An Investigation into the Potential Use of TDR Measurement Systems to Accurately Assess the Moisture Content at the Center of Completed Earthen Walls

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An investigation into the potential use of TDR measurement systems to accurately assess the moisture content at the centre of completed earth walls

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1.0 Introduction

When conserving or extending historic buildings, the ability to improve fabric thermal performance is often limited by the traditional nature of the original material. This limits the ability for historic buildings to adapt to our changing climate. Following greater awareness of the climate emergency, there is a growing argument that traditional building materials and methods should evolve to become more climate resilient. Whilst traditional cob has inherent thermal qualities, it's inability to meet stringent thermal insulation standards is the rationale behind this study.

The CobBauge walling system is one iteration of the traditional cob building technique to allow cob and other historic earthen building methods to conform to many country's thermal building regulations. The moisture content of earth walls has a well-known impact upon the development of wall strength and corresponding rates of shrinkage when repairing and extending historic earthen buildings. There is a known relationship between the density and thermal conductivity of earthen walls (Volhard, 2016, Minke, 2000), yet the ability to safely construct an earth wall system that incorporates two layers of different densities to improve the thermal performance of historic earth buildings raises questions concerning differential shrinkage. To assess the shrinkage this research develops a methodology that can be used to investigate moisture distribution and shrinkage movement within an innovative composite cob walling system (CobBauge) that can be used to repair or extend historic earthen structures.

Objectives

- To design a moisture measurement system that uses TDR probes and can be placed within existing, upgraded and extended composite earth walls.
- To analyse the impact upon accuracy of positioning of TDR sensors in an earth wall.
- To compare the shrinkage of small-scale samples with a full-scale CobBauge wall throughout the build process in relation to the moisture readings provided by the TDR moisture measurement system.

2.0 Literature

The impact of high moisture levels to the interior of an unbaked earth wall both in repairs and extensions of historic earth buildings can lead to movement, and shrinkage (Goodhew et al., 2021, Jaquin and Augarde, 2012, Pearson, 2015, Warren, 1999). This issue is particularly pertinent when assessing the shrinkage of and between two vertical layers of different densities of earth and fibre material within the CobBauge wall. It is therefore important to establish realistic moisture measurements from the centre of load bearing earthen walls and relate that to measured shrinkage.

Researchers have utilised different in situ moisture measurement techniques for appropriate conservation of earth building materials (Pinchin, 2008). Specifically the dowel method (Ridout and McCaig, 2016) & wood block sensors (Carfrae et al., 2011, Goodhew et al., 2004). With the increase in use of TDR and similar soil probe sensors (Lekshmi et al., 2018, Sinha et al., 2017), there is a need to understand how well modern moisture detection systems perform when located at the centre of a 600mm earthen wall.

In association with these moisture measurements the authors will build on the work that has focused wholly or in part upon the shrinkage of earth walls and plasters/renders (Hamard et al., 2013).

3.0 Methodology

The CobBauge construction system comprises of two layers of cob with different material densities (Goodhew et al., 2021). One 300mm layer comprises of low density (50% fibre by dry weight) / "thermal" cob, with the other 300mm layer comprising of high density (2.5% fibre by dry weight) / "structural" cob. The aim of this composite construction is to provide a new version of traditional cob that meets thermal and structural building standards. However there remains some questions over how the two cob materials respond to differential drying and shrinkage. The experiments in this paper seek to investigate the moisture content and shrinkage rate of a trial wall over a three-month period from August to November 2020.

Figure 1. The experimental CobBauge wall and construction process in the background.

To measure moisture and shrinkage, a 600mm thick, 700mm high and 3000mm long CobBauge experimental wall was constructed with mesh formwork in a well-ventilated laboratory at the University of Plymouth
Figure 1).

As the wall was being constructed, two different soil specific TDR moisture sensors were set into the low and high-density cob layers. These sensors comprised of a single 0.5m long SoilVue10 sensor and three CS655 sensors, which are typically used to monitor the moisture content of ground-based soils, however similar TDR sensors have been previously used on earth constructions with good success (Chabriac et al., 2014). Both types of sensor were connected to a Campbell CR1000X data logger via an SDI-12 protocol. This was programmed to record volumetric water content (VWC) every 15 minutes. All the sensors were located at 350mm from the ground, which was at the mid-point of the lift. Figure 2 shows the TDR sensors located within the trial wall before being buried. Two different TDR sensors were used to verify results and compare measurement methodologies. Internal laboratory conditions were recorded using a HOBO MX1011.

Figure 2. Location of sensors within the CobBauge trial wall. Three number CS655 sensors (Left), One number SoilVue10 sensor (Right).

To measure the shrinkage rate over 3 months of the trial wall a variety of different methods where used. For reasons of clarity in the context of this paper we are using the results from four threaded construction screws embedded into the wall. These were inserted into the end face of the wall at a height of approximately 665mm (Figure 3).

Figure 3. 3D representation (left) and photo (right) of screw locations for measurement (mid experiment).

As a shrinkage reference, a series of six representative 300mm x 150mm dia. cob cylinder samples were made of the same material.

4.0 Results

4.1 Cylinder samples

Initial results from the cylinder samples found that on average the high-density cob cylinders shrank by an average of 5.9% from 300mm to 282mm in height. In comparison, the low-density cob cylinders expanded by around 0.55% from 300mm to 302mm in height, (Figure 4. Comparison of low (left in first image) and high-density (right in first image) cob cylinder samples.

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Figure 4. Comparison of low (left in first image) and high-density (right in first image) cob cylinder samples.

4.2 Moisture monitoring

Overall results from the two different sensor types are presented in Figure 5, which illustrates the drying rate of the two cob layers over the monitoring period.

Figure 5. VWC results from CS655 and SoilVue10 sensors. Blue lines = high-density cob layer. Amber lines = low-density cob layer. The darker the line, the closer the sensor is to the centre of the 600mm thick wall. Dimension noted on the key are measured from the external face of the low-density cob layer.

These results were then presented at weekly intervals over the thickness of the entire wall (Figure 6 and 7). This method enabled further comparison between the different layers of the wall and a deeper analysis of the flow of moisture through the wall.

Figure 6. CS655 VWC results. The darker the line, the earlier the data. The blue vertical lines denote the approximate thickness of the wall, showing the approximate location of the sensor within each layer.

Figure 7. SoilVue10 VWC results. The darker the line, the earlier the data. The blue vertical lines denote the approximate thickness of the wall, showing the approximate location of the sensor within each layer.

4.3 Shrinkage monitoring

Figure 8. Graph showing measurements from fixed screws over time.

shows the change in height of the screws over the six weeks of the initial drying of the measured first lift. The outer edge of the high-density cob experienced the greatest degree of shrinkage.

Figure 8. Graph showing measurements from fixed screws over time.

5.0 Discussion

On review of the moisture monitoring, a number of interesting findings were encountered. Firstly, while in general the low-density cob had a lower VWC at the start of the experiment and dried at a slower rate than the high-density cob, this material closest to the high-density layer appeared to gain moisture after placement. This was likely due to a transference of moisture from the high-density layer to the low-density layer. After losing some of this moisture, this sensor location showed an increase in VWC in the second week. This was due to the addition of a second lift of CobBauge representing the impact of the traditional construction process, with additional moisture passing from the new lift to this measured lift by way of gravity. After these initial rises in VWC, the low-density layer closest to the centre of the wall dried at a similar rate to that of the high-density cob closest the centre of the wall.

VWC results between the CS655 and SoilVue10 sensors at similar depths were comparable, which gave confidence between the two data sets. However, there was a disparity in results at the mid-point through the wall. The central CS655 measured a higher VWC than the SoilVue10 sensor at a similar depth (30cm),due to the CS655 sensor straddling the two cob materials, while the 30cm Soil-Vue10 sensor was located inside the low-density cob layer. While there were three CS655 sensors spread through the wall, the SoilVue10 had six sensors along it's 0.5m length. This meant that for the SoilVue10, there were at least two sensors in each cob material. When comparing Figure 6 and **Error! Reference source not found.**, the added resolution in data from 6 sensors gives greater clarity over the movement of moisture through the depth of the wall.

Upon reflection of the shrinkage measurements, it is clear that the greatest degree of shrinkage is at the outer edge of the high-density layer (structure 4), and that the majority of this shrinkage occurred within the first week of measurement. This corresponds with the moisture data, which also shows that the outer edge of the high-density cob (50cm SV10) dried more quickly at the start before becoming more gradual. When compared with the findings from the high-density cob sample cylinders, these results could be expected.

Yet an unexpected measurement was gained in "structure 3", the high-density cob shrinkage measurement closest to the centre of the wall. Here results appeared to mirror the measurements taken in the low-density cob layer, counter to findings from "structure 4". While this could be due to the slower drying rate at the centre of the wall, another justification for this came from reviewing the low-density cob layer. Shrinkage results in the low-density layer found that at the outer edge (thermal 1), the material was expanding slightly. This could be due to the fibres taking their original shape after initial compaction into the formwork, which replicates to a certain extent the results from the cylinders (Figure 4. Comparison of low (left in first image) and high-density (right in first image) cob cylinder samples.

). Despite this, where the low-density cob was measured close to the centre of the wall (thermal 2), the material appeared to be being pulled down by the shrinkage of the high-density layer. This is born out by the thermal 2 and structural 3 results suggesting that the two layers are working together rather than separating. This is backed up by visual inspections, which show that the two layers do not separate at the junction.

6.0 Conclusion

The TDR based moisture measurement system trailed in the full scale CobBauge wall proved to be an effective method to measure moisture contents from deep within a 600mm composite CobBauge wall. Whilst some variations between the SoilVue10 and CS655 TDR systems were encountered these were associated with sensor positioning between the two different density earth layers.

The Shrinkage associated with the composite CobBauge wall was generally far less than that measured within the small-scale samples of the same material. The moisture measurement system played an important role in informing the researchers about the position of moisture within the wall at any particular point in time. This then allowed the team to observe that the two layers of the CobBauge wall were influencing the moisture content through a cross section of the wall. This influence tended to even out differential shrinkage and maintain the walls overall dimensions in a way that was not observed in the smaller samples. This method of moisture monitoring can be beneficial when assessing the drying, shrinkage and movement of new earthen material when placed immediately against existing historic earth material, which will have a more stable moisture state, and is especially important when using new material around fenestration apertures.

7.0 Future work

The CobBauge team will be monitoring the current full-scale walls over the remainder of 2021 to ensure that the current results can be compared to the completed work. The linkages between the moisture and shrinkage of these walls will be compared with published data from repairs undertaken in similar historic cob buildings in the SW of the UK. A new Prototype CobBauge building will be built on the University of Plymouth campus and will be monitored using the system described in the paper. The new building will offer opportunities to investigate the influence internal conditions on wall moisture contents and the part that rendering plays linked to weather conditions of a maritime climate such as Plymouth.

8.0 References

CARFRAE, J., DE WILDE, P., LITTLEWOOD, J., GOODHEW, S. & WALKER, P. 2011. Development of a cost effective probe for the long term monitoring of straw bale buildings. *Building and Environment,* 46**,** 156-164.

CHABRIAC, P. A., FABBRI, A., MOREL, J. C., LAURENT, J. P. & BLANC-GONNET, J. 2014. A Procedure to Measure the in-Situ Hygrothermal Behavior of Earth Walls. *Materials (Basel),* 7**,** 3002-3020.

GOODHEW, S., BOUTOUIL, M., STREIFF, F., LE GUERN, M., CARFRAE, J. & FOX, M. 2021. Improving the thermal performance of earthen walls to satisfy current building regulations. *Energy and Buildings,* 240**,** 110873.

GOODHEW, S., GRIFFITHS, R. & WOOLLEY, T. 2004. An investigation of the moisture content in the walls of a straw-bale building. *Building and Environment,* 39**,** 1443-1451.

HAMARD, E., MOREL, J.-C., SALGADO, F., MARCOM, A. & MEUNIER, N. 2013. A procedure to assess the suitability of plaster to protect vernacular earthen architecture. *Journal of Cultural Heritage,* 14**,** 109-115.

JAQUIN, P. & AUGARDE, C. 2012. Earth BuIldIng. History, science and conservation.

LEKSHMI, S., SINGH, D., TARANTINO, A. & SHOJAEI BAGHINI, M. 2018. Evaluation of the Performance of TDR and Capacitance Techniques for Soil Moisture Measurement. *Geotechnical Testing Journal,* 41**,** 20160240.

MINKE, G. 2000. *Earth Construction Handbook,* Boston, WIT Press.

PEARSON, G. T. 2015. *Conservation of clay and chalk buildings*, Routledge.

PINCHIN, S. E. 2008. Techniques for monitoring moisture in walls. *Studies in Conservation,* 53**,** 33-45.

RIDOUT, B. & MCCAIG, I. 2016. Measuring Moisture Content in Historic Building Materials. *Discovery, Innovation and Science in the Historic Environment.* Historic England.

SINHA, S., NOROUZI, A., PRADHAN, A., YU, X., SEO, D.-J. & ZHANG, N. 2017. A Field Soil Moisture Study Using Time Domain Reflectometry (TDR) and Time Domain Transmissivity (TDT) Sensors. *DEStech Transactions on Materials Science and Engineering*.

VOLHARD, F. 2016. *Light Earth Building: A Handbook for Building with Wood and Earth*, Birkhäuser.

WARREN, J. 1999. *Conservation of earth structures,* Oxford; Boston, Butterworth-Heinemann.