125] and  
249 hoes [32,118,132] to stir the cob mixture [9,16]. When the mixing of the first layer was completed, the process  
250 was repeated several times to realize other layers over the first one [88,115,116] in order to create a pile of earth  
251 60 to 100 cm thick [88,115]. The treading could last 1 – 2 h [124], a half-day [118] and up to 3 days [133]. Cob  
252 mixture is ready to be placed inside the wall, but it could have been let to dry overnight up to a few days before  
253 to be used [24,31,116,118,126,128].  
254 The purpose of cob mixing is to evenly distribute clay, water and, if added, fibres in the cob mixture in order to  
255 maximise the contact surface between wet clays and other constituents of the cob mixture  
256 [9,10,14,16,64,100,126]. Indeed, as it has already been demonstrated for other earth construction materials,  
257 cohesion is provided by capillary forces of water menisci attached to clay particles [1,71,136–138]. Thus,  
258 mechanical strength and durability is enhanced if clay particles are evenly distributed inside the earth matrix  
259 [9,71,100]. Soils are usually organised in peds [114]. In order to evenly distribute clay particles inside earth  
260 material, it is then necessary to break those peds to mobilize clay [9,126]. For wet earth construction techniques,  
261 this is achieved thanks to kneading action of soaked earth, water playing the role of a dispersing agent.  
262 Dispersing action of water is efficient if water is well distributed and in sufficient amount inside earth material.  
263 Cob mixing is easier and more efficient if earth was pre-soaked and mixing realized on the “wet side” of the  
264 plastic state [9,10,14,47,55,100,126].  
265 Besides kneading action, blending action of the mixing process allowed an even distribution of the constituent of  
266 the mixture [9,64,100,126]. Indeed, inhomogeneity would create weak points inside cob walls [126]. This was  
267 even more essential when another constituent was added to the cob mixture (sand, stones, fibres ...). Fibres  
268 provided extra tensile-strength to cob walls and improved weathering resistance [9,10,14–  
269 16,19,26,31,49,87,100] but this was only true if fibres were evenly distributed [55,100].

### 270 3.3 Wall construction

#### 271 3.3.1 Earth elements implementation

272 Cob walls were made by the stacking of: (a) clods of earth snatched from the cob mixture pile, (b) plastic  
273 elements of earth cut in squares, (c) plastic elements of earth modelled by hand into specific shapes, or (d) wet  
274 clods of earth snatched from the cob mixture pile inside a shuttering.

275 In case (a), which was the most widespread vernacular cob construction techniques, material was taken from the  
276 cob pile next to the wall with a fork, with hands or with a shovel by a workman and given to the skilled

277 craftsman, standing on the wall, who arranged the clods of earth: a first one was placed on one side of the wall, a  
278 second one on the other side of the wall and a third one in the centre, ensuring that they correctly overlapped  
279 each other in order to provide sufficient cohesion between elements [9,10,14,16,17,19,20,24,31,32,35,37,74,76–  
280 78,87,88,91,95,104,105,108,110,115,117,119,123–125,128,131,133,139–141]. Clods of earth were disposed so  
281 that they overhung the plinth on both sides of the wall by 5 – 15 cm  
282 [14,16,24,35,77,78,87,88,91,95,104,115,124,125,141]. Clods were often arranged in diagonal layers  
283 [16,31,87,111,115,125], by, for example, an angle of 35 – 45° [31,111]. Sometimes fibres were placed around  
284 each clod [26,134,140] or between each 6 to 8 cm layer of clods [22,31,32,35,76,117,134,140]. The use of wood  
285 dowel between each clods [108] and the use of bed of stones and/or tiles between each layers of clods [31,108]  
286 were also mentioned. Once in the wall, clods of earth were compacted by the trampling of the craftsman who  
287 worked on the wall [14,16,17,20,46,54,87,100–102,125,140], by hand [47,84,131] and/or with a tool (fork, stick)  
288 [10,14,16,24,54,87,88,100,101,140]. As the cob mixture was implemented in plastic state, the material subsided  
289 under its own weight and tended to overflow. During the construction, sides of the wall were then regularly  
290 beaten with a stick, feet or a fork to tighten the faces of the wall [14,24,26,35,74,77,95,104,115,123].  
291 In the United Kingdom several authors referred to a “quick process” by opposition to a “slow process”  
292 [9,22,54,142]. The “slow process” is the technique described above, i.e. stacking of clods of earth in a lift, left to  
293 dry for several days or weeks before another lift could be implemented on it. The “quick process” consisted in  
294 stacking clods of earth in small courses (around 8 cm) separated by a layer of straw in a continuous way through  
295 the completion of the wall. According to McCann [22], walls were completed in 1 day thanks to the “quick  
296 process”. In this technique, fibre layers should have played a significant structural role at fresh state.  
297 In case (b) the cob mixture was spread on the ground in a 10 cm thick layer [124] and cut in squares of 20-25 by  
298 25-30 cm [24,35,131] with a sharp tool. These small rectangular blocks of cob could have been left to dry before  
299 they were placed in the wall [31]. They were then arranged in the wall in horizontal layers or in *opus spicatum*  
300 [31,32,35,76,98,124,131,140]. This technique is called *gazon* or *pâtons de mâssé* in Normandy [24,31,64,124]  
301 and *caillibotis* in Brittany [35].  
302 In case (c) the cob mixture was modelled by hand in a specific shape [82,83,111] (cylinder, ball, cigar, triangle)  
303 before to be stacked and compacted on the wall. *Massone* in Italy [52,143,144] and *Banco* in Africa  
304 [84,91,118,145] are some examples of this kind of technique. In Italy, unfibered cob mixture were modelled in  
305 the shape of cylinders called *massone* (8 – 15 cm in diameter and 30 – 40 cm long), rolled and covered by straw  
306 before they were implemented on the wall [52].

307 For case (d), several authors referred to the use of shuttering for cob wall construction [9,16,22,82,87–  
308 89,98,111,125]. This technique was called shuttered cob or puddled earth [9,22,87,107]. For example, shuttered  
309 cob is attested in Devon from around 1820 right up to 1914 [9,16]. According to Keefe [9], shuttered cob  
310 mixture is wetter than unshuttered one. Thus, in this case, drying times were long.

### 311 3.3.2 Lift subsidence

312 Since cob was implemented at plastic state, its mechanical resistance was low and the material subsided under its  
313 own weight during construction process. The height of wall done in a same time was limited. As a result, cob  
314 walls were a superimposition of successive monolithic earth raised, called lifts. A new lift was realized when the  
315 previous one was dry enough to bear the weight of the new lift without deforming [21,34,46,54,87,123,133]. The  
316 height of a lift varied with soil type, plasticity and stress applied on the wall during construction. Lift heights  
317 ranged from 10 to 120 cm with an average of 59 cm (Figure 4). Wall thicknesses ranged from 10 to 150 cm with  
318 an average of 62 cm (Figure 4). In 17<sup>th</sup> century and earlier, wall thicknesses was 80 to 90 cm or more  
319 [22,32,77,125]. It decreased to 50 to 60 cm in 18<sup>th</sup> century [9,22] and reached 50-45 cm during the 19<sup>th</sup> century  
320 [9,77]. With time and improvement of the technique, craftsman were more and more confident and built thinner  
321 walls [9,10,14,16,22,32,34,35,77,103,125]. Slenderness ratio ranged from 0.5 to 1.6 with an average of 1.0 and a  
322 standard deviation of 0.3 (Figure 5). Slenderness ratio of lifts is proposed as an indicator of convenience of earth  
323 and of associated process variation, the higher the slenderness and the better the convenience. Four classes of  
324 slenderness are defined for cob lifts (Figure 5).

325 Earth consistency depended on its clay content, which differ naturally from one soil to another, and its water  
326 content, which was determined by the cob mason, according to his building practices [9,16,31,34,55,126]. To  
327 realize higher lifts and save time, clods of earth with a firm consistency were preferred, i.e. on the “dry side” of  
328 the plastic state [9,14,100,126]. This is in contradiction with the optimal mixing water content suggested in  
329 section 3.2 (“wet side” of the plastic state). Several strategies have been employed to overcome this problem:  
330 some masons used a drier mix, which required higher kneading force or longer kneading action, some let cob  
331 mixture to dry before implementation and others used shuttering to ease the placing of wet mixture inside the  
332 wall [14,47,100].

333 Fibres were employed to assist handling of clods and provide extra strength to fresh cob lifts and therefore built  
334 higher lifts [9,10,16,22,26,31,84,100,117,118]. The higher the water content was and the higher the fibre content  
335 should be. This relationship was illustrated by Saxton [100].



## 336 3.3.3 Faces rectification

337 Another consequence of the sagging of cob lifts was the bulging of the material over the face of the plinth,  
338 creating an excess of material. Thus, faces of the wall had to be rectified  
339 [21,35,54,85,87,91,101,102,126,128,134]. This operation could have involved one or a combination of the three  
340 following actions: (1) trimming thanks to a special flat, sharp edged spade called “paring iron”  
341 [16,17,24,31,32,34,46,47,74,77,88,95,104,115,124,125,132,139–141,146,147] and sometimes a fork  
342 [35,76,78,108,121,146], a mattock [16], an adze [46,141], a saw [31,141], a shovel [49], a knife [47] or an axe  
343 [83]; (2) beating the faces of the wall thanks to a stick [26,31,35,47,88,95,109,124,139,140], hands [34,47],  
344 mallet [31] or stone [47] ; (3) scraping [134] overflowing material thanks to a fork [116,117,139,140] or a garden  
345 claw tool [139,140].

346 In case (a) (see section 3.3.1), cob was implemented in order to overhang the plinth of the wall creating a  
347 significant excess of material that has to be trimmed or scraped. This operation was carried on when the cob  
348 material was quite dry to avoid bulging of the lift but not too dry to ease the process [78,141]. Depending on the  
349 weather, it took place few days up to 3 weeks after the achievement of the lift  
350 [16,31,35,46,54,78,88,124,128,139].

351 The most cited trimming technique is the use of the paring iron. The trimming with the paring iron smoothed the  
352 faces of the wall, unless cob material contained oversized stones. In this case the paring iron edge pushed  
353 oversized stones down, creating vertically elongated cavities called *cheminées* (chimneys) in France [35,74,104].  
354 This was one reason why large stones were removed from earth (see section 3.1.1). Another imprint left by the  
355 paring iron is the downward orientation of fibres [139].

356 The faces of the walls were beaten in order to rectify the shape of the lift, to get the gravels inside the walls, to  
357 fold fibres down into the walls and to close the drying shrinkage cracks [26,35,88,95,124]. The beating of the  
358 faces of the cob lift could be performed before and/or after trimming and all along the drying period  
359 [35,88,95,124].

360 An example of an elaborate lift face rectification was provided by Bardel and Maillard [35]: the faces were  
361 trimmed thanks to a first specific paring iron, beaten and left to dry for 4 days before they were definitively  
362 trimmed thanks to a second specific paring iron.

363 For the cases b, c and d, it was usually not necessary to trim the cob lift, but the faces of the walls were generally  
364 rectified by beating actions [31,35,124].

365 When unrendered, the faces of the wall could have been smoothed by a trowel, hand or plaster float  
366 [88,108,120,133,134]. When rendered, faces of the wall could have been finger-marked in order to provide



367 roughness and a better key for the plaster [108]. Rectification process determined the final shape of the wall. It  
368 could have been straight [94] or tapered [24,31,34,47,78,88,95,108,116,139,140,144] to provide more stability to  
369 the wall.

### 370 3.4 Drying

#### 371 3.4.1 Drying time

372 Average drying times of a cob lift ranged from 11 to 21 days (Figure 6), depending on climate  
373 [9,24,31,34,35,47,49,76–78,85,88,97,104,105,116,118,123,125,139]. Then, the estimated time necessary to  
374 achieve cob walls, excluding “quick process” (see section 3.3.1), ranged from 3 to 20 weeks  
375 [21,22,24,105,125,131].

376 Drying of lifts was a major time constraint of cob process. Drying was only possible during hot months of the  
377 year, thus imposing a “season of cob” [14,19,21,26,35,74,104,107,124,125,139]. The implementation of cob on  
378 “dry side” of plastic state could accelerate the drying process. It was also suggested that fibres played a role to  
379 ease drying by channelling water from the core of the wall to its outer face [9,14,19,26,35,100,107]. Anyhow,  
380 cob walls had to be dried before the first frost to avoid damages [108].

#### 381 3.4.2 Shrinkage

382 As the cob material dried, it shrunk and shrinkage cracks could expand inside the lift. If this expansion was too  
383 large, this could lead to structural damages. Shrinkage rates depended on clay content and manufacture water  
384 content of cob mixtures, high clay content and high manufacture water content leading to high shrinkage rate  
385 [9,100,126]. Several strategies were employed by former cob masons to restrain shrinkage effect. Drying first  
386 concerned faces of lifts where shrinkage cracks were initiated. This was the reason why faces of lifts were  
387 rectified, by beating the faces in order to close shrinkage cracks and/or by trimming excess cob material in order  
388 to cut the shrunk outer part of lifts (see section 3.3.3).

389 Another strategy was to use a cob mixture constituent as “shrinkage crack barriers”. This constituent could have  
390 already been present inside the natural soil (gravels) or added on purpose (gravels, sand, fibres, branches, wood  
391 pieces, adobes ...) and it could have been evenly distributed or arranged in a specific manner (Figure 7). Layers  
392 of fibre, of stone or a course of adobe laid inside or between each lift [9,34,106,128,139] can be interpreted as  
393 “shrinkage cracks barriers” [34,128] (Figure 7). The aim of those barriers was to stop the expansion of shrinkage  
394 cracks thus avoiding their coalescence and therefore the development of large cracks [9,16].

395 This distribution of shrinkage cracks throughout the wall mass is well documented for fibres  
396 [9,14,16,19,22,24,26,34,49,100,107,128,129]. Tensile strength of fibres embedded in the cob matrix is a

397 supplementary factor that participated to the resistance to crack opening [9,100,129,148,149]. When enough  
398 gravel was present in the earth material to contain shrinkage cracks, fibre addition was not necessary [35].

#### 399 4 Discussion

##### 400 4.1 Proximity of earth construction processes

401 Compressed Earth Bloc technique is quite dissimilar from cob. On the contrary, adobe, wattle and daub, rammed  
402 earth, and plasters do have similarities with cob. Rammed earth differs from cob since it is a dry technique  
403 requiring a compactive effort [96,107]. A confusion comes from the use of shuttering for both rammed earth and  
404 shuttered cob [17,139]. For rammed earth, shuttering are employed to make the ramming process efficient,  
405 whereas for shuttered cob, shuttering are employed to avoid the trimming of the faces of the wall and therefore  
406 accelerate the wall faces rectification stage [17,107].

407 Wattle and daub, plasters and adobe mixtures are prepared in a similar way to wet cob mixture [150]. However,  
408 maximum particle size diameter is higher for cob mixture than for wattle and daub, plasters and adobe mixtures  
409 [9].

410 Wattle and daub is quite different from cob since earth is infilled in a timber frame and do not play any structural  
411 role [32] as well as plasters that are overlaid on wall face. It should be noted that some authors related the use of  
412 both cob and wattle and daub inside the same building [35,140].

413 Adobe and the cob process variations that consist in stacking cut or modelled plastic elements (case b and c,  
414 section 3.3.1) are quite similar, but adobes are dry implemented and require to be grouted with a mortar, whereas  
415 cob elements are implemented without mortar [32,35]. It should be noted that some authors related the use of  
416 both cob and adobe inside the same building, or next to each other [9,106], or together with an alternation of  
417 courses of adobe and cob [34].

418 Proximities between cob and other earth construction processes can be drawn at mixture and implementation  
419 stages (Figure 8). This proximity can be the result of mutual technical exchanges and/or shared past of earth  
420 construction processes. There is a link between earth construction processes and cob can be regarded as a link  
421 between adobe and rammed earth (Figure 8).

##### 422 4.2 Identification of key points of cob process

423 This bibliographical analysis allowed us to identify three key points in cob construction process: (1) the mixing,  
424 since constituents of cob mixture should be evenly distributed, (2) the consistency of the cob mixture during  
425 implementation, since it should not subside too much in order to build higher lifts and (3) the management of  
426 shrinkage cracking, since no structural damage cracks should propagate inside cob walls (Figure 7). Considering  
427 that raw materials were natural and locally sourced, cob masons had to do with available materials. Earth type

428 was the major constraint that dictated construction strategy (particle size distribution, clay content, clay activity,  
429 maximum particle size).The variety of strategies employed by former cob masons at each stage of cob process is  
430 illustrated in this paper (Figure 3) and it is possible to estimate that, at least, hundreds of variations existed for  
431 this process. In addition to technical constraints, cob construction had to face two major social constraints: (1) it  
432 was a slow process, since it took months to build the walls and (2) it was a labour intensive process thus  
433 requiring mutual aid system to make it competitive. Those constraints were not adapted in the Western societies  
434 of the 20<sup>th</sup> century and this enforced cob masons to develop mechanization and prefabrication.

#### 435 4.3 Cob, a process in constant innovation

436 Cob is a slow and labour intensive process. Cob masons have experimented alternative construction techniques  
437 in order to ease the construction process and to save time. Generation after generation, cob masons better  
438 understood the behaviour of the material and enhanced their techniques. This innovation process is highlighted  
439 by the reduction of wall thicknesses, as illustrated in section 3.3.2. The use of animal power for mixing, the  
440 development of specific cob tools, the “quick process” and the use of shuttering are other examples of past  
441 innovations.

442 More recent cob innovations involved: (1) use of damp proof courses, (2) prefabrication, (3) mechanization and  
443 (4) new mixing and implementation techniques.

444 Plinths of heritage cob walls are made of stones and earth or lime mortar  
445 [17,30,35,41,46,54,74,78,87,88,102,104,125,126,151] that drove capillary rise. Consequently, cob walls were  
446 exposed to humidification by capillary rise. If excess water is not evacuated from the wall, water content of the  
447 cob wall can rise and lead to poor thermal comfort and/or structural damages [9,16,30,87,152]. In Germany,  
448 layers of compacted clay underneath foundations of cob heritage buildings dating back to 17<sup>th</sup> up to 19<sup>th</sup> century  
449 were interpreted as poor damp proof courses [10]. The first mention of efficient damp proof courses made of  
450 bitumen cardboard concerned cob houses in the beginning of the 20<sup>th</sup> century [10,15]. The use of cement  
451 concrete in lieu of stone masonry for the plinth during the 20<sup>th</sup> century also participated to the protection in the  
452 cob walls from capillary rises [50,78,153].

453 Prefabrication of cob elements is a way to reduce the wall fabrication time [53]. Plastic elements of earth cut or  
454 modelled (case b and c, section 3.3.1), i.e. *Gazon*, *Massone* or *Banco* techniques, can be regarded as  
455 prefabrication techniques. The regular shape of earth elements eased their placing on the wall and their dry-  
456 plastic state accelerated the drying of the wall. Joce [21], in 1919, proposed a cob prefabrication process which  
457 however seems that it had never been employed. Another prefabrication process has been developed and  
458 employed by Jean Guillourel in Brittany in the 1980's [94,154,155]. Cob mixture was casted in a mould that

459 contained two hooks attached to three wooden pieces disposed on the bottom of the mould. Hooks were used to  
460 handle cob elements. Cob elements were unmoulded 24 h after casting and left to dry for 1 month. Height of the  
461 prefabricated cob elements was 50 cm, thickness was 40-50 cm and length was 50-70 cm. Elements were  
462 assembled in the wall thanks to a crane and jointed with an earth stabilized mortar [94,154,155].  
463 Mechanization of the mixing of cob reduced the number of workers required, the work painfulness and should  
464 improve the mixing action. The first mention of mechanization of the cob mixing was made by Clough  
465 Williams-Ellis in 1920 [125]. The author stated that a power-driven “pan-mill” has been tried with success.  
466 Since, attempts have been made to mix cob, using machine such as concrete mixers [9,19,64,100,126], mortar  
467 mixers [9], vertical shaft mixer [31,94,154], rotavator [9] and clay brick mixer [52]. The kneading action of most  
468 of those machines was too little to force the straw and clay into contact. Thus, they required a higher  
469 manufacture water content, which increased the drying time. Those machines are considered as inappropriate for  
470 cob mixing [9,19,64,100,126]. Another mechanized technique developed in England consist in treading the cob  
471 mixture thanks to the wheels of a digger and in stirring it thanks to the digger bucket [9,14,19]. The mixing  
472 action of the digger is judged satisfactory but, as for other mechanized techniques, it required higher  
473 manufacture water content. It was then necessary to let the cob mixture to dry for a while before implementation  
474 [9,14].  
475 New mixing and implementation methods were developed in the USA during the 1980’s and 1990’s  
476 [50,55,64,153]. These methods introduced the use of tarp to stir the cob mixture and the implementation of cob  
477 by hand, using a thumb, a stone or a stick. Reedcob is a new cob implementation technique developed in  
478 Portugal that consists in employing giant reed cane as bond beams [156].  
479 Joce [21] did a clear distinction between an old-fashioned cob method and a modern one with prefabricated  
480 elements. In fact, it is quite difficult to draw a line of demarcation between an old cob process and a modern one.  
481 As highlighted above, innovations concerned the past period of the cob process as it concerned the modern  
482 period. Modern cob is in the continuity of vernacular cob.

#### 483 4.4 Cob and society

484 Social, economic and technical evolutions of societies had a great impact on the evolution of the cob process  
485 [4,42,76]. Until early 20<sup>th</sup> century in Europe, masons moved by foot or by bicycle and building materials were  
486 transported by animal-drawn tumbrel [74,77,105]. Consequently, masons had to use locally available materials  
487 and had a range of action restricted to a few kilometres [74,75,77,80,87,122]. This isolation was more dramatic  
488 in marshlands [27,88,110]. Cob construction process know-how was orally transmitted generation after  
489 generation [9,22,24,31,43,46,118] and the limited transportation means did not foster the exchange of know-how

490 between cob masons. This generated local practices and habits for construction [42,75,77,87]. This is illustrated  
491 by the variety of names given to cob mixture in Brittany that were different from a town to another [75,76]. In  
492 Europe at the end of 19<sup>th</sup> century, the railway brought stones and new construction materials (brick and cement)  
493 that entered in competition with cob [42,80,87,98,110,119,125,126].

494 Cob site work required an important workforce [154]. Usually, a skilled cob mason, eventually accompanied by  
495 1 or 2 employee or apprentice, conducted site operations [74,78,87,105]. Workforce was supplemented by the  
496 owner helped by his family and his neighbours [74,88,104,120]. Sometimes cob houses were self-build by the  
497 owner [32,78,84,87,94,118]. In all cases mutual aid brought by the neighbours' workforce was essential to face  
498 cob site work [118,119,154]. Mutual aid relied on the reciprocity of favours. In Brittany, another way to  
499 motivate neighbours to give a hand on site involved free cider, traditional music and songs to make them dancing  
500 and singing while treading cob [76,90]. Rural migration depleted available workforce and know-how, and  
501 commodification broke rural solidarity [24,35,43,97,118,119]. Without mutual aid system, labour charge became  
502 unaffordable for a part of the rural population [1,154]. Mechanization of the process was an answer to this issue  
503 [1].

504 In Europe, before 1900, because cob houses were cheap to build, it was the unique affordable construction for a  
505 part of the population [1,74]. For them it was therefore not a choice but a constraint that highlighted their social  
506 class [157,158]. Therefore, for a large part of the population, cob was synonymous with poverty, archaism,  
507 unhealthiness and low strength [9,26,38,42,78,84,88,97,98,144,154]. This is why where stones were available it  
508 was preferred to earth as a building material [24,35,80,104,159]. Earth was considered as a default material  
509 choice [74]. However, some authors noted that in late 19<sup>th</sup> and early 20<sup>th</sup> century, high status buildings were built  
510 in cob (manors, schools, town halls, churches) proving that cob is not only a building material for the poor  
511 [4,14,17,32,38,87,154,159–161]. Nevertheless, with the introduction of industrial building materials (brick,  
512 cement), regarded as a social symbol of modernity, cob fell into disuse [9,26,42,84,97,125,144,157].

513 Finally, political decisions also had a great influence on cob construction. For example, the old regime land law  
514 in Brittany [98,119,160] and an old tax on bricks in the United Kingdom [22] supported cob construction sector.  
515 On the contrary, building regulations were established without regard to cob, which was a major obstacle to the  
516 development of the sector [16,87,97,126,162]. Building regulation is still an obstacle for modern earth  
517 construction [2].

518 4.5 The future of cob process

519 Vernacular cob construction has many environmental, social and health benefits (see section 1) and is therefore a  
520 source of inspiration in order to reduce the impact of modern building sector. Nonetheless, this slow process was

521 time consuming and required a large workforce, which is inappropriate in West modern economies  
522 [1,14,52,53,163]. In order to comply with this economic constraint, two options can be identified for cob: the  
523 recourse to self-build houses or the recourse to mechanisation and/or prefabrication (see section 4.3). Self-  
524 builders have little site equipment and usually use the vernacular, low-impact, process. This solution may  
525 however satisfy only a small part of housing needs. The other solution is to go on with the development of  
526 mechanized/prefabricated cob process. These processes may however consume more energy and fewer  
527 workforces than the vernacular one, thus reducing environmental and social benefits.  
528 The cob material source is another issue, since earth is a natural material and varies from a site to another. To  
529 overcome these variations, two different approaches are observed: (1) adapt the material to the process, thanks to  
530 a granular correction [10,81], forcing its particle size distribution into a grading envelop predetermined in  
531 laboratory and/or addition of hydraulic binder [164–167]. These solutions reduce the environmental benefits of  
532 cob [2]; (2) adapt the process to the material [2,14,168]. This solution optimizes the consumption of natural  
533 resources and relies on the expertise of skilled craftsmen, architects and on performance tests. It therefore  
534 requires the education of specialist of cob construction.

535 Cob, like other earth construction process, encounters a renewed interest thanks to its low environmental impact.  
536 However, the economic and regulation constraints of the building sector impose to speed up the construction  
537 process and to strengthen the material, which reduces cob environmental and social benefits. A balance has to be  
538 found between a zero-emission vernacular material and a fast implemented and strengthens material. The future  
539 of cob will be the result of an optimization of the economic and environmental sustainability of the process.

## 540 5 Conclusion

541 Better describing and understanding cob technique will permit an appropriate care and repair of cob heritage  
542 buildings and to consider its application in the field of modern sustainable building. Cob is one of the less  
543 studied load bearing earth construction technique, whereas its large widespread evidenced its adaptation to  
544 different soil natures, climates and social needs across the world. Cob technique participates to the diversity of  
545 earth construction processes. This diversity is a key to promote the use of locally available and unprocessed  
546 construction materials, as it broaden the range of sustainable construction solutions and therefore the possibility  
547 to find a sustainable construction process adapted to a local context.

548 Cob masons expertise was orally transmitted, therefore little written materials exists on the description of cob  
549 vernacular process. To go further on the description of this process, it is necessary to describe and analyse  
550 existing cob heritage buildings. Scientific methods should be developed to go on with this rediscovering  
551 movement.



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905 Caption for figures

906 *Figure 1. The oldest attested cob building of Brittany, located in La Chapelle-Thouarault and dating back to*  
 907 *1608 [35]. This picture was taken in 1975 (Service de l'Inventaire du Patrimoine Culturel © Région Bretagne).*

908 *Figure 2. Earth construction processes classification, adapted after [9,17,71]. Distinction is made between load*  
 909 *bearing and self-sustaining techniques (bearing) and non-load bearing techniques (non-bearing). ( $W_m$  =*  
 910 *manufacture water content,  $W_{OP}$  = optimum Proctor water content;  $W_P$  = water content at plastic limit;  $W_L$  =*  
 911 *water content at liquid limit)*

912 *Figure 3. Summary of vernacular cob process. Water contents are to be regarded as order of magnitudes.*  
 913 *(elements in brackets are optional;  $W$  = water content,  $W_L$  = water content at liquid limit,  $W_P$  = water content at*  
 914 *plastic limit,  $W_{SH}$  = Water content at shrinkage limit)*

915 *Figure 4. Cumulated citations of minimum (Min) maximum (Max) and average values of cob lift height and cob*  
 916 *wall thickness.*

917 *Figure 5. Cumulated frequency of lifts slenderness ratio together with average slenderness ratio (1.0 with*  
 918 *standard deviation of 0.3) and average +/- standard deviation. Slenderness ratio are divided into 4 classes :*  
 919 *Low (< 0.7), Medium low (0.7 – 1.0), Medium high (1.0 – 1.3) and High (> 1.3).*

920 *Figure 6. Cumulated citations of minimum (Min) and maximum (Max) drying time of cob lifts, together with*  
 921 *calculated average minimum drying time (Min average) and average maximum drying time (Max average) of*  
 922 *cob lifts.*

923 *Figure 7. Crack shrinkage barriers placed between lifts (a: layer of fibre or wood, b: layer of stones, c: layer of*  
 924 *adobe), between clods of earth (d: between each clod, e: between each layer of clods) or inside the matrix (f:*  
 925 *fibres, g: gravels)*

926 *Figure 8. Cob process stages and related earth construction processes*

927 Table captions

928 *Table 1. Geographical distribution of cob construction process description in bibliographical references. France*  
 929 *and United Kingdom together represent 72 % of the bibliographical references.*

930 *Table 2. Vernacular names of cob construction process.*

931 *Table 3. Maximum particle size diameter, fibre type, preparation and length, fibre content (when data are given*  
 932 *for 1 m<sup>3</sup> of earth, a density of 1600 kg.m<sup>-3</sup> for earth has been considered to calculate the fibre content by mass,*  
 933 *those calculated fibre content are labelled \*) and manufacture water content by weight of cob mixture according*  
 934 *to literature.*

935 *Table 4. Number of citation and bibliographical references of different fibre type employed with cob.*

936 Figures with captions

937



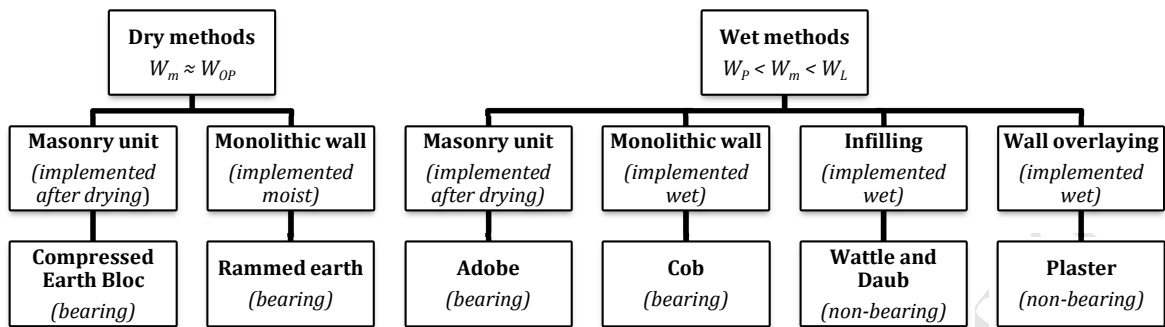
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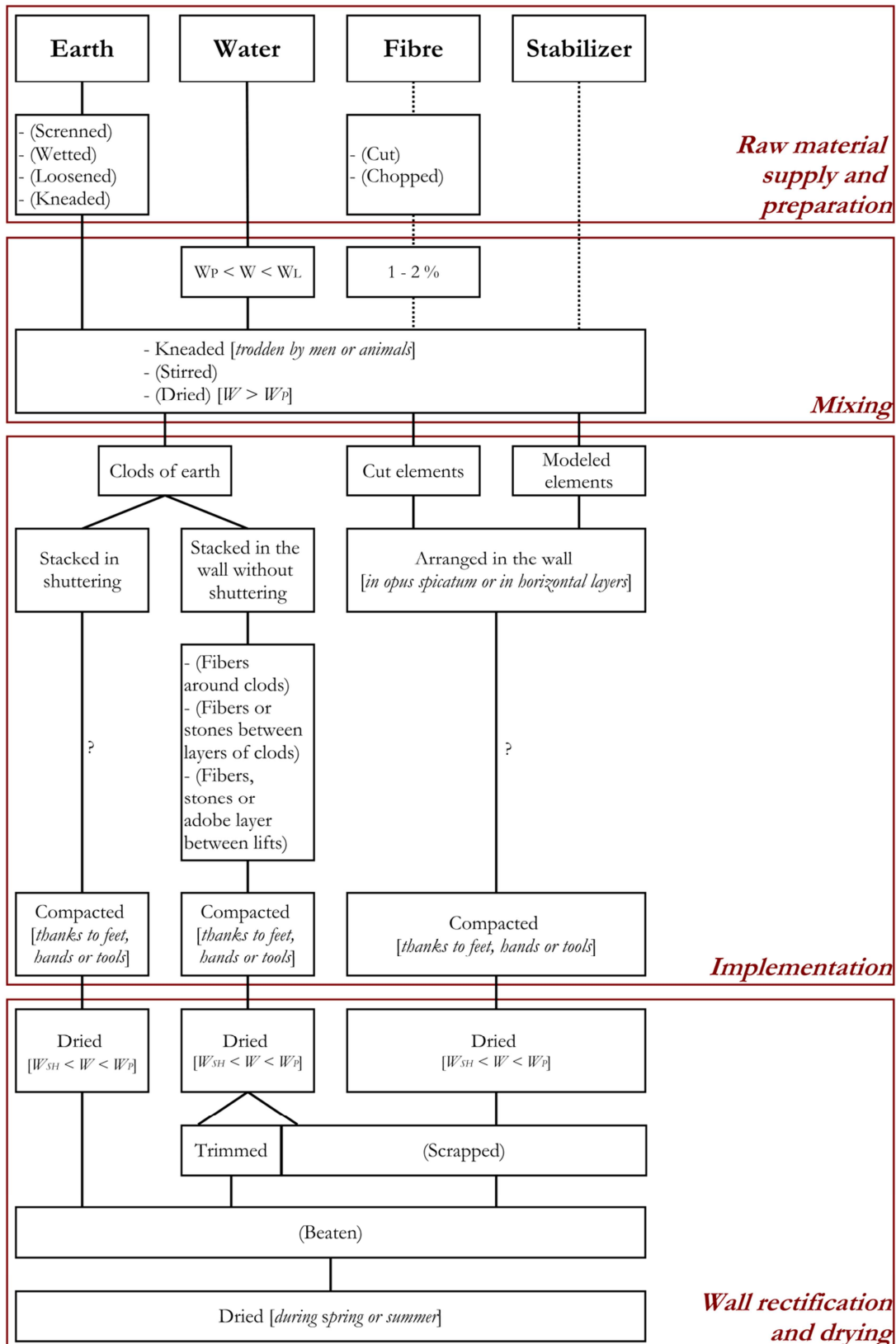


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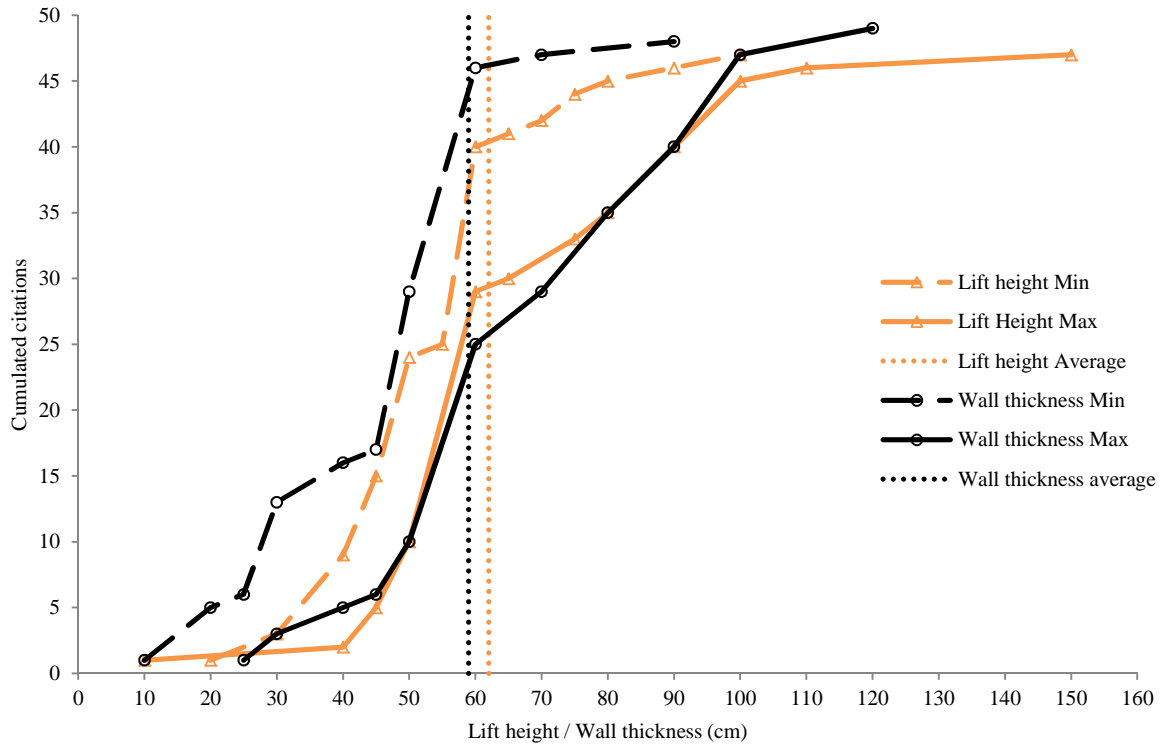




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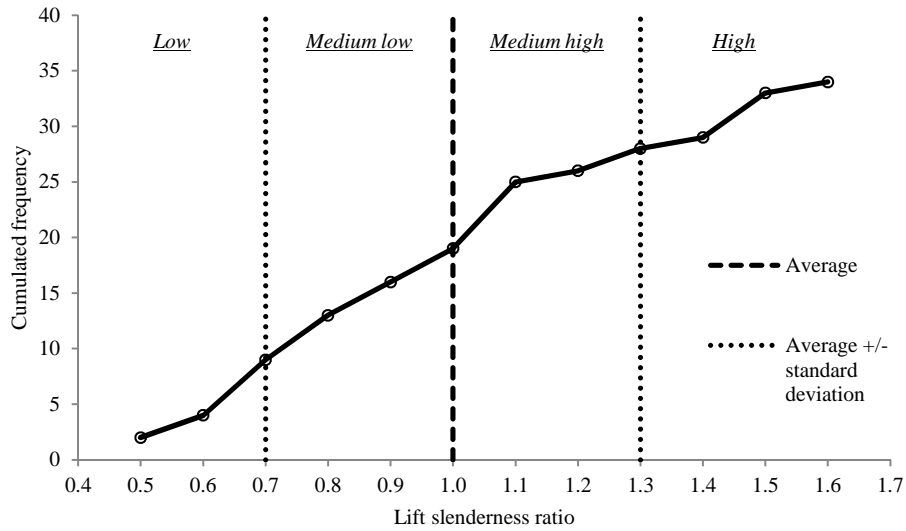


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956 *Figure 4. Cumulated citations of minimum (Min) maximum (Max) and average values of cob lift height and cob*  
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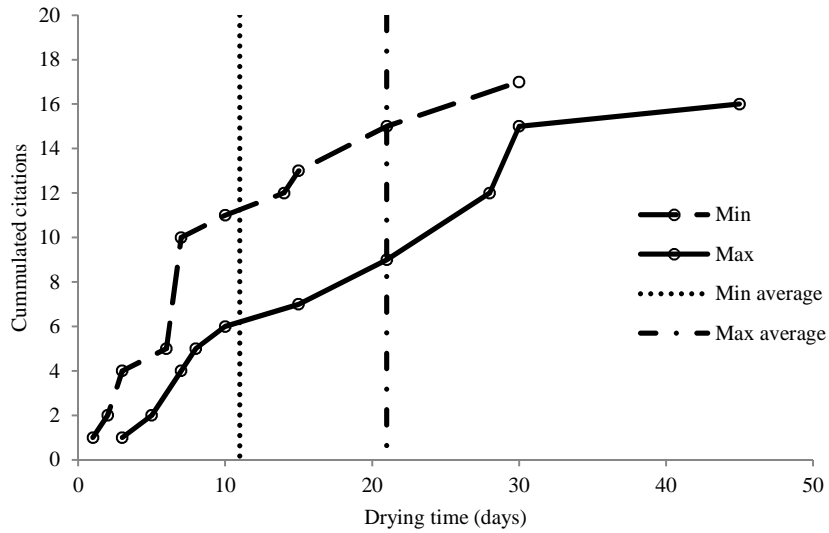
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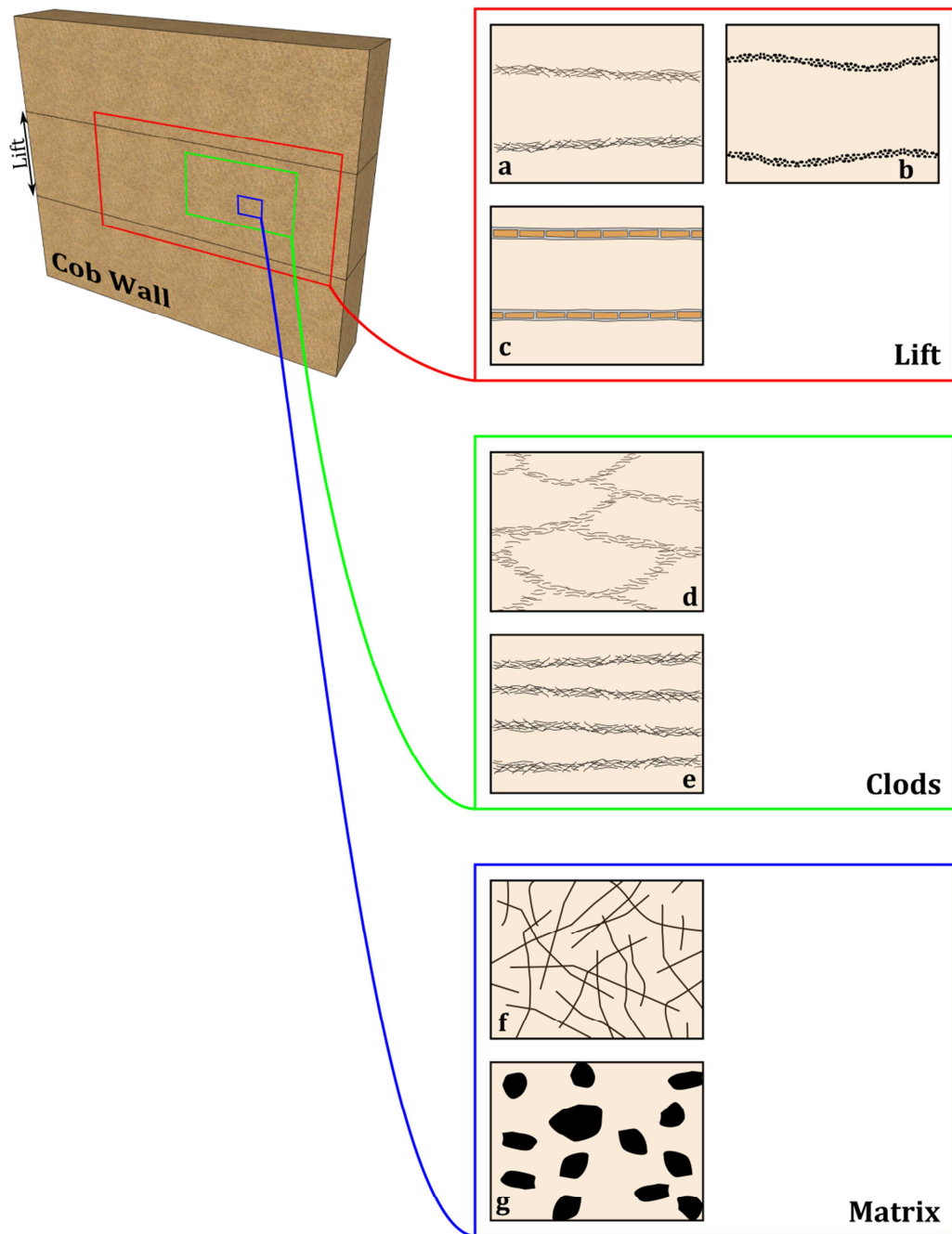
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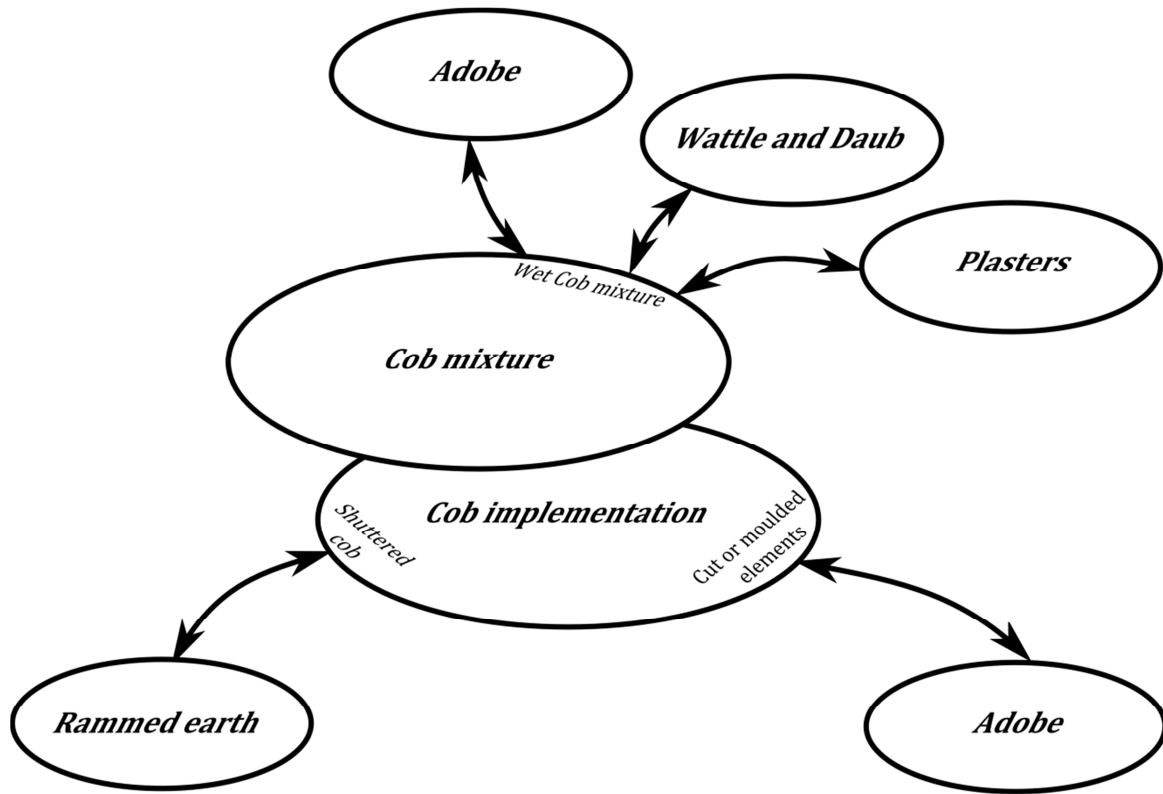


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970 *Figure 7. Crack shrinkage barriers placed between lifts (a: layer of fibre or wood, b: layer of stones, c: layer of*971 *adobe), between clods of earth (d: between each clod, e: between each layer of clods) or inside the matrix (f:*972 *fibres, g: gravels).*

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979 Tables with captions

980

981 *Table 1. Geographical distribution of cob construction process description in bibliographical references. France*982 *and United Kingdom together represent 77 % of the bibliographical references.*

Country	Number of citation	References
Afghanistan	3	[34,128,131]
Belgium	1	[73]
Burkina Faso	1	[120]
Czech Republic	3	[82,83,111]
France	59	[18,26–29,31–33,35,43,57,62,74–77,80,85,88–90,92–98,104,106,108–110,116,117,119,121,124,134,139,140,146,154,155,157,159,160,169–180]
Germany	4	[10,15,30,91]
Ghana	1	[131]
Hungary	1	[36]
India	3	[34,131,133]
Iran	1	[47]
Ireland	2	[107,181]
Italy	3	[52,143,182]
Ivory Coast	1	[118]
Madagascar	1	[94]
Mali	2	[145,183]
New Zealand	3	[37,51,55]
Nigeria	2	[79,127]
Senegal	1	[118]
Slovakia	1	[83]
Sudan	1	[131]
Tajikistan	1	[34]
Togo	2	[84,118]
Turkey	1	[36]
Turkmenistan	2	[34,184]
United Kingdom	44	[14,16,17,20–25,38,41,42,44–47,49,54,78,81,86,87,100,102,103,105,107,115,122,123,125,126,151,152,162,185–193]
United States of America	4	[37,50,91,153]
Yemen	1	[47]

983

984 *Table 2. Vernacular names of cob construction process.*

Country	Local names	Reference
Afghanistan	pakhsa	[34,36,101,128]
Belgium	tourton	[73]
Czech Republic	nakladani, valek, války	[36,83,111]
East Africa	daga	[36]
France	bauge, bigôt, bouzillage, caillibotis, coque, daube, gachcoul, mâtse, mâtssé, mur d'argile, paio-bard, paillebart, paillebort, palho-bard, pâtons de mâtssé, terre, torchis	[18,24,27,31,35,36,95,105,108,110,121,150,173,179]
Germany	lagenlehmbau, lehmweller, wellertechnik	[15,36]
Hungary	valgoy	[36]
Iran	chineh	[36,101]
Iraq	tawf	[36]
Ireland	tempered clay	[107]
Italy	atterati, maltone, massone,	[36,144,194]
Madagascar	tamboho, tovam-peta	[36,94]
Portugal	terra empilhada, terra modelada	[36,194]
Spain	chamizo, muro amasado, pared de mano, terra apilado, terra amassado, fang	[36,194]
Slovakia	lepanice, nakladana stavba, vykladanie, valok	[36,82,83]
Sudan	jalous	[131]
Turkey	pahsa	[36]
United Kingdom	clay dab, clay dabbin, clob, clom, cob, dab, daubin, dung wall, korb, mudwall, mud walling, puddled earth, tai clom, tai mwd, tai prid, witchert, wychert	[9,14,17,22,46,87,101,107]
West Africa	banco, banko, terre de bar, swish	[36,120,131]
Yemen	zabour, zabur	[17,36]

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986 Table 3. Maximum particle size diameter, fibre type, preparation and length, fibre content (when data are given  
 987 for 1 m<sup>3</sup> of earth, a density of 1600 kg.m<sup>-3</sup> for earth has been considered to calculate the fibre content by mass,  
 988 those calculated fibre content are labelled \*) and manufacture water content by weight of cob mixture according  
 989 to literature.

Reference	Maximum particle size diameter (mm)	Fibre type	Fibres cut	Fibre length (cm)	Fibre content by weight (%)		Manufacture water content (%) by weight
					Minimum	Maximum	
[169]		straw	Yes				
[169]		hay	Yes				
[87]					1.3		
[75]		furze	Yes	10 – 15			
[75]		straw	Yes				
[98]	80 – 100	straw	Yes				
[116]		straw	Yes	15 – 20			
[119]		straw	Yes				
[131]		straw	Yes				
[97]		straw	Yes	15 – 20			
[76]		straw	Yes	15 – 20			
[117]		straw	Yes				
[78]		straw	Yes	40			
[105]		straw	Yes	60			
[104]		straw	Yes	60			
[24]					1.6*		
[47]					0.3*	1.0*	
[88]					1.6*		
[16]	50						
[100]					1.0	2.0	
[126]	50 – 60	straw	Yes				
[172]		straw	Yes				
[162]					1.5	2.0	
[55]		straw	No				
[90]		straw	Yes	15 – 20			
[124]					1.6*		
[25]					2.0		18
[15]		straw	No	70			
[173]		straw	No				
[173]		hay	No				
[91]		straw		40 – 50			
[81]	50						18 – 25
[74]		heather	Yes				
[95]					1.6*		
[102]		straw	Yes				
[9]		straw	No		1.0	1.5	
[54]		straw	Yes				
[85]							10 – 20
[14]	50						18 – 25
[10]		straw	Yes	30 – 60	1.4*	1.8*	
[135]		straw	Yes	30 – 50	1.3*	1.9*	
[79]		straw	Yes				
[147]							15 – 30
Average					1.4	1.7	-

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991 *Table 4. Number of citation and bibliographical references of different fibre type employed with cob.*

Fibre	Number of citation	References
animal hair	4	[14,88,107,124]
barley straw	8	[14,16,22,97,102,107,116,126]
bean pod	2	[76,98]
broom	5	[22,33,35,74,95]
cow parsley	2	[14,107]
fern	5	[22,24,31,33,140]
flax	3	[14,19,107]
furze	11	[14,31–33,74,75,98,104,107,108,119]
grass	6	[14,24,88,95,104,107]
hay	22	[14,16,22,24,26,31,35,74–76,88,95,98,104,107,110,121,124,140,169,173,179]
heather	18	[14,19,22,24,32,33,35,41,74–76,98,104,106,107,119,139,140]
leaf	1	[118]
moss	2	[14,107]
needle	1	[108]
oakum	3	[75,76,98]
oat straw	12	[14,19,31,64,74–76,89,98,104,107,119]
quack grass	2	[14,107]
reed	2	[19,107]
rice straw	2	[64,183]
root	1	[118]
rush	8	[14,22,24,31,88,95,98,124]
rye straw	7	[10,15,19,26,35,64,74]
sedge	5	[14,107,108,110,121]
straw	47	[9,20,22,24–26,32,33,35,46,47,49–52,55,74–77,83,84,87,90,95,98,100,105,106,108,110,115,117–119,121,123,128,131,140,144,153,162,169,173,179,183]
stubble	2	[87,92]
twig	6	[14,16,24,26,35,107]
vine shoot	1	[139]
wheat straw	13	[10,14–16,19,31,64,78,89,97,102,104,126]

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