18th January 2013

Review

of

Earth Conservation Approaches in Practice

Holburne Museum, Bath, England

26th November 2012

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Mud and Wood

Last November I attended a one day workshop on Earth Conservation Approaches in Practice hosted by the University of Bath. It proved to be a highly informative and thought-provoking day. I re-established old connections, met face to face with people I had previously only known through the internet, and made many interesting new contacts.

On the plane on the way over, I got the chance to re-read Laurence Keefe's (of Devon Earth Building Association - **www.devonearthbuilding.com**) excellent book, **"*Earth Building: Methods and materials, repair and conservation*"**. So my head was full of the characteristics, strengths and problems associated with the repair of earth buildings.

A huge benefit of researching and understanding how old earth buildings have been so successful is that this knowledge can then be applied to contemporary earth buildings.

This review of the workshop is a mix of synopses of the speakers' presentations, occasional additional clarification by me (where I think readers new to these concepts may benefit from some background explanation) and my own commentary on and/or experience of the topics under discussion. Not all of the presentations are reviewed.

For example, Dr. Louise Cooke (Earth Building UK and International Scientific Committee on Earthen Architectural Heritage), presented a talk on a number of archaeological digs and investigations in which she participated. She discussed the importance of recording the current condition of the structures they found and experimenting with different ways of best achieving that. She also queried the need to physically conserve the structures in every case. Sometimes it might be appropriate to let time do its thing. Personally, I feel that that is part of the beauty of earthen architecture – that if allowed, it will eventually disintegrate back into the earth and leave no trace.

Another important issue was listening to the local people. It is their tradition, history and culture that is to be conserved after all. She cited a few examples in Asia, where the local people have been trained to carry on the conservation work. This has proven to be successful.

Review 1

Building Materials in Conservation

Dr. Andrew Heath - BRE Centre of Innovative Construction Materials

ICOMOS is the International Council on Monuments and Sites. In 2003, they ratified the ***ICOMOS Charter: Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage***. There were 2 clauses in this document that were of particular interest to Dr. Heath.

2. *Research and Diagnosis*

2.3 *A full understanding of the structural and* ***material characteristics*** *is required in conservation practice….*

2.5 *Diagnosis is based on historical, qualitative and* ***quantitative*** *approaches; the qualitative approach being mainly based on direct observation of the structural damage and material decay as well as historical and archaeological research, and the quantitative approach mainly on material and structural tests, monitoring and structural analysis.*

He observed that while many architects and archaeologists are very keen to get to grips with the historical and qualitative aspects of the building/material, we are not always so keen to tackle the quantitative aspects.

The historical assessment might include the way in which the building was built, *e.g. for a cob cottage, the rising stone wall could be knee-height, shoulder-height or almost non-existent. This might reflect a local "fashion"; it might reflect an abundance or lack of building stone in the area; it might reflect a localised use for these* *buildings, e.g. livestock rubbing against the building called for higher stone bases. Other historical aspects might include: Was shuttering used? Were the cob walls built plumb or battered (the bottom of the wall is wider than the top).*

The historical assessment might also bring to light regional differences in the materials themselves, depending on what local resources were available, *e.g. earth buildings with a high chalk content, different types/quantities of straw mixed through the cob itself, etc.*

Dr. Heath referred to the ***"Terra Literature Review: An Overview of Research in Earthen Architecture Conservation"*** edited by Erica Avrami, Hubert Guillaud and Mary Hardy - (**www.getty.edu/conservation/publications_resources/pdf_publications/terra_lit_review.pdf**).

It outlines the material properties of earth. They are:

• Particle size distribution (psd)	How much of the earth sample is stone or gravel, how much is sand, how much is fines (silt/clay)?
• Plasticity	How mouldable is the earth? This will depend largely on its clay content. Soils that are non-plastic or of very low-plasticity are, as a general rule, insufficiently cohesive to be used for building[1]. The plastic limit of a soil sample is the driest "wet" mix at which one can still mould that soil.
• Cohesion	How well do the particles in the soil stick to each other? A non-cohesive soil will be crumbly. A highly cohesive soil will stick to itself, to the shovel, to your hand, etc.
• Compactability	All earthen construction retains a small quantity of water within the material, even when 'dry'. Compactability refers to the point at which the earth material reaches its optimum water content under compaction[2]. There will be lot more about water content and its effect on the behavior of earth as a building material later in this article (**Review 2 and Review 3**).
• Shrinkage	Earth will absorb and release water. Depending on the make-up of the soil, in particularly in relation to the clay content and clay type, the volume of earth will increase as it takes in water and shrink as it loses water.

[1] **Earth Building: Methods, materials, repair and conservation** by Laurence Keefe – Soil consistency p. 34
[2] **Terra Literature Review: Characterization of Earthen Materials** by Hubert Guillaud – Compactability p. 25

• Void indices	How porous is the material? How much rain will it let in? This is relevant to the conservation of historic buildings as it highlights the material's susceptibility to degradation[3].
• Erosion resistance	If the building is exposed, how easily will the surface start to wash away?
• Chemistry	Are there salts in the soil? Is there decomposing organic matter?
• Mineralogy	What type of clay is present? Is it kaolinite, smectite, etc. Different types of clay have different properties, largely based around their tendency to swell and shrink as they absorb and release water. For building, one obviously wants a stable soil which is not prone to dramatic swelling/shrinkage.
• Classification	Is it a sandy soil? Or a clayey soil?

Dr. Heath looked at the Particle Size Distribution first. Why is this important? Different earth-building techniques require different mixes of the components of earth.

What are the components of earth?

- Stones and gravel
- Sand
- Silt
- Clay

For building, we need the stones, gravel and sand as the skeleton, the strength in the material. The clay acts as the binder, the glue that holds everything together. We need enough clay to stick everything together. However too much clay can lead to problems of swelling, shrinkage and cracking (*see **Shrinkage** and **Mineralogy** above*) Generally speaking, we do not want much silt in our mix. It is so fine that it acts like talcum powder, reversing the binding properties of the clay.

Different recipes are appropriate for different construction methods, e.g. traditional cob will work with a clay content of 10 – 25% of the total mix; rammed earth needs a much lower figure and has a narrower margin for error, 7 – 15%[4]. One of the reasons for this is the addition of fibre reinforcement, usually straw, to cob. This provides tensile strength within the material and helps to counteract shrinkage due to the clay content. The straw literally pulls all of the material together.

[3] **Terra Literature Review: Characterization of Earthen Materials** by Hubert Guillaud – Porosity, Permeability, and Capillarity p. 25

[4] **Earth Building: Methods, materials, repair and conservation** by Laurence Keefe – Modifying Soils p. 54

With adobe bricks (air-dried mud bricks), a clay content in excess of 25% might be acceptable, as all of the clay-associated shrinkage takes place before the material is built into the wall. However, soil with a relatively high clay content would also have increased stickiness. It might be quite difficult to work with before it is dry[5].

The size and distribution of the stone, gravel and sand particles can play an important part too. For example, there are parts of England where the soils are quite chalky and the vernacular earthen buildings in these regions are naturally built with chalk. Particles in these mixes should not exceed 20 – 25mm in diameter. Smaller particles help to increase cohesion[6].

Anyone who has come on one of our **Mud and Wood** cob building or earth plastering courses, or who has read "***The Hand-Sculpted House"*** by Ianto Evans, Michael G. Smith and Linda Smiley, will be familiar with the Shake Jar Test. A sample of soil is put in a jar which is filled with water. It is shaken vigourously and set down on a table or shelf. The heaviest material – stones, gravel, coarse sand - will fall out of the mix first and settle on the bottom (up to 10 seconds). Silt will separate out next (up to 10 minutes). The last component to settle out is clay which could take between a few hours and a few days. There will be a clear layer of water at the top when the process is finished. Each layer should be marked on the jar as it settles out. This process is supposed to yield the ratios of the different components.

At **Mud and Wood**, we use a combination of over 15 field tests to determine what soil type we have, including the Shake Jar Test. It can be handy for identifying whether or not there is a high level of silt in the soil, which does not make for a good building material. However, there are other tests we find are much better indicators of strength or clay content. Even so, I was quite surprised to learn from Dr. Heath that the margin of error for the Shake Jar Test can be as much as 1,750%. As he stated himself, this is hardly a quantitative analysis of the material.

Maybe as an architect, I do not get as excited about the quantitative aspects of building materials (although, the further I research earth, the more fascinating I find it). One of the things I love about cob is that it is a very forgiving material to build with. It doesn't really matter if the clay content is 10% or 25%. It doesn't really matter how big the grains of sand are. The walls are 600mm wide, the straw twists in every direction. As long as you work within some sensible parameters, detail the building properly and use compatible finishes, cob walls will stand the test of time. I know for sure that my ancestors were not a bit worried about particle size distribution. They had an intuitive feel for the material and that is what we try to teach at **Mud and**

[5] **Earth Building: Methods, materials, repair and conservation** by Laurence Keefe – Modifying Soils p. 54
[6] **Earth Building: Methods, materials, repair and conservation** by Laurence Keefe – Soil Preparation and Mixing p. 56

Wood too. However, and this is important, when dealing with the conservation of historic buildings, I believe that precision matters.

Dr. Heath suggests that samples of soil need to be lab tested. For some tests, the samples need to be quite big. It may not be practical to send a few kilos of soil to a distant lab. This is particularly relevant when working on earthen buildings of international heritage importance in far flung areas such as Asia or Africa. So he has developed a portable field test kit. It allows samples to be quantitatively examined in a way that can stand up to scrutiny.

Using the simple contents of the field test kit (sieves, beakers, a small balance, etc.), Dr. Heath was able to analyse the particle size distribution of soil with an error margin of only 1 – 2.5%, acceptable when dealing with earth and a vast improvement on 1,750%. This margin can even be reduced to virtually nil if temperature control is introduced into the test. How can this be achieved out in the field? The test equipment is placed in a bucket of water and hot or cold water is added as required to keep the temperature stable. Simple, yet highly effective.

There were some other nice examples of lateral thinking associated with the components of the field test kit. Compressive strength tells you how much weight a material can bear before it will collapse. To test compressive strength, materials are usually formed into a cylinder or cube, cured or dried, and then crushed by a very large and powerful machine. The weight under which they fail is measured.

Dr. Heath has included a modified car jack in his field test kit. Its upper limit for 'crushing power' is $5N/mm^2$. This would not be adequate to break stone, for example. However, in cob walls, the normal range of compressive strength is $0.6 – 1.1N/mm^2$. In rammed earth walls, the normal range for compressive strength is $0.8 – 2.0N/mm^2$ (this is one of the reasons that cob walls are so wide and some rammed earth walls are comparatively thin)[7]. So a car jack is more than adequate for this purpose.

The kit has been tested and is ready to go on the market. However, lawyers for the British Institution of Civil Engineers have been examining the instructions for the kit to ensure there are no liability issues. They have been examining it for a few months now. Watch this space for news of its launch.

[7] **Earth Building: Methods, materials, repair and conservation** by Laurence Keefe – Compressive Strength p. 41

Review 2

A Better Understanding of the Hydrothermal Behaviour of the Material to Avoid the Wrong Kind of Earth Conservation Practice in France

Prof. Jean-Claude Morel – Laboratoire de Troibologie et Dynamque des systèmes de ENTPE

It may not have the snappiest title, but it proved to be a really interesting presentation, provoking a lot of questions and debate afterwards. Prof. Morel began by looking at some of the thermal properties of earth.

Thermal conductivity measures how quickly a material will allow heat to pass through it. *For example, metal is a material with high thermal conductivity. If you sit on a metal bench, you will feel cold pretty quickly. The metal bench is literally channelling the heat out of you. If you sit on a wooden bench, you will feel much more comfortable. Timber has lower thermal conductivity. Heat passes through it more slowly. Most insulations work on the premise that they have extremely low thermal conductivity. Thermal conductivity is measured in W/mK (energy [watts] passing through 1metre [m] of the material with 1degree temperature difference [K] between inside and outside).*

The presence of water in earth as a building material can affect its thermal conductivity. Prof. Morel dried a sample of earth to 0% water. Its thermal conductivity was measured at 0.02 W/mK. He then measured the same sample with 25% water content. Its thermal conductivity was measured at 2.00 W/mK (100 times greater). Prof. Morel concluded that water builds bridges between the particles within the earth (*essentially building a cold bridge across the wall*) and so transfers heat more quickly. His point was that unless you know the moisture content of your material, you cannot assess its thermal performance. Earth walls are known to absorb and release water in response to the moisture levels in the surrounding environment (see **Review 3 – Dr. Paul Jaquin** for a lot more detail on this).

Prof. Morel stated that not only water in its liquid state needs to considered (such as rain), but also water in its gaseous state or water vapour (exhaling *[breathing]*, steam from cooking/bathing, etc.). The relative humidity of the atmosphere *(how much water is present in the air, compared with how much water would be present in the air if it was completely saturated)* also plays a part.

Carrying out tests on rammed earth, Prof. Morel established that the dryer the earth, the higher its compressive strength. He varied the clay content in the mixes (within a stable range) to see if this would have a bearing. The results indicated that the compressive strength depended more on water content than on clay content.

Prof. Morel referred to Vincent Rigassi, a French architect who specialises in alternative, low-cost, environmentally-friendly building materials. He oversaw the renovation of a rammed earth farmhouse in the Rhone region and was having trouble making the earth walls comply with the French energy-efficiency regulations. (This is an issue close to my own heart – read **www.mudandwood.com/cob-and-thermal-comfort.pdf** for more on this).

The building was monitored during and after the build to collect valuable scientific data. Where the walls were pure rammed earth, the water content of the wall stabilised at 1.7% almost immediately (there is always a small amount of water in a 'dry' earth wall – later we will look at why this water is actually necessary for the wall to remain stable – **Review 3 - Dr. Paul Jaquin**).

To meet regulation requirements, insulations and plasters were added to the walls. If I recall correctly, I believe that lime plasters were used, which are deemed to be compatible. However, it was not clear if lime putty/fat lime was used or if it was a natural hydraulic lime. Neither was it clear what type of insulation was used. Although, given Mr. Rigassi's background, it was likely to be natural and breathable (and therefore compatible – or so one would think).

The moisture content took months to stabilise. When it finally did, it remained at just below 5%, almost 3 times higher than in the untreated wall. The addition of insulation was supposed to improve the thermal properties of the wall. However, it also increased the moisture content of the wall, which increased the thermal conductivity of the wall, which reduced its thermal performance.

Perhaps, in spite of lowering the thermal performance of the rammed earth wall itself, the insulation did actually have a positive effect on the overall thermal performance of the envelope. Prof. Morel did not give values for the thermal performance of the wall pre-insulation and post-insulation (u-values). It would be interesting to follow up on these figures to see if one, in fact, cancelled out the other.

It should be noted that this increase in retained water also had an effect on the compressive strength of the wall. Too much moisture in an earth wall will eventually lead to collapse. This then leads to the question, how much is too much?

Prof. Morel showed an example of a mud-walled house whose end wall had collapsed in 2012. The house had been refurbished in 2004. The wall was lined with plasterboard internally with mineral wool sandwiched in between the plasterboard and the rammed earth wall. Externally, it was rendered with a lime render (allegedly compatible with earth walls – however, there is a lot more detail on this under **Review 4 – Nigel Copsey**). The type of lime, the strength of lime and even the cement content (which may have been considerable) in the render was not measured after the collapse, which was catastrophic. It was noted that a large advertising billboard had been hung on the wall and the weight of this may have contributed somewhat to the collapse.

Prof. Morel measured the water content of the collapsed wall at 10 – 11%. When building rammed earth walls, the earth should have a moisture content of 8 – 14%[8]. This 'moist' earth is supported within shutters until it is dry enough and strong enough to support itself. Note the Prof. Morel found a correlation between dryness and compressive strength. He also found that untreated dried rammed earth walls had a moisture content of only 1.7%. Clearly, 10 – 11% moisture content within the wall would lead to collapse.

Somehow, the combination of materials applied to help protect the wall from the weather and to improve the thermal performance of the wall, had actually resulted in its destruction.

Mineral wool is not a particularly effective insulation, especially in situations where it is combined with materials which absorb and release moisture. When mineral wool gets wet, it stays wet for a long time and when it gets wet, it does not function anywhere close to its dry performance values. An increase of only 10% in humidity levels can reduce the insulating effect of mineral wool by 30%[9] .

I raised this point with Prof. Morel, wondering whether a more complex (natural) insulation used internally (which may facilitate moisture movement out of the wall, rather than inhibit it) may have helped the situation. At the time of the collapse, the type of insulation used was not a priority for the research team. It is, however, a factor to which they will pay attention in the future.

Currently Prof. Morel is carrying out field tests on a rammed earth house in France under Project Terra (**http://www.getty.edu/conservation/publications_resources/pdf_publications/terraguidelines.pdf**).
There are 3 sensors embedded in the rammed walls; one near the inner face of the wall, one in the centre of the wall and one near the outer face of the wall. As the house is not yet lived in, there is no heating internally and therefore no temperature difference between inside and outside the house. The inner and outer sensors are losing moisture at much the same rate. This would most likely change if the house became occupied. The centrally embedded sensor is losing moisture at a much slower rate. This is to be expected.

On completion of the build, the walls had a moisture content of approximately 25%. In the first year since completion, this has dropped steadily to 7%. There are no treatments/finishes applied internally or externally. The wall being tested is a south-west facing wall.

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[8] **Earth Building: Methods, materials, repair and conservation** by Laurence Keefe – Building with rammed earth p. 85
[9] **www.viking-house.ie** Insulation Facts No. 5 – source not verified (17/01/2013)

This raises a point that we have noticed living the **Mud and Wood** house.
According to Prof. Morel's measurements, there was a reasonable level of moisture in the newly-built walls (25%). Most of the drying occurred in the first year (7%). However, if we look at the Rigassi house, the moisture content dropped down to 1.7%. We could expect the monitored house to do the same.

We can literally feel our own house getting drier, and therefore warmer, year on year. Some people say that the way to solve cob's difficulties with energy-efficient regulation compliance is to increase the thickness of the walls. Looking at Prof. Morel's results from the embedded sensors, the further the sensor is from the wall surface, the slower it is to lose moisture. Hugely thick walls may have better u-values on paper. The reality is that the building could take years to dry to its optimum level. Wetter walls mean lower u-values.

Review 3

<u>The Role of Water in the Philosophical Aspects of Conservation</u>

Dr. Paul Jaquin – Integral Engineering Design

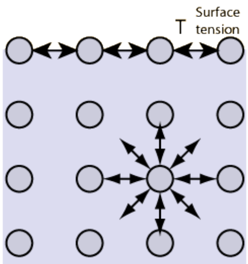
Dr. Jaquin's presentation followed on neatly from Prof. Morel as he examined the presence of water in soil and how that soil behaves as a result. So while Prof. Morel warned about negative effects on structural stability and thermal comfort associated with excessive moisture content in earth walls (mainly from inappropriate repairs), Dr. Jaquin began to examine why.

To begin with, he cited a number of physics-based phenomena that play a part in the relationship between earth and water.

- Surface Tension
- Friction
- Pore Water Tension
- Relative Humidity
- Pores and Particles

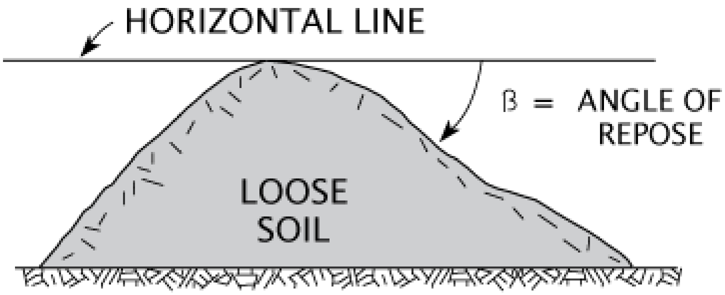
- <u>Surface Tension</u>

Molecules on the surface plane of fluid experience different forces to the molecules within the body of the fluid.



Each molecule on the surface creates a bridge with the molecules on either side. This creates an attractive force, i.e. it pulls two things together.

Completely dry materials have an angle of repose. If you pile up dry sand, it will settle into a slope. If you pile up dry pebbles, they will also settle into a slope. If you pile up dry soil, it too will settle into a slope.



However, what happens if you add a little bit of water?

Sand Castle by Calvin Seibert[10]

How can adding a small amount of water allow you to build vertical faces? Earth walls consist of lots of particles with lots of pores or voids between the particles. When water is added to the mix, bridges of water form across the pores between the particles (thanks to surface tension), essentially pulling the particles (or grains of sand) together.

However, if the earth wall (or sand castle) is submerged in water, it returns to its angle of repose (i.e. collapses). The surface tension (the pulling effect) has been lost

[10] **www.flickr.com - box builder – My "Sand Castles" -** Photo reproduced with kind permission of Calvin Seibert

because of all the free-flowing water. The “water-bridges” between the particles collapse. The bonds are broken.

- <u>Friction</u>

This is the force which resists movement between two solid surfaces in contact with each other. With non-moving solids (such as the particles in earth), it is referred to as static friction or ‘stiction’. This indicates friction’s ability to ‘stick’ the touching surfaces together at a microscopic level.

I already mentioned that walls built with chalk perform better if there are no particle sizes bigger than 20 - 25mm (**Review 1 – Dr. Andrew Heath**). In fact, many chalk walls contain a predominance of extremely fine particles[11]. Part of the reason is that it allows a greater number of separate surface areas to come in contact with each other, increasing the friction and therefore the cohesion between the particles.

Friction starts the process of particles sticking or interlocking together. The presence of water strengthens this cohesion by building water bridges between the particles, pulling them even tighter together.

- <u>Pore Water Tension</u>

Pore water pressure refers to the pressure of water held within the gaps between particles in saturated soil. Where the soil is not saturated, the pressure in the pores is referred to as tension or suction.

- <u>Relative Humidity</u>

Air carries moisture. When the air is saturated with water vapour (water in its gaseous state), it is at 100% humidity. This is the point at which the water vapour condenses and turns into water (liquid state). Warm air can contain a higher volume of water vapour without reaching saturation point, compared with cold air. So the actual amount of water vapour present in the air depends on the temperature.

Relative humidity first looks at how much water vapour is in the air at a given time and a given temperature. It then looks at how much water vapour would be in the air if it was 100% saturated (just about to condense) at that temperature. Relative humidity is expressed as a percentage. This number tells us how dry or moist the air feels. *Aeroplane cabins operate their air-conditioning systems at about 20-30% RH. We feel pretty desiccated after a long plane journey. 80% RH feels stifling in hot weather or damp in chilly weather. The optimum range for human comfort is 40-60% RH.*

What has this got to do with earth and water?

[11] **Earth Building: Methods, materials, repair and conservation** by Laurence Keefe – Chalk p. 48

Saturation vapour pressure refers to the point when the rate of evaporation (liquid turning into vapour) is equal to the rate of condensation (vapour turning into liquid). In very basic terms, the overall outcome is that you end up with as much liquid and as much vapour as you started with, despite some of it evaporating and some of it condensing (*think of a container full of boiling liquid, covered by a glass bell – the steam [vapour] condenses on the glass and slides back down into the liquid*).

Earth consists of particles (stones, gravel, sand, clay, silt) and voids or pores. The water vapour in the surrounding environment makes its way into the pores. Within these tiny, confined spaces, water molecules start to cling to the surrounding surfaces.

Water in a pore acts like water in a tiny tube or capillary. The action of pore water tension or suction is present. Surface tension on the water also comes into play. The water in the pore will form a skin, a meniscus (*this is what pond-skaters glide about on*). In a pore, the meniscus is not flat, but curved. The curve creates a stronger bond between the molecules compared with a flat meniscus. In this condition, the saturation vapour pressure of the water-skin's surface is reduced. The smaller the pore, the greater the curve of the meniscus, the lower the saturation vapour pressure.

The air within a room or outside a building at ***x***% RH will have a particular vapour pressure. The surface of a strongly curved meniscus will have a much lower saturation vapour pressure. As the ***x***% RH moisture-laden air from the room comes in contact with the meniscus in the pore, a high vapour pressure will 'meet' a lower saturation vapour pressure. As far as the meniscus is concerned, this encroaching air is super-saturated and it will condense.

Water will condense first in the smallest pores and then in increasingly larger ones. Eventually, the ***x***% RH moisture-laden air will arrive in a larger pore with a smaller-radius meniscus. The vapour pressure of the air and the surface of the meniscus will be equal. At this point, the earth construction material is in equilibrium with the surrounding air. Earthen buildings constantly seek to achieve this state by a process of condensation and evaporation.

It is clear that excess water will cause damage to earthen buildings. However, the water need not necessarily be liquid. Sustained increased relative humidity in the environment of earthen walls can also cause damage. As we have seen above, water vapour will condense within a porous material (such as earth) before the air in the room or the air outside has reached its saturation point. In very small pores with very strongly curved menisci, water vapour may condense with a relative humidity (RH) as low as 50% upwards

- <u>Pores and Particles</u>

Simply put, earthen buildings transport water through them by evaporation and condensation of the bridges of water in the pores between the particles.

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When it rains, water droplets are absorbed into the earth wall by capillary action (suction into the network of tiny pores). The RH of the wall increases. This, in turn, causes the pore water tension to decrease. The walls can take in an amount of water. When conditions change (i.e. it stops raining and the external RH drops), the walls can release the water through a process of evaporation from pore to pore. The wall does not become 100% saturated.

There is also another phenomenon which occurs within earth walls that was not raised by Dr. Jaquin, but which is important in how they respond to water vapour penetration. Clay is an important component of earth as a building material. It is the binder, the glue. Clay is also a rather remarkable mineral. In the simplest terms, it consists of alternating aluminium and silica plate-shaped molecules. This arrangement creates a charge which attracts water. The water forms bridges between the molecules, giving them strength. But it also causes the molecules themselves to swell. They physically get bigger, blocking the voids between them, preventing any further water penetration[12].

If water is continuously in contact with the wall, eventually the clay will be overwhelmed, the bonds broken and the water will cause damage. However, it should be noted that while there are other ‘breathable’ materials, such as lime, which absorb and release water, earth (and in particular its clay component) is the only one which can actually limit the amount of water or water vapour entering the wall when it has expanded sufficiently at a molecular level.

This point was raised with Dr. Paul Jaquin in discussion with Gail Haddow, conservation plasterer (Earth and Lime Ltd.), after the workshop. When applying coats of plaster to a lime-faced wall, the pre-wetting of the wall is critical. If the substrate (or base wall) is not wet enough, it will suck the moisture out of the newly applied plaster coat. If this happens too quickly, the plaster will not cure properly and a whole range of problems can ensue. There are also problems, however, if the lime-faced substrate has been over-wetted.

However, when preparing earth walls to receive plaster coats, Gail has noticed that this never seems to be a problem. Her theory is that the wall is ‘intelligent’ about how much moisture to absorb. Because it self-seals, this problem of over-suction does not seem to occur. Having worked with earth plasters myself, I must say that it is a very forgiving material to work with and I would agree with Gail.

Getting back to Dr. Jaquin’s presentation, he began to look at examples of decay and structural damage in earthen walls. Like Dr. Heath, he insisted that a full

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[12] **Using Natural Finishes** by Adam Weismann and Katy Bryce – The mechanisms of earth plasters as a wall finish p.147

understanding of the material, both in its make-up and its structural behaviour, was vital. Unfortunately, this is not always the case out in the field.

As an example, he showed a photograph of an historically important earth-built stronghold. There was a large crack running almost all the way from the top of one wall to the base. The whole corner of the building was leaning out. The crack required a number of stitches to prevent collapse - at the top, the middle and near the bottom. Perhaps funds ran out, but only one stitch had been inserted. Logically, this should have been at the top, where the greatest force was acting. The renowned and respected expert on the job had put the stitch in at the bottom. This displays a lack of understanding of the structural problems which presented themselves and money was spent on an inappropriate and ineffective repair.

Dr. Jaquin explained how staining can occur on earth-walled buildings. Rainwater flows over the wall and picks up small particles. As it runs down the wall, the water starts to evaporate, depositing the particles lower down the wall.

He also gave an explanation for the universal use of a stone plinth at the base of mud walls. The tiny pores in the earth would draw up water resting on or in the ground by capillary action. The larger gaps between the stones prevent this from happening. The earth is raised a safe height from the potentially water-logged ground.

We know that earthen walls can absorb and release water and water vapour. However, it is also clear that if an earthen wall is continuously in contact with water, it will become saturated and the material will want to revert to its natural angle of repose (i.e. collapse in a heap).

Water collecting at the head of a wall is a problem. Anywhere water can pond or pool is a problem. In these situations, roofs must be repaired, damaged gutters and rainwater pipes replaced, window sills reset. The key is to prevent water getting to that point. Do not allow the water in.

Sometimes adding a new roof may not be suitable. Dr. Jaquin showed an example where only the earth walls of an ancient building remained standing. From a philosophical conservation point of view, it was not appropriate to put a new roof on this building. So they made a simple capping for all of the walls, a mat of bamboo, packed with earth, with a reasonable overhang on either side of the wall.

You may think that packing the bamboo with earth seemed an odd solution to prevent rain reaching the earth wall below. The capping will need to be replaced from time to time, but the materials are cheap, abundant and readily available to the local community. Also, when using the right kind of clay, an excellent seal against water can be provided.

Traditionally, bentonite (a type of expansive clay [swells and shrinks dramatically]) was used to line canals thanks to its excellent self-sealing properties. It is still used today in conjunction with geo-textile membranes. A few years ago, Colin and I visited a 150 year old Scottish Black House on the Isle of Lewis in the Outer Hebrides. It *had been sensitively restored. Its gutters were actually stone troughs lined with clay. They worked beautifully*.

It is clear that the head of a wall needs protection. It is also often appropriate to protect the sides of the walls, by applying a compatible render. A large amount of the damage I have seen to existing mud-walled structures has been due to the use of cement-based renders. These are non-breathable. Once moisture gets into a mud wall behind a cement render, it cannot get out again. This can eventually lead to saturation and failure. There are other issues associated with the excessive rigidity and strength of cement renders, but that is for another discussion.

It has been known for some time now that cement-based renders are absolutely unsuitable for application to earth-walled buildings. However, what struck me during the workshop was that Prof. Morel's measurements of higher-than-expected moisture content in walls which had lime-based renders applied, indicate that the majority of lime products may not be appropriate either (**Review 2**). This is discussed in detail under **Review 4** and Nigel Copsey seems to corroborate this idea.

Dr. Jaquin pointed out that depending on circumstances, it will not always be possible to prevent water getting in. In this case, it is important to let the water out. Renders, plasters and paints must be permeable (breathable). The provision of drainage at the base of an earth building can go a long way to rectifying saturation problems.

When dealing with conservation, there are many philosophical issues wrapped up with the desire to fix the problem. Should the building be repaired? Should damaged parts of the building be rebuilt? What is the historical value of the building? Is it the idea of the building or is it the material itself that is important? The simple fact is that earth buildings by their very nature require ongoing maintenance and that should be taken into account when considering how to conserve them.

Dr. Jaquin showed an example of the Castillo de Tabernas, a towering rammed earth castle, most likely dating to the Muslim occupation of Spain. Both historically and culturally, the castle is highly significant for locals. It features on the label of their globally exported olive oil. The castle has been extensively repaired with concrete. Research and field observations suggest that these repairs will, in all likelihood, destroy the remaining earth walls. In this case, what was more important to conserve? The technology of an ancient, rammed-earth, multi-storey building, or the intact image of the building? Hopefully, with a better understanding of earth as a building material, in the future it should be possible to do both.

Dr. Jaquin's presentation finished with an excellent quote, which I have borrowed (and which also displays common misconceptions about earth buildings' relationship with water). As Morocco gained independence from France and Spain in 1956, a French officer was defending a rammed earth castle,

"It's not their guns I'm frightened of, but God help us if they use water pistols".

*(**Maxwell 2000**)*

Dr. Jaquin also curates an informative website, **www.historicrammedearth.co.uk**.

Review 4

Practical Aspects: Earth Mortars and Plasters in Masonry Construction across a Range of Building Types

Nigel Copsey – Earth, Stone and Lime Company and Associates

Nigel Copsey is a building contractor specialising in conservation and restoration. He carries out a lot of his work in the northeast of England. Much of his presentation focused on historic buildings in and around Malton, North Yorkshire.

There is often a perception that mud was only used for lowly buildings of the poor. However, Mr. Copsey has found through experience that this is not the case. Working on the restoration of many different types and ages of buildings, from 12th and 13th Century churches to a 16th Century cruck-house (the roof structure ties into wall posts embedded in solid, load-bearing walls), he found that earth was used as a building component in all of them. In fact, he would go as far as to say that up to 1800 earth mortars were used in all buildings in Malton.

Old Malton priory Church was built between 1150 –1200. The core of the limestone walls was filled with a very sandy earth mortar. For the structural ribs of the roof, a lime mortar was used (interestingly, the lime was mixed with limestone dust and not sand). However, earth mortars were used for all of the infill panels and earth plasters were used throughout.

Mr. Copsey commented that the prevalent specification for lime mortars currently used for conservation repairs is 1 part lime to 3 parts sand (1 lime: 3 sand). In 25 years of conservation work, he has never found this ratio to exist historically. The lime used is a hot lime mix, highly calcinated and the mortars have a ratio closer to 2 parts lime to 3 parts sand.

I researched this comment a little further. Patrick McAfee, a renowned Irish stone mason and lime expert explains the following in his book **"*Lime Works – using lime in traditional and new buildings*"** *(the italics are my own additional clarifications),*

> " Many old specifications mention such mixes. Even simple observation shows that the lime content is higher than one part of lime putty to three parts of sand. One reason for this may be that they were mixing quicklime (calcium oxide) with sand in the proportion of 1:3. On slaking with water, quicklime produces approximately twice as much lime putty by volume as the original quicklime. Sometimes, old specifications and writings took it for granted that this was understood by everyone involved in building.

It is unlikely that the lime they used was a lime putty, and it is probable that they used quicklime. The quicklime would probably have been high calcium or fat lime, possibly used with a pozzolan (*an additive to help the mortar set*). Or the quicklime used could have been feebly hydraulic (*can set under water*). Quicklime was sometimes converted to a hydrate (*just enough water added to convert the lump lime to a powder*) before being mixed immediately with the sand. This could have been used right away or allowed to sour out (*the workability of lime mortar improves if left to sit underground or under water*) for an extended period before using.

Today, the use of hot lime mortar for the repair of buildings in Ireland is virtually unknown. There are also serious health and safety implications in preparing such mixes. However, it has been used elsewhere with success (*Nigel Copsey being one example*), and specialists may find that it is worth reviving for certain projects. If not mixed thoroughly, hot lime mortars may create later problems from expansion and jacking, particularly on thinner wall construction".[13]

High calcium lime is produced by burning lumps of pure or near-pure limestone in a kiln heated up to 900ºC. At this temperature, the carbon dioxide gas evaporates out of the limestone. The lumps that remain are the same size, but weigh about 55% of their original weight. These lumps are quicklime.[14] The quicklime is then combined with sand and mortar, creating a steaming hot reaction. It is has excellent workability. It stiffens within minutes, allowing work to proceed at a good pace. Even though it hardens quickly, it has not begun to carbonate (that is a process which occurs over a long time). The lime mortar has only lost its water content. By adding water, it can be reworked and used cold.[15]

There are two other ways of preparing lime mortars once quicklime has been produced. The first is to slake the quicklime. It is added to a vat of cold water. The mix will start to boil in a very short time. The lumps of quicklime are broken down. The mix is stored in a pit. Any excess water is removed until there is just a thin layer protecting the lime from the air. Exposure to the air will begin the carbonation process. The second is to barely wet the lump lime or quicklime to reduce it powder form. This can be stored in paper sacks.

Mr. Copsey referred to ***"The Compleat Builder's Guide"*** by Richard Neve, published in 1726 and still available in print to buy. There are recipes and discussions on earth and lime mortars and plasters. He also referred to historic documentation which evidenced that stonemasons were well paid in that era. In fact,

[13] **Lime Works – using lime in traditional and new buildings** by Patrick McAfee – Hot Lime Mortar p.182
[14] **Lime Works – using lime in traditional and new buildings** by Patrick McAfee – High Calcium Lime Mortar and the Lime Cycle p.45
[15] **Lime Works – using lime in traditional and new buildings** by Patrick McAfee – Traditional Hot Lime Mortar s p.58

when the current cost of living is taken into account, the stonemasons of the mid-eighteenth century were probably better off than their present-day equivalents. Mr. Copsey pointed out that well-paid craftsmen do good work. Indeed, the well-paid stonemasons' work of the past still stands today.

He lays some of the blame for decreasing wages at the feet of architects, who emerged on the scene in the 1850s. They introduced competitive tendering which lead to stonemasons undercutting each other to get the work. Mr. Copsey sees a correlation between dropping wages and dropping standards of workmanship.

Mr. Copsey has spent a number of years conserving the Thompson Cruck House in Crambe. He uses it as a practical workshop for conservation students of York University (**www.centretsb.wordpress.com/projects/pond-farmhouse/**). Built between 1570 and 1590, earth mortars and plasters were used extensively on this sandstone and timber cruck-frame house. The joints were initially pointed with an earth mortar, which was struck very close to the face. A very lime-rich and hairy mortar was then thinly laid on top.

The Earth, Stone and Lime Company use hemp as a fibre in their earth plasters. This allows them to work with them in a very wet state, which facilitates easy application. As long as the ratios are right (and it is critical that the ratios *are* right), they find that less shrinkage occurs when applying a very wet mix.

Over the years, they have collected and examined multiple samples of earth plasters. Many of them have white flecks in them, indicating the presence of hot mixed lime in traditional earth plaster and mortars. Historic samples do not contain sharp sand, although that is the convention nowadays.

They have also found that using hot mixed lime, rather than natural hydraulic limes (NHLs) leads to drier buildings, as the material is highly porous.

Mr. Copsey warned against the use of natural hydraulic limes for conservation work on earthen buildings. Old lime samples are never stronger than 2 – 3 N/mm^2. Good practice dictates that mortars, plasters and renders should be weaker than the substrate, i.e. a lime mortar should be weaker than the brick or stone it is bonding, a lime or plaster should be weaker than the mud wall it is covering.

Natural hydraulic lime comes in 3 strengths, NHL 2, NHL 3.5 and NHL 5, which corresponds to 2 N/mm^2, 3.5 N/mm^2 and 5 N/mm^2. The rule of thumb that I would have accepted up until now is that NHL 2 is suitable for soft substrates or for fine internal work. For general building work, NHL 3.5 is appropriate. For extremely exposed areas or underwater work, NHL5 should be specified.

However, Mr. Copsey pointed out the following facts, which have definitely made me rethink the way I will specify lime in the future.

- NHLs reach their given strength after 28 days.
- However, one month after that, they will have doubled their strength.
- A year after that, they will have doubled again.
- After another 2 years, it is possible that they could double again.
- The strength indicated by the NHL number is actually the lowest number in a range. For example, NHL 2 has an actual range of 2 – 7 N/mm²; NHL 3.5 has an actual range of 3.5 – 10 N/mm²; NHL 5 has an actual range of 5 – 15 N/mm².

For an earthen wall, a plaster with a strength of 2 N/mm² should be specified. However, in applying a natural hydraulic lime plaster of NHL 2 to the wall, these are the circumstances which might actually be taking place:

- The plaster applied to the wall achieves a strength of 7N/mm² after 28 days.
- One month later, the plaster is at 14N/mm².
- One year later, the plaster is at 28N/mm².
- Two years later, the plaster is at 56N/mm².

Within a year or two, the plaster has become much too strong and has reduced its vapour permeability to such a degree that it is no longer compatible with the wall beneath. In fact, it is probably causing damage to the earthen wall.

At **Mud and Wood** we specify earth plasters internally for cob buildings and a hemp and lime-putty render externally. For us, lime putty seemed to be a more logical match with earth. It is identical chemically, in bond strength and in vapour permeability to hot mixed lime. I am relieved that we did not choose to specify NHL 2 and wonder if the examples of collapse and excessive moisture retention cited by Prof. Morel (**Review 2**) could have been caused by the disproportionate strength of the lime plasters and renders?

Mr. Copsey is not a fan of lime putty in practice because it is messy to work with. Hot mixing gives absolute control over the moisture content of the mix and the benefits of increased workability and quick stiffening have already been outlined.

There are health and safety issues associated with the extreme heat generated when mixing, as well as raw quicklime's potential to react explosively to water (with which it can quite easily come into contact if not transported or stored carefully). However, experience, care and common sense can overcome these issues. In many parts of Britain and Ireland, limestone is abundantly available. Abandoned lime kilns all over the country are evidence of this. Mr. Copsey recommends burning your own lime (with appropriate training beforehand). £35 of material and a few hours work can produce the equivalent of £600 of imported lime. This lime will be superior in its quality control, in its appropriateness for conservation applications and it is more environmentally-friendly as it has been sourced and made locally.

At the end of his presentation, Mr. Copsey laid out a range of earth plaster samples. The amount of animal-hair fibre in some of the samples was remarkable, as he said himself, more like a carpet than a plaster. I questioned whether there was much evidence of traditional additives in the plasters, such as animal urine or manure. At **Mud and Wood** we experiment with natural additives such as flour paste, cow manure and milk products. Mr. Copsey said that sometimes there was a smell of ammonia which could indicate the presence of such additives. However, more often than not, the plasters were made from earth with specks of hot lime, fibre and nothing else. This is now the way the Earth, Stone and Lime Company are making their own earth plasters and find that there is no need for extra additives to improve adhesion, increase abrasion-resistance, improve workability, etc.

Ben Gourley, Mr. Copsey's associate, brought up the fact that many maps which highlight areas around the country where there was a tradition of building with earth are wrong. The more that they research it, they are finding evidence of earth building everywhere. Mr. Gourley's feeling is that the maps for Britain and Ireland should be coloured solid.

In Ireland, a mud-wall tradition has been identified in the southeast and in counties north and west of Dublin. However, the proliferation of earthen buildings in these areas is only recently coming to light. Over 600 buildings have now been logged in the southeast, with approximately 150 making it on to the National Inventory of Architectural Heritage, according to Brian Tobin, a Wexford-based builder specialising in cob repair.

In my experience, people have been contacting me about surviving mud-wall cottages, terraced houses and farm out-buildings in Co. Tipperary, Co. Limerick, Co. Sligo and Co. Leitrim. I am absolutely sure that there are hundreds of examples in every county in the country; we just do not know it yet.

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If you do discover that you have a mud-walled building under your care, please let us know. And if you decide to repair or upgrade it, please ensure that you carry out the works carefully and properly, to ensure your earthen building survives for generations to come.