T4. The Process of Constructing a CobBauge Building.

An Outline Methodology for how to build a CobBauge building using the University of Plymouth Prototype Building as a case study.

Introduction:

This document outlines the basic methodology for constructing a CobBauge building and partners report T4.1, which lists the performance levels and quality assurance that will be maintained during the building process.

Contents:

1. Formwork

1.1. Design and construction of formwork

The contractor is to construct the formwork that will be used to shape the CobBauge walls.

Formwork comprises of two sections of framework that are spaced over the thickness of the intended wall and held in place with long bolted rods / threaded rebar at two or three locations along the length of the formwork, both top and bottom.

The method of constructing the formwork is not prescriptive, though past examples of formwork used in the construction of CobBauge walls have been formed from timber and metal framing.

Figure 1. Photos showing metal (left) and timber (right) formwork examples. (Photo: Matthew Fox)

To ease / enable the removal of the formwork after completing a lift of CobBauge, it is important to use wire mesh sides to the formwork frame. This mesh is located on the inner / cob side of the frame. The use of wire mesh also aids the drying process and provides a visual indicator of the compaction of the material within the formwork. Mesh gaps / holes should be around 25mm^2.

To further aid relocation of the formwork, it is suggested that any excess cob material (that has compressed through the wire mesh) be scraped away while it is still wet. Should this dry around the mesh, it could become difficult to detach the formwork from the cob surface.

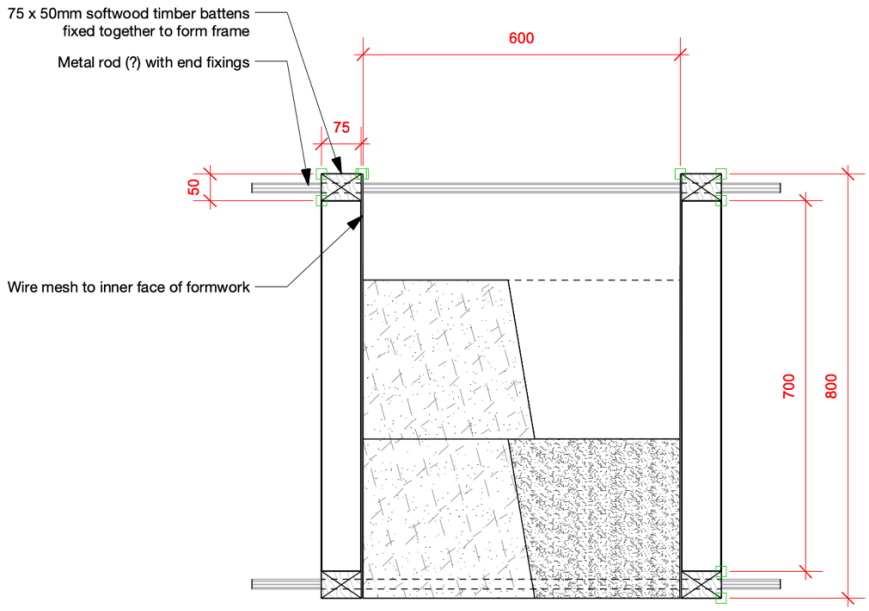

Figure 2. Design section for formwork. (Source: Fox Ecological Architects)

There is no prescribed length of formwork that can be used; however, contractors should be mindful of the weight and manoeuvrability of the formwork. Past examples of CobBauge formwork have comprised of 3m long sections. Even at 3m length, this formwork was found to be heavy and awkward to move. Lengths of 2m or 1m might be more practical and contractors could consider methods of bolting / connecting multiple short sections together.

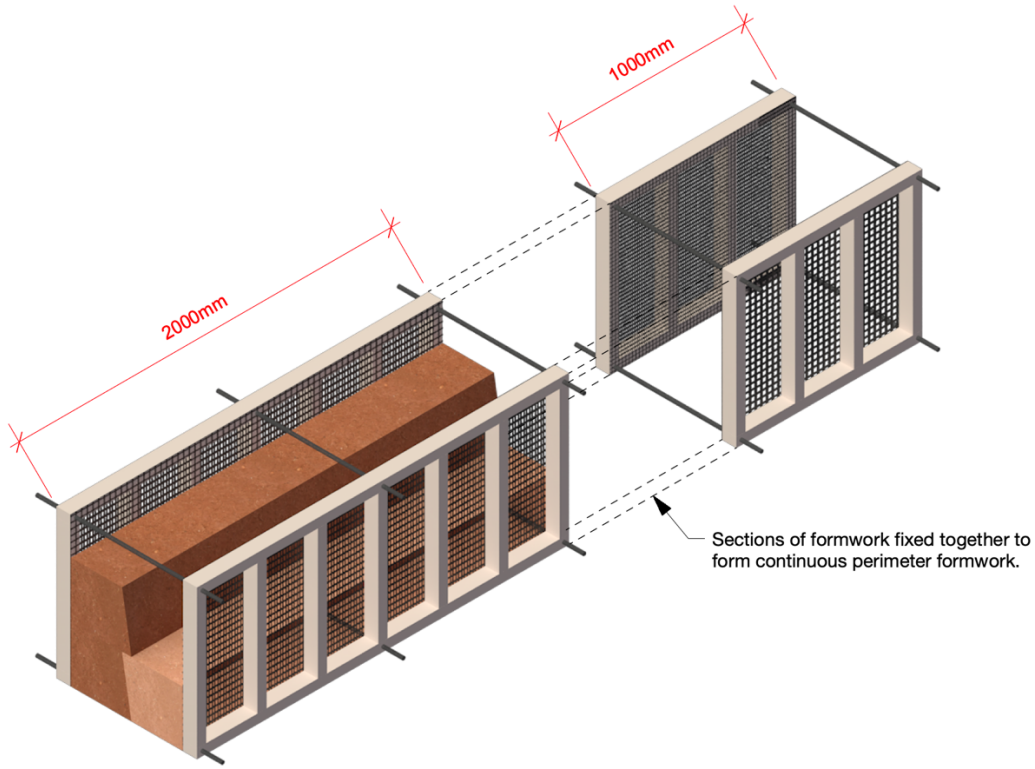

Figure 3. 3D view of formwork setup / size. (Source: Fox Ecological Architects)

The height of the formwork should be sufficient for one lift of CobBauge. Past examples of CobBauge formwork have comprised of 0.75m high sections. One lift of CobBauge can vary from approximately 500 – 650mm in height.

The formwork should be fixed together using long rods or threaded rebar. These lengths should be sized to allow for the formwork to be expanded or contracted depending on the thickness of the wall being constructed.

Sourced of the threaded bar have previously been:

> TAM Mandelli – Setra: https://www.mandelli-setra.fr/produits/materiels-de-coffrage/tiges-accessoires/ Where the following products have been used with good success:
> Bars ref **007549** and nuts ref **007810.**
>
> A UK alternative is:
> DY.CO DYWIDAG Form Ties: https://www.dywidag-formties.com/products/threadbars/ where a similar thread bar and nut can be sourced.

Other types of threaded rod could be used, though ease of bolting and removal are essential criteria.

The spacing between formwork is dependent on the thickness of the wall. A typical CobBauge wall is 600mm thick. With 300mm of thermal and 300mm of structural cob within this thickness. To help space the formwork, a pre-formed spacing block of wood could be used to aid positioning the formwork.

Figure 4. Photo showing spacing of formwork using wooden spacing block (Photo: François Streiff)

1.2 Using the formwork to create a cob lift

In addition to the formwork holding the cob material in place, there is an additional tool, which is used to separate the thermal cob layer from the structural cob layer during construction. This is a timber placement tool, which comprises of two angled timber surfaces.

The shape of this tool enables one 250mm high sub-lift to be formed. The angle of the timber is such that it provides a slight angled batt to the face of the structural cob layer, and also makes it easier to remove the placement tool.

Figure 5 Photo showing angled batt / toothed joint between thermal and structural layers. (Photo: Lloyd Russell)

The contractor will be required the construct this placement tool.

Figure 6. Photos showing an example formation tool. (Photo: Matthew Fox)

The procedure for laying cob involves putting the placement tool into the formwork. A 200 - 250mm sub-lift layer of structural cob is placed in the void between the placement tool and the formwork mesh. This cob material is compacted into the void by foot and or with a hand stamping tool. The hand stamping tool shown in the photos below comprises of a plywood plate fixed to the end of a mattock handle.
The cob is compacted until there are no voids within the structural cob layer. Once this section of structural cob has been laid, the placement tool is removed and re-positioned adjacent, but slightly overlapping the first section of cob, ready for a continuation of the structural cob layer.

Additional structural cob is then laid along the length of the formwork / wall etc. until the entire perimeter of the building has a 250mm sub-lift layer of structural cob.

Figure 7. Photos showing use of the placement tool. (Photo: Matthew Fox)

Figure 8. Photos showing the placement tool on site. (Photo: François Streiff)

Once 250mm of the structural layer has been completed, a 250mm high layer of thermal cob can be placed up against the face of the structural cob. The thermal cob is also compacted into the void between the structural cob and the formwork using the hand stamping tool, though this layer requires less force than used with structural / traditional cob. The aim with compaction is to remove voids between the material rather than compress the material, which will impact on the density and thermal conductivity performance.

Figure 9. Photo showing filling of thermal cob layer against structural cob layer. (Photo: François Streiff)

When a complete 200 – 250mm sub-lift layer of thermal and structural cob have been laid into the formwork, the placement tool is laid on top of the first layer of thermal cob, ready to accept the next

200 – 250mm sub-lift layer of structural cob. The above process is repeated until there are two or three 200 – 250mm layers of both cob materials. This should bring the CobBauge wall close to the top of the formwork and signifies the completion of a single / full lift of cob.

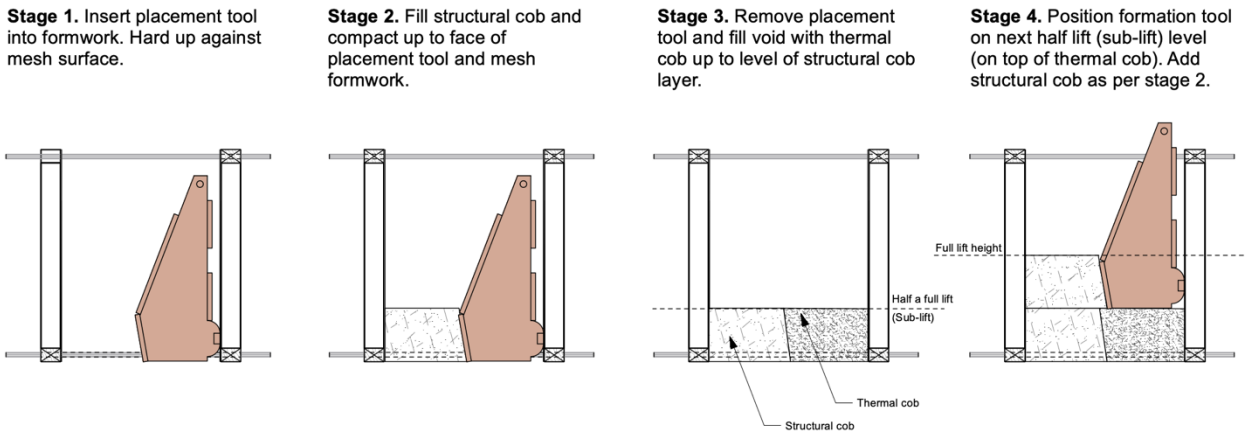

Figure 10. Illustrated use of placement tool with sub-lifts. (Source: Fox Ecological Architects)

1.3 Checking compaction of cob in formwork

To check the quality of cob compaction, it is advisable to look between the mesh as the layers of added to the formwork. This will give a visual indication of compaction or if there are any voids in the material. At this point, it is also advisable to remove excess cob material (with a trowel or similar tool) that has pressed through the mesh.

Figure 11. Photo showing thermal cob viewed through mesh. (Photo: Matthew Fox)

1.4 Re-positioning the formwork

When constructing lifts of cob above the first lift (or when forming a CobBauge wall on top of a raised plinth), contractors are to sit the connecting bolts on top of the previous lift before attaching the formwork frames (See method for raising the cob in Figure 12). This will help to support the formwork

for the new lift. It is important to carefully, but forcefully remove the buried rods from the CobBauge walling while it is still wet. Using lengths of bar that are threaded along the entire length will aid removal by un-screwing them from the wall if necessary.

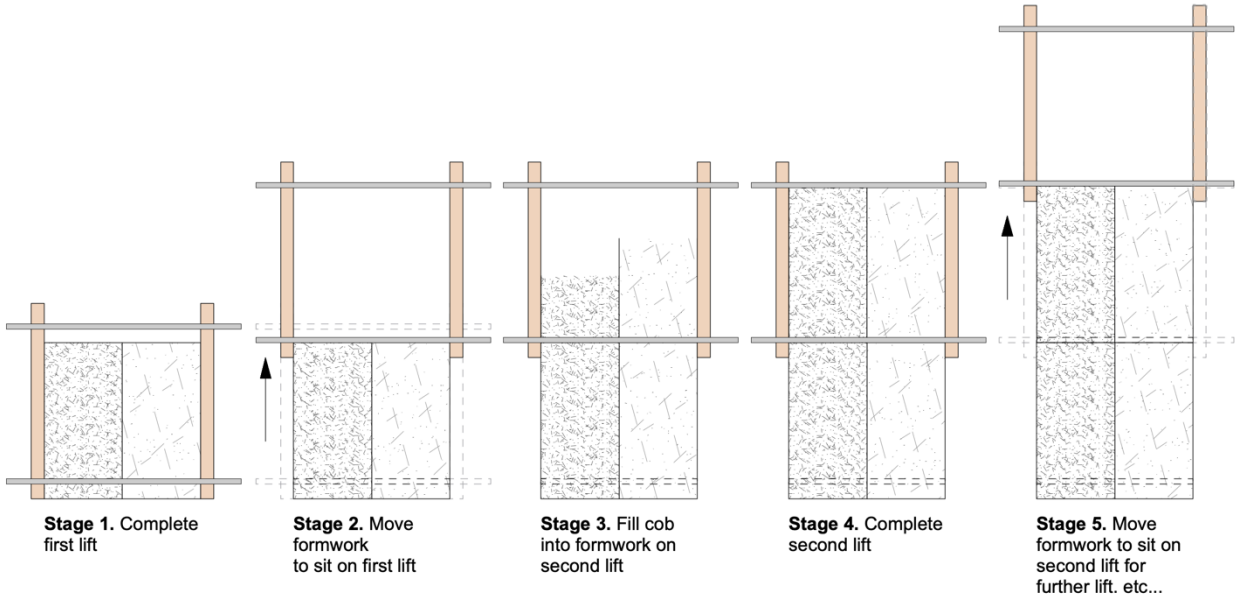

Figure 12. Illustrated method for raising formwork. (Source: Fox Ecological Architects)

Contractors will need to carefully plan the construction of the formwork, as there should be enough formwork in place to completely construct one entire lift of the external walls.

Following completion of a lift of CobBauge, formwork should be left in place to dry for 2 – 3 days before being re-positioned.

1.5 Time between CobBauge lifts

Upon completion of a CobBauge lift, contractors should wait around three weeks before laying the next lift. During this time (after 2-3 days as described above) contractors can prepare for the next lift by re-positioning the formwork and preparing new material.

As a guide, the approximate time it takes to construct one lift of 650mm CobBauge on a 30sqm square building is three days. This timescale uses around three operatives to form the lift.

2.Potential issues encountered on site

This section discusses some of the possible issues a contractor might be faced with on site in relation to the construction of a CobBauge wall.

2.1 Rain / precipitation during construction.

The impact of rain on the wall during construction depends on the severity of the weather.

- Light rain. Both the thermal and structural layers of cob can be left unprotected or can continue to be worked on during light rain showers.
- Heavy rain / driving rain. If very wet weather is forecast or encountered during the construction of a CobBauge wall, it is advisable to protect all walls and un-used cob / earth material.

Failure to protect walls and material from heavy rain will alter the water content of the CobBauge, which can result in structural instability and longer drying times. It is therefore essential that walls and material is protected at all times during the construction process.

Protection of the walls could be using tarpaulin sheets or sheets of plywood (over the top of the formwork). In both cases coverings should be weighed down enough to hold the protection in place from wind. The use of plywood / timber sheeting is preferrable as it keeps the sides well ventilated, which will help the cob to dry.

Figure 13. Photo showing sheets of timber protecting tops of wall. (Photo: François Streiff)

Protection of unused material should also be a priority. To protect unused material, polythene or tarpaulin sheets should be placed over this material. Such protection should be commonplace, since this material will also require protection from excessive drying due to wind and or solar exposure.

2.2 Cracks within the cob layers

It is not uncommon to encounter cracks in the CobBauge layers. This can be due to a variety of reasons, such as differential drying. The extent and size of the crack should be considered before undertaking remediation action.

- Small cracks (see number 1 in Figure 14) in cob layers can be filled with slip before starting a new lift / layer.

- Large cracks (see number 2 in Figure 14) should also be filled with slip / structural / thermal cob depending on the location / layer the crack is present in. These cracks should also be protected at the top of the crack opening with a 1m long timber batten, which should be pressed into the cob over the length of the wall, with the crack in the mid-point of this batten. This should help to prevent the crack from travelling further through subsequent layers.

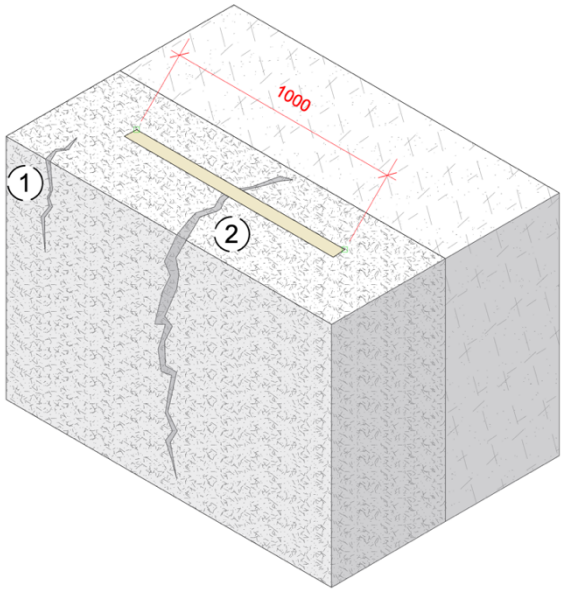

Figure 14. Illustration of cracks in CobBauge walling. (Source: Fox Ecological Architects)

3. Scaffold for a CobBauge building

It is highly likely that scaffolding will be required for the construction of a CobBauge wall or building.

It is advisable that there are two stages to the erection of scaffolding on a CobBauge project.

3.1 Stage 1. Working from the ground

While working on the first lift or two of a CobBauge wall, contractors might find it relatively easy to work from ground level or from a simple platform. This will enable contractor's free movement around the site during the early stages of the build.

Figure 15. Photos showing the use of a small scaffold tower to aid low level construction. (Photo: Matthew Fox)

3.2 Stage 2. Erecting a scaffold

Once the wall rises beyond two lifts, it becomes difficult to form further CobBauge lifts safely. Therefore, scaffolding should be erected. Contractors should decide whether to add scaffolding to the inner and outer sides of the CobBauge wall, though care should be taken with manoeuvring formwork panels if only using scaffolding on one side.

Contractors should pay particular attention to typical standards of health and safety while working on scaffolding, moving formwork and material around on the scaffolding and when lifting material up to a higher level.

To aid protection of the CobBauge walls from weathering during construction, contractors might consider a full scaffold with tarpaulin covering the entire building area. Such measures might also lower the risk of differential drying / shrinkage due to solar exposure in warmer months.

4. Moving cob material around on site

4.1 By Hand

At a very basic level, either cob materials can be moved around on-site using wheelbarrows or trolleys. Care should be taken not to overload these, which could lead to injury. From these barrows, cob can be hand shovelled into the formwork with spades and forks.

4.2 By Machine

Easing the transportation of material on site comes from the use of machinery. Past examples of mechanised CobBauge construction have used telehandlers (front loader) with forks or bucket attachments to carry the material in the bucket or by sack. In other examples a forklift has been used to move material around site. Material transported via these machines can also be used to lift material to high levels on scaffolding, where contractors can move the material around by hand once laid down at a higher level.

However, the benefit of using machinery has the potential to double when also used to help place the material in the formwork. Both telehandlers and forklifts can be used to lower or tip material into the formwork.

Additional mechanical aids that could be used include mobile cranes, cherry picker / boom lifts and electric lifts on scaffold systems could also be used successfully to transport and position CobBauge material on site.

5. Running services in a CobBauge wall

Electrical, data and water services that are designed to be concealed within the structural / inner cob layer of a CobBauge wall are to be “chased” into the material prior to being plastered.

To minimise the risk from differential movement in surface plasters over these services it is proposed that EML (Expanded Metal Lathing) be fixed over the service cavity prior to being plastered.

6. Mixing of CobBauge material

6.1 Mix ratios

Both thermal and structural cob materials are to be either mixed on site, close to site or imported from an external supplier. In each case, the following procedures should be followed to ensure the soil and mixture is suitable for use in a CobBauge building:

> **Stage 1.** 1kg of the sub-soil intended for use us to be extracted and sent to a suitable geotechnical laboratory for analysis.
>
> **Stage 2.** The geotechnical laboratory will analyse the soil to determine clay content and silt fraction etc. This will help to determine the proportion of additional ballast and clay required for the soil if necessary.
> This laboratory research will also help to determine how much fibre is needed for each layer of cob.
>
> **Stage 3.** Contractors will then use this information to add any additional material into the soil, and to measure out the correct quantity of fibre to soil using the ratios provided by the laboratory.

In past examples undertaken by the CobBauge project team, soils that have been found suitable for CobBauge construction have required the following bucket ratios (by volume):

- Structural cob. 1 bucket of soil to 1 bucket of wheat straw fibre.
- Thermal cob. 1 bucket of earth slip to 3 buckets of hemp shiv fibre.

These roughly translate to 2.5% fibre content by dry weight of soil for structural cob and 50% fibre content by dry weight for thermal cob.

It is important to note that the above bucket ratios are not an absolute rule, and contractors are encouraged to send their soil for laboratory testing before mixing their cob as ratios may differ slightly.

6.2 Mix methods

The method for mixing thermal and structural cob materials differs due to the density of the material in each case. The following method offers a guide on how each material could be mixed on or away from site.

Structural cob:
Structural cob is the term used in this document for a cob mixture that comprises of approximately 2.5% fibre by dry weight of soil. This mixture is typical of historic and traditional cob mixtures.

The procedure for preparing the structural cob on site should be familiar for traditional cob builders, but is outlined below:

> **Stage 1.** A suitable subsoil (verified by a geotechnical laboratory) is collected and mixed with water until the right consistency is achieved. To verify the consistency the contractor should conduct a simple drop ball test.

To undertake a drop ball test, roughly one litre of the soil mixture (without fibres) is formed into a ball approximately 125mm in diameter. This ball is dropped from a 1m height onto a flat surface. The diameter of the soil on the surface is measured to determine whether the soil is too wet, too dry or suitable for mixing with fibre.

If the diameter measures 175mm, the mixture is too dry. If the diameter measures 250mm, the mixture is too wet. Therefore, the optimal range is between these two diameters.

Figure 16. Photos of a drop ball test. (Photo: Matthew Fox)

Stage 2.

Once the correct consistency of subsoil has been achieved, fibre can then be added. Good experience has been had with fibres such as wheat straw. As explained in section 6.1, this is approximately on a ratio of 1:1 soil to fibre, with water added to aid mixing.

Mixing can be undertaken by foot or machine. In either case fibre should be added a little at a time to aid the mixing process and to ensure that fibre is well mixed through the soil.

Figure 17. Mixing structural / traditional cob by machine or foot (Photo: François Streiff)

Once fully mixed, this material is ready to be added into the formwork of a CobBauge wall as described in section 1 of this document.

Further information can be found in report T4.1, the performance levels and quality assurance document, which partners this document.

Thermal cob:
Unlike structural cob, thermal cob is mixed using a soil slip. In summary the slip comprises of suitable subsoil that is then mixed with lots of water until it becomes very viscous in consistency.

The procedure for preparing the slip is as follows:

> **Stage 1.** Take a large bucket (approx. 800ltrs in capacity) and fill this to about half the bucket with subsoil that has been approved for use in a CobBauge wall. Then fill the remaining bucket with water. This should be left (usually overnight) until the soil has broken down and become viscous. This process can be aided by using a hammer / crowbar etc. to break the solid soil down and by churning the slip at stages in becoming viscous by using a hand mixing tool.

Figure 18. Mixing water with soil to form slip (Photo: François Streiff)

Figure 19. A photo showing the consistency of the earth slip. (Photo: Matthew Fox)

Stage 2. Once the soil has become thoroughly viscous in consistency, this mixture is sieved using a mesh of approx. 8mm^2 holes to remove any large stones and other large pieces of material. Ideally, the slip is sieved into several smaller buckets for ease of further use.

Figure 20. Sieving the slip (Photo: François Streiff)

Stage 3. There is an optimum viscosity for the slip. This is measured using a puddle test, which can be undertaken on site.

To undertake a puddle test, 100ml of soil slip (without fibres) is poured from a 100mm height onto a flat surface. The diameter of the slip (puddle) on the surface is measured to determine whether the slip is too wet, too dry or suitable for mixing with fibre.

If the diameter measures 70mm, the mixture is too dry. If the diameter measures 140mm, the mixture is too wet. Therefore, the optimal range is between these two diameters.

Figure 21. Photos of the puddle test. (Photo: Matthew Fox)

It is recommended that the initial slip mixture is made less viscous than the final slip needs to be, as adding additional water to achieve the desired viscosity is easier than adding further soil.

Once the correct water content is achieved for the slip, the chosen fibre can be added to the mixture. Fibre should be added a little at a time before being slowly mixed into the soil. Mixing of the soil can be either by machine or hand. In past examples at Plymouth and in France, a hemp shiv material has been used. This is commonly used as animal / horse bedding.

Figure 22. Photos showing the mixing of slip into hemp fibres. (Photo: Matthew Fox)

Figure 23. Photos showing mixing of thermal cob on site (Photo: François Streiff)

The resultant mix of slip and fibre to the correct quantity finishes the production of the thermal cob mixture. This is then ready for placement into the formwork as described in section 1 of this document.

7. Further information

Should contractors / construction professionals have any specific questions in relation to a CobBauge building, they are advised to contact the contract administrator and or CobBauge research team (cobbauge@plymouth.ac.uk).