CobBauge – A hybrid walling technique combining mechanical and thermal performance

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Introduction

Cob is a vernacular raw earth building technique common in Europe and especially in the north-west of France and the south-west of England (Figure 1). This mixture of often silty-clayey soils and plant fibres used in a plastic state, generally with the help of simple tools and without formwork, made it possible to build the thick load-bearing walls of thousands of buildings. Apart from the archaeological remains from Roman, Gaulish and medieval times, most of the present heritage was built between the 16th and 19th centuries.

This technique, along with other earth materials was subsequently abandoned in favour of industrial materials deemed to be more efficient, but cob has experienced renewed interest since the 1980s, particularly in England. The ease of implementation, the simplicity of the tools, the formal freedom that it allows, and its low environmental impact have made it a technique particularly appreciated by self-builders. A number of architects, engineers and craftspeople have nonetheless taken it up and have created several remarkable contemporary projects (Figures 2 & 3).

Unlike rammed earth, which has gained an aesthetic following, the use of cob in contemporary architecture is still very marginal. While cob's cost price is generally lower than rammed earth and is less sensitive to bad weather during the construction phase, and its use of plant fibres stores carbon and thus reduces greenhouse gas (GHG) emissions, it does not seem to enjoy the same popularity and has not managed to seduce the designers.

As is often the case with vernacular techniques, cob is also not so able to comply with increasingly demanding thermal regulation stipulations aimed at reducing climate change. Traditionally its low thermal resistance does not allow it to achieve the required performance. Values in the literature specify a U-value of ~2.26 W/m²K for a 50 cm thick wall in England (in research by Rye and Scott, 2012), between 1.2 and 1.4 W/m²K in Germany (Ziegert 2003, Volhard 2016), both of which remain far below the levels specified in French (0.11 W/m²K < U-wall < 0.33 W/m²K) and English (UK Building regulations-Part L1A: Uwall < 0.3 W/m²K) regulations.

The objective set by the partners of the CobBauge project – the University of Plymouth, ESITC Caen, University of Caen, Pnr des Marais du Cotentin et du Bessin, EBUKI , Hudson Architects, project funded by the INTERREG 5a (FCE) program of the European Union –is therefore to find an optimum mixture making it possible to achieve the required performance levels while designing the construction process to increase efficiency and reduce construction costs.

Optimisation of materials and laboratory tests

To achieve this objective, a range of 12 different soils representative of the variety of soils available in north-west France and the south-west of England were chosen. The same logic was applied to the choice of six types of fibres from four plants present in the environments or cultures of the same regions. Flax and hemp in the form of raw straw and shives, wheat straw traditionally used in cob construction, and reed, a potential resource from wetland maintenance. The geotechnical characteristics of the soils were determined, including particle size distribution, clay content by laser diffraction, clays activity and proctor tests. The tensile strength and the water absorption capacity of the fibres were also determined.

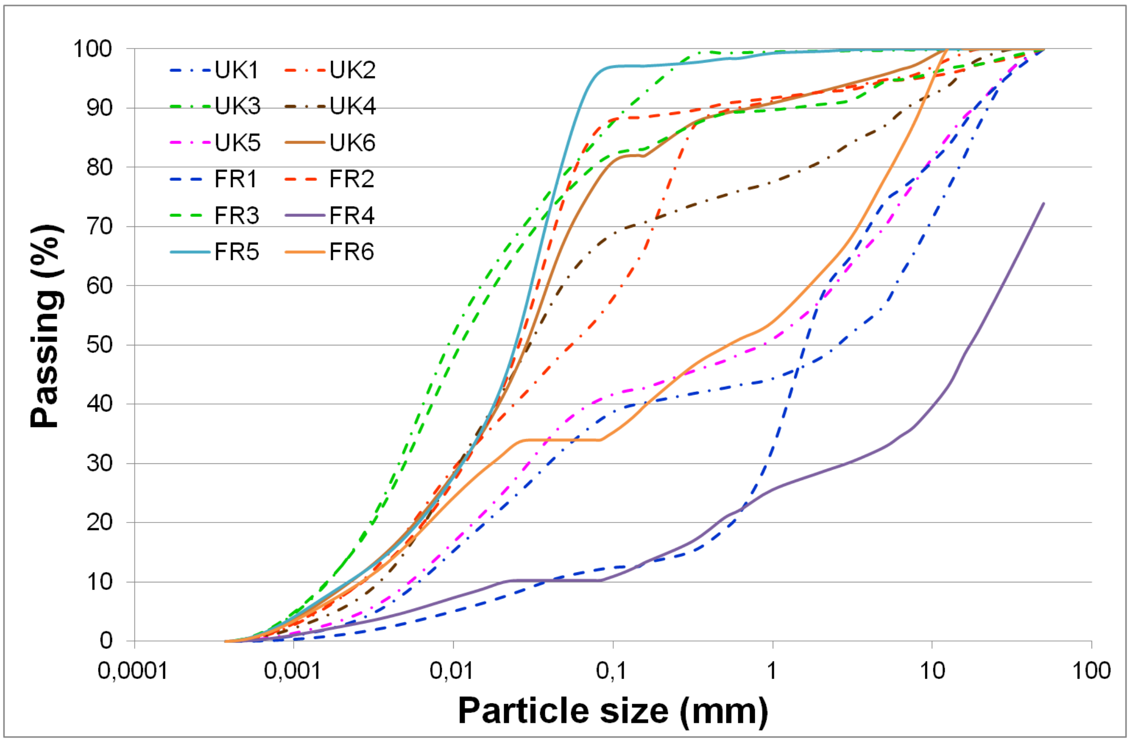

Table 1: Particle size distribution of the different soils.

Fibre	Wheat straw	Flax straw	Hemp straw	Reed	Hemp shiv	Flax shiv
Water absorprtion after 24h (%)	309	185	336	200	266	320

Tensile strength (MPa)	29	112	73	129	/	/
Absolute density (g/cm³)	1.182	1.337	1.391	1.390	1.410	1.455

Table 2: Properties of the fibres.

Parallel to this, the builders involved in the project employed their know-how to produce samples of a single soil at two levels of water content (at limit states from firm plasticity to viscous) with a view to assessing the impact of the fibres on the plasticity of the mixture depending on their proportion and their absorption capacity. Each plastic sample was assessed by crushing (dropping 1 l of mixture from a height of 1 m onto the ground) to determine the plastic limit of the mixtures usable in cob construction. Dried cubic samples were tested for compressive strength (Figure 4). These values made it possible to determine set common fibre contents and water contents for the laboratory tests.

An experimental plan was established from the six fibres and six soils retained after geotechnical analysis so as to be able to extrapolate the behaviour of each possible different mixture. The samples were tested for compressive strength and thermal resistance.

These tests confirmed the relationship between density and thermal resistance, but also the influence of the characteristics of soils and fibres used. Two silty clay soils and two fibres (flax and hemp in the form of raw straw) were identified as giving the best structural results (compressive strength at 2% shrinkage between 0.95 and 1.5 Mpa) while two other fibres (crushed reed and hemp shives) and two other clay soils were selected for thermal properties (lambda value between 0.10 and 0.15 W/mK for a density between 360 and 500 kg/m³).

The measurements also showed that it was impossible to reconcile the ability to bear load and insulate in a single mixture. The densities required for good loadbearing capacity have poor thermal properties and vice versa. In the densest mixtures, varying the fibre content has very little impact on the thermal resistance, but considerably affects the mechanical resistance. In low density mixtures, varying the fibre content has little effect on the mechanical strength but considerably modifies the thermal resistance. The upshot of this experimental investigation was the realisation that a composite wall technique would be needed in which one part provides the loadbearing function and the other the insulating function.

How to construct?

The obvious need to use two different mixtures raises a fundamental question about the constructive process. Should we make the loadbearing wall and then insulate it? What is the point of placing a wet mixture of light earth against a loadbearing cob wall once it is dry, thus incurring two long periods of drying, impacting indirectly on the efficiency and cost of construction?

The traditional cob technique consists of mixing earth, water and fibre using the feet of people or animals, then stacking clods by hand or using a fork, without formwork. During this process, a generous amount of material is used and the overflow then trimmed to size after a short drying time to produce the final face. The surface obtained can then be rendered or beaten to densify the surface and finish the wall.

In addition to the fairly long work of mixing, paring the walls is a task that places considerable strain on the workers. Many contemporary companies have therefore experimented in adapting the technique for use with mechanical devices such as mixers or diggers. A few attempts at formwork have been tried, making it possible to reduce a good part of the work of cutting the walls but these were never significantly developed, probably because formwork removes some of the flexibility and simplicity of the constructive process. However, one method explored in Normandy almost 10 years ago, in which cob is applied to metal gabion structures went on to inspire the creation of formwork regularly used since then, made of a metal framework supporting a skin of mesh.

Light earth has, for its part, been the subject of numerous tests and developments, notably in Germany (Volhard) and France (Marcom), both with respect to the process of manufacturing the mixture and in developing effective, lightweight formwork for construction.

The meeting of these older and newer experiments in adapting traditional techniques and the question of how to bring together two different mixtures to deliver structural strength and insulation as part of the same wall gave rise to a hypothetical concept for the simultaneous construction of the two layers.

The formwork necessary for light earth increases speed and reduces the risks in paring the cob. By combining its construction, it was possible to imagine implementing the two mixtures in the same formwork. However, the question of drying and connecting the two mixtures of different density immediately arose. A first intuitive implementation test carried out by two practitioners of cob building at the Grands Ateliers de l'Isle d'Abeau (France) during a training course on cob proved quite encouraging (Figure 5). Cob was first shaped into a wall with a thickness of 20 cm providing a stop against which it was possible to press the light earth mixture. Analogous to some connection methods between traditional cob and stone masonry, the cob was angled on the surface adjoining the light earth layer so that each row overhangs the next, protruding into the layer of light earth, which has the same thickness as the structural cob, to create a wall with a saw tooth profile.

Other tests were subsequently undertaken at scaled sizes corresponding to the desired thermal performance simulations (U = 0.26 W/m²K), with the objective of developing loadbearing walls suitable for two-storey buildings with optimum mixtures studied in the laboratory. As part of this, the quality of the shaping of the cob in the main formwork is important for the wall performance. An intermediate formwork was therefore devised to regulate the thicknesses. In order to verify the apparent cohesion of the two facings, two samples were cut into several sections. All of them showed a strong bonding between the two facings, particularly in the contact area (Figure 6). The simultaneous wet on wet implementation is probably the mostly likely explanation for this.

In order to validate these findings and observations by practitioners more scientifically, the construction of a test wall and prototypes was designed. The test wall was scheduled to be built in summer 2020 at Plymouth University and when built will be subjected to vertical pressure to observe the behaviour of the two layers and their cohesion under heavy loading.

Test phase: Construction of a prototype

The construction of a first prototype building was started in October 2019 in Normandy. This project was designed as a laboratory on a scale of 1 to 1 allowing the CobBauge team to develop and study various technical details in relation to contemporary architectural methods, and to compare the first implementation tests in a real site situation against the experiences of earthbuilding professionals.

The 13m² building has two floors with half of the walls reaching a height of one storey (3.2 m), and the other half rising to two storeys (4.40 m) (Figure 7). The overall thickness of the walls varies between 50 and 70 cm, bringing cob to the limit of the slenderness ratio (according to French good practice guidelines), or half as much as the thicknesses encountered in traditional buildings where the loadbearing cob alone can be 50 to 70 cm thick. In order to benefit from thermal inertia, the dense load-bearing layer faces the interior of the building while the insulating layer is on the outside. The formwork used in the test phase has been adapted from conventional aluminium formwork (Figure 8) but replaces the plywood lining with a wire mesh. Each lift is subject to monitoring of times per task and for each operator, the tools used and their energy consumption. This data makes it possible to compare variations in the construction process and to determine the most effective organisation principle and method. Combined with the results obtained on the same type of monitoring for the prototypes planned in England, this data can also inform a life cycle analysis of the process.

The first lift was the subject of a change request by the craftsmen. The main formwork was placed so that an entire cob lift could be carried out (Figure 9) and then, two days later, the outer section of formwork was shifted outwards to accommodate the light earth layer. The goal was to facilitate direct filling of the formwork from a digger bucket. The increased efficiency was obvious compared to the first tests built by hand, but the connection between the two facings seemed weaker: cracks were observable after drying in the region of the opening rabbets. The next two layers were carried out more in accordance with the initial design. The intermediate formwork was the subject of a specific design to facilitate its handling and allow the filling of materials using construction machinery (Figure 10).

An objective of the prototype was also to determine the impact of the juxtaposition of two mixtures of different densities, water content and various soil qualities on the drying of each of them during the construction phase. 55 sensor probes measuring the moisture content of the soil (campbell scientific CS655) were placed close to the surface of each of the layers as well as at the interface of the two layers of cob and light earth (Figure 11). These probes were also regularly placed at different heights in each lift to make it possible to observe the drying behaviour of newly laid mixes in the upper part, which is exposed to the environment on three sides, in the middle of the lift, where the material is exposed on only two external faces, and finally in the lower part of the lift, which has two external faces and a bottom contact face with the preceding lift which is inevitably drier. These probes were also distributed on the west, south and north walls (Figure 12) to assess the impact of exposure to wind and sun on each of the mixtures. The weather conditions were recorded by a weather station installed on the site.

The sensor probes can also be used to measure temperature and thus to evaluate the transfer of heat. Other types of probe developed for straw construction (Carfrae 2011) are also used to compare different types of measurement. In order to have reference data for comparison and calibration, samples of the material used were taken to measure water content levels. The prototype will be equipped with other measuring devices once completed in order to be able to trace heat transfer within the different walls, but also to monitor moisture transfer in different seasons and thus determine the effective behaviour of the materials and compare them to theoretical results from laboratory tests.

First results and provisional conclusions

The construction of the first lift demonstrated the effects of building in successive layers of low height with closely associated insulating and loadbearing mixes that maintain a good structural connection. This was a concession to reduce difficulties in construction on site. Following the first tests, it became clear that the intermediate formwork we designed still requires a number of improvements in ergonomics to make it lighter and more manageable.

The use of a digger turned out to be the most rational choice because it allows both quick preparation of the cob and great efficiency in filling the formwork. However, it is of more limited use when walls are higher than a single storey. Beyond the space and height limit of the respective machine, the site requires different mixing tools and handling equipment, which impacts on the speed and cost of the building.

Measurements of the moisture content of the walls are still in progress, but the observations of the craftspeople on site suggest that the simultaneous construction with two mixtures does not affect drying compared with a traditional earth wall of the same thickness. On the other hand, despite efforts to calculate the proportions of earth and fibre for the light earth, facilitated by the use of the dry clay soil mechanically crushed and sieved, the samples taken on site and measured in the laboratory show that the construction process has a high impact on the density, and in turn on the thermal properties. The compaction force exerted on the light mixture can vary the density of the mixture from 350 kg/m³ to 400-450 kg/m³. Regarding the loadbearing mixture, the estimate on site of the amount of fibre relative to the volume of soil remains fairly uncertain, rather against the amount of fibre. This does not affect the mechanical strength in this sense, but can affect the behaviour of the mixture when shrinking during drying, creating cracks.

The first analysis of construction times shows the importance of the organisation of the site and the machines. Between the first lift and the third, the construction times reduced by almost a third. The small scale of the project means that a greater proportion of time is required for more complicated details compared to simple wall construction. This suggests that savings in construction times could be greater for larger projects. On the other hand, the analysis of the costs of raw materials and their preparation raises the problem of structuring supply chains. The use of crushed reed almost quadruples the cost of the raw material compared to hemp. The impact is lessened when using dry crushed and sieved clay soil. The longer time required on site to sieve a raw earth to prepare a slip means that it is worth the purchase price of procuring the same earth pre-prepared by a local industrial supplier.

These initial findings show the need to continue the collaborative work between academics and industry in order to achieve the expected levels of performance and to increase the level of knowledge and competence among professionals. At the same time, this project develops on a traditional technique, leveraging its reduced carbon emissions and reductions in energy consumption while catering to demand beyond the renovation of heritage buildings. But to take this beyond the niches of eco-building and the safeguarding of heritage, one needs to convince the users of conventional construction to take up these methods. The time required for drying remains a major constraint that inhibits widespread adoption. One response to this that could open up new lines of research may lie in prefabrication.

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