Rammed earth

Environment, Climate

Rammed Earth Historical Use

The use of earth itself in construction dates back thousands of years, the first recorded city – Jericho was built of earth. The first recorded use of rammed earth was by the Babylonians in 5000BC. Parts of the western portion of the Great Wall of China 300BC are built of rammed earth. Almost every European country has a history of rammed earth construction but is usually a material associated with arid areas. 780-1850 Rammed earth experienced popularity in the USA until mass production of fire bricks and sawed lumber became readily available. These materials were now favoured for being more elegant and modern than using rammed earth – or " dirt". However during World War I and theGreat depression, supply shortages prompted a return to Rammed Earth. Rammed Earth remained fairly unpopular then until the 1970's when it began to be rejuvenated by the environmentally conscious.

Despite Rammed Earths extensive use throughout history, its use is still not so popular within the UK. Reason for this is largely due to architects/ Builders not knowing enough about the material and sticking to the familiar concrete, timber and brick ways that they know, rammed earth can often also be perceived as having cruder finishing and not in keeping with the clean-sharp lined finished which are so often preferred in today's architecture- Though with the appropriate shuttering clean finishes can be achieved.

Building with rammed earth is considered to carry greater risk and uncertainty, the material is yes, more suited to arid climates, but even in arid climates modern method of construction using rammed earth are being continually tried and tested e. g. in Australia. Rammed earth is a perfectly

viable and good material to be used within the UK – there is a need to get past the reluctance to use and experiment with it more here - the climate presents a challenge which can be won in innovative ways.

The Use of Rammed Earth within the UK

Things which prohibit the wider use of Rammed earth within the UK

- The longer than average period needed for construction.
- The formwork and Labour costs.
- The climates high humidity climate – Moderate external temperatures.
- Concerns which are had about the careful detailing which can be required.
- Poor thermal resistance – The need for external walls to require additional insulation.
- Not all soil types are appropriate importation of soil for a rammed earth construction will significantly detract from its environmental credentials. The Quality control required for rammed earth constructions is quite high.
- Moisture movement can be caused by high clay content.
- The UK has few modern examples of rammed earth buildings – relatively untested in this climate – comparative to other countries.
- There are currently no UK codes of practice on rammed earth construction.
- Adding cement stabilisation can compromise its attributes as a sustainable material.
- It can be difficult to find insurance for rammed earth construction. It needs to be kept dry during construction which can result in the need

for temporary roof structures. After construction this presents the needs for overhangs or on exposed sights structures to protect from prevailing elements- can compromise aesthetics.

- People hungry construction.
- Some more high profile examples of rammed earth building in the UK have experienced problems e. g. the Eden project- over hangs were not big enough and the splash back of rainwater has eroded some of the facade. Reasons why rammed earth would be chosen over other materials It distinct appearance.
- Natural and readily available.
- It has a low embodied energy.
- Rammed earth is hygroscopic – due to high moisture mass – it will regulate humidity.
- Post demolition – unstabilised earth is reusable.
- Supports sustainable practices by using local soils.
- High Thermal mass – though the extent of which has yet to be quantified.
- Airtight construction is achievable.
- It can be considered a traditional form of construction.
- Modern methods have and continue to be widely tried and tested overseas. An integrity of building is expressed which is often lacking nowadays.
- Expression of cultural conditions.
- Acoustic properties- its dry density (pd) is typically 2, 100 kg/m3 therefore the weighted sound reduction index (Rw) would be 58. 3dB

[1] and thus more than satisfies Building regulations (2000), Doc E Resistance to the Passage of Sound. Other considerations when Using rammed earth Rammed earth is hygroscopic, therefore external cladding systems must be vapour permeable to allow for evaporation.

Important for unstabilised walls and less so for stabilised walls where stabilising agents will impair breathing, still it is better to consider vapour permeable solutions for both instances to reduce chances of condensation build up on the inside face of insulation. Water resistance the need to keep the structure dry post construction is done in various ways, large overhangs, plinths upon which the wall is constructed, rendering or cladding to the facade- these options will affect the structures sustainability, look and thermal mass.

A comparison between the calculated U-values for both 'conventional' masonry and Stabilised rammed Earth wall designs [pic][2] Rammed earth as a sustainable material CO2 Emissions are greatly reduced with the use of rammed earth, as opposed to cement which due to the need for burning limestone produces CO2 contributing about 10% of the global CO2 emissions. Rammed earth taking soil from the site not using a stabiliser is the most sustainable method; however the addition of a cement stabiliser is common practice and considered to reduce considerably the risk and uncertainty, cement is used making up 6-7% of the mix.

The embodied energy is low- its inherent recyclability and reduction of CO2 during the structures lifetime, high thermal mass and low operating costs. If the clay can be sourced from site, and is suitable then it eliminates all transportations cost. If the clay is not so suitable, then a stabiliser of cement

can be added. If the soil on site is not at all suited for a rammed earth construction then clay can be transported to site- however both of these options will compromise the environmental integrity of the building, the latter of which doing so quite considerably.

Also due to the need for rammed earth to be kept dry at all times during construction there can be a need for temporary roof structures to keep the rain away, this will therefore impact its sustainability. Depending also on what type of shuttering is used can lead to waste, for e. g. timber shutter although can be reused, its reuse is limited as it will become saturated from the moisture in the clay. Thermal Performances, Rammed earth has a high thermal mass – walls will naturally regulate both the internal temperature spaces, and can also regulate the temperatures of external spaces such as courtyards.

Energy required to heat and cool a building can be greatly reduced if rammed earth is designed into the heating system, however the UK requires the addition of either internal or external insulation, this aside from affecting the aesthetic of either facade it is fixed to, will compromise the thermal mass of the adjacent space. Structural Performance, whilst the structural strength and stiffness is compromised with increased waster content, if designed correctly and waterproofing measure taken then rammed earth is perfectly capable of acting as a load bearing structure.

Rammed earth which is imported in not only contribute to the cost and environmental issue of transportation, it also leaves a scar on the landscape as it is being taken from elsewhere, e. g. a quarry, even if this is later turned into some sort of nature reserve it is still leaving a permanent change to this

landscape. Insulation – in the UK there are few examples of rammed earth combining insulation, most contemporary walls are unclad, but there is an increased need for insulation to be used in conjunction with the thermal mass of the walls.

Weather protection

- Weather needs to be drained away from walls
- Construction upon raised footings
- Avoidance of sites vulnerable to flooding
- Protecting wall from rain using adjoining elements e. g. roof overhangs
- Allow evaporation of moisture from walls • Onsite which are considerably exposed there is a need to consider rain screen cladding or render.

Construction Week Aims

The aim of the work we did within the workshop was to question the building processes as a whole, by means of both small and large scale prototypes, to push the presumed limitations of a material and its formwork, to not just accept, that rules have been predetermined, but to push for innovation. As we studied, the idea of the “ builders yard” allows for just this, meaning a material can be taken and experimented with, in a specific location which possesses the same limiting factors as the actual site e. g. Climate and resources, and test particular means of creating the desired construction before doing so, it is a hub for construction in the area- encouraging risk by means of experimentation rather than out casting it.

The advantages of such an idea are that when a material can be experimented with it allows for greater understanding and judgment of its

limitation- rather than acceptance of existing limitations, and therefore systems of constructing and spatial relationships can be explored. The community have a personal knowledge of the neighbourhood its character and needs, they are given the power to modify and contribute to it, their personal attachment means, as workmen they have a continuedresponsibilityto the changes which occur with building in the area as well as maintenance of them. The people who work together within the builder’s yard understand and achieve better quality meaningful results; the workmen are uniquely and specifically educated, and the buildings produced are, unlike much of the current construction possess a humane quality, a warm character.

The focus on the act of making allows for and evolution and a subsequent greater understanding of everything involved in the construction and about the materials. By making the rammed earth wall within the studio we were pushing the boundaries of predetermined limitations, re-examine the architectural production of rammed earth, and coming up with our own unique response. We explored the possible use of fabric formwork by means of making and testing prototypes on a small scale and then on progressively larger scales we see how it uniquely responds to specific methods thus learning learn how the material and structure can better work together, creating a successful wall with fluid innovative shapes, with lower embodied energy.

Whilst making our wall every element was specifically made and tested and altered, until the best result were achieved, for example we experimented a lot with the sizes of our buttons, trying to get them to sufficiently restrain the

wall –without damaging it when removing them, we were fortunate to stumble upon a size which not only did the job we required but more. This scenario is similar to what happens in the builder’s yard; it is this experimentation –and risk taking which leads to the discovery and sometimes unexpected discovery of innovative solution and inventions. There can be other factors, such as keeping cost down driving the invention of new materials and components.

Prototype I

As a group did we met with Roland for a quick briefing on what direction we should take for our rammed earth wall, he suggested that we should first sit down together and come up with some ideas and sketches to make some prototypes, and that we should also sort out the earth so that it would be ready for when we begin construction. We discussed some ideas about what sort of shaped wall we would like to achieve, including some over ambitious ideas of constructing the walls then flipping it! We agreed we wanted to design a wall to incorporate a curve, a variation in thickness of the wall from bottom to top. We divided into three groups and set about coming up with a design each and building a prototype to text these ideas. Once the earth and fabric had been sorted we each returned to our prototypes, and began to each work out and start making our frame work. Our group decided to make a framework by cutting a .

Semi Lunar shape to incorporate some variation in thickness throughout the wall the . Assembling a frame to which we could pin the fabric to at intervals after each period of . Ramming. The Idea was that one side of the wall would be taut and quite flat and the . other we would periodically place round ties

to restrain the wall and create an undulating shape to it. Basic framework Difficulties with attaching fabric and supporting threads Excessive budging over buttons. Issues highlighted by Prototype 1:

- First of all we needed to add further supports as the structure was not as stable as hoped. Tight spaces need to re-think to consider a pneumatic rammer fitting inside the formwork/ framework.
- The way the formwork was constructed some of the supports hindered the pinning of the fabric to wood.
- The button and tie system we used was not as successful as we hoped- we believed this to be down to the size of the wooden buttons being too small in diameter , which resulted in them become stuck under the overhanging rammed earth and were difficult to remove without causing damage to the wall. They did not restrain the width of the wall much either, this was also partly due to us leaving the thread too long. Also initially we put on the ties without the wooden disc which resulted in a serious overhang. When we were ramming the earth we did so by hand, using some pieces of wood with flat ends, the highlighted another problem-as due to the way the framework was constructed we had a piece of wood running across the top we made manoeuvring a piece of wood let alone a pneumatic rammer difficult.
- Despite having made a definite shape in the base board, to influence the shape of the wall- it in reality had no effect as the fabric took its own shape.
- The need to be taught correctly how to mix the earth and test it.

- The need to not put too much earth in at each layer as the lower down parts were not getting properly compressed

Prototype II

This prototype consisted of 3 wooden sides and a wooden base cut with a curve the fabric was then pinned to the front and around the curve – the idea being that pinning the fabric to the curved base would create a curved facade. However this prototype was pretty unsuccessful – it suffered structural issues and was not strong enough to withstand the pressure of the rammed earth inside, as it was simply nailed together. The fabric also failed to restrain the form of the wall and budged with little shape. Another issue was that as this prototype required a wooden base beneath it, -not so practical! – In reality this would be likely to make the wall less structurally sound- and would be pretty impossible to remove as a rammed earth wall is extremely heavy. In conclusion this wall was afailure. Compressing the soil then dropping from arms length away.

Whilst making the first prototype our earth was not of the correct consistency – which resulted in our wall crumbling a bit. We had used the earth which we had moved indoor on day one - we added some water to the clay- thinking this would help the earth-stick and compact better. It wasn’t until Rowland came on the 3rd day and was able to tell us immediately, the mistakes we had made, and then showed us the correct for mixing, preparing and testing the earth. We broke down our prototypes returning the earth to the pile and also broke down the previous year’s pillars so the soil could be recycled.

At first we used the pneumatic rammer to break down these pillars- this was also our first encounter with using the pneumatic rammer, so we learned some general things about using it – safety precautions with turning it on and off, how it must be held, and despite having identified issues of safety in our risk assessment – not many precautions were taken – wearing of safety clothing/boots/goggles. We then began to break it up further using shovels and spades- a lot of dust had been created by this process so we got buckets of water and using bottles threw water over the earth and clay. Once it had all been broken down we began to mix it altogether whilst adding water at the same time. The earth needed to be constantly moved and shovelled – thoroughly so that it's would be of the same consistency throughout. When the appearance of the mix changed and seemed to be getting close to what we wanted - it looked darker and less dry and dusty, we began to testing it.

To test the soil we picked up a handful – squeezed it tightly between both hands, then holding it at arm's length away from the body- arm held straight – dropped the earth from this height and if it broke into 3 main pieces then we would know that it was ready to ram. It took several testing remixing / adding extra moisture attempts before we did get the earth just right. We also needed to continue testing the earth as over the days it could dry out – so we regularly mixed the soil and tested it adding water when necessary.

Prototype III

On the third day, when Rowland came and saw each of our sub groups prototypes. He was able to give us feedback, and give us some explanation to why some things had occurred which we hadn't expect. In our prototype

the spacing of the buttons presenting some issues, as did the several elements of the framework.

As a group with the help of Rowland we began work on another prototype, again involving a curve, this time a more defined one with the hope it would have an impact on the shape of the wall. This time however we were to make are formwork as minimal as possible. At first we used just two pieces of wood placed either side of the fabric, and at the other end we used thread to sew it up. Sewing a few inches at a time, to make manoeuvring the pneumatic rammer easier. It was then decided we would place a piece of timber at one end-to achieve a flat surface. We spaced the buttons further apart from each other and more evenly spaced. We made planned the wall so it would be 1. 5m long but due to the excess budging which occurred it was approx 1. 2m in length and 1. m high, we positioned 3 rows of 2 button / thread equally spaced. Also when with the previous prototype when we placed the threads simply did so and then proceeded to ram the earth, however this presented a problem when it came to trying to remove then- it was really not possible to remove then without serious damage to the wall occurring. So to avoid this problem, we used some plastic tubing, through which the threads would sit, this would allow use to remove the threads and re use them again within the same wall. When using these we had to be careful whilst ramming and not hit or cause excess pressure on the threads as they could break or bend. [pic][pic][pic][pic]

Tubing covering Threads Button buckling under pressure sewing of one side wooden panel at other side When ramming the wall we added a few inches of earth at a time, making sure that it was even first then rammed it until it

compressed down and then added the next layer- it is quite a long process. It was necessary to ram the edges first keeping the rammer moving at all times moving from the edges inwards, ramming around the thread/tubes until it was at a point where enough earth was above the thread it was safe to ram on top. This prototype was largely successful the few things were again highlighted which we would resolve within the final piece.

Again something highlighted by the buttons; was that because of the way we made them- 75mm diameter, bigger than in the first prototype, but they were made using thinner wood than before and due to the pressure of the rammed earth above the buttons- they had actually buckled and bent. This however was a positive thing as they both allowed them to be removed easily-and without damaging the wall, and also created a nice effect on the wall aesthetically. [pic] [pic]Final Wall We had been quite successful in our final prototype so our intention was pretty much scale this up for our final wall. We began by cutting a piece of timber to create a hole sized 1. m by 300mm, to which the fabric which we had cut 4m x 2. 2m was then pinned to the underside of the piece of wood- to keep it in place and restrained during ramming. We used on piece timber 2m x 300mm on one end which we nailed to the fabric and base board at One end, to achieve our flatter surface, and on the other end, we used the method of sewing to create a more curvaceous crafted appearance. The fabric was sewn at intervals, approx 30mm at a time. The Earth which we had prepared as outlined- in Earth preparation, had 2-3 people constantly working to keep its consistency and moisture content even, and at interval shovel it into the structure.

Earth was filled and evened out at approx 15mm at a time and then rammed and compressed down. Two people were needed to ram at all times, with 2-3 supporting people, holding material, and also as we got higher and higher- needed to help hold and steel the pneumatic rammer as it became more and more difficult with height. The process of ramming would begin once the earth had been levelled, begging at edges and moving systematically towards the centre, taking care when approaching the plastic tubes containing the treads and attached to the buttons- directly ramming above them could cause them to bend and distort the shape and support they gave.

At 350-400mm vertical spacing's buttons and threads were attached, piercing the fabric with a knife to create a hole through which the threads within their plastic tubes were placed, to the end of these on the exteriors of the fabric were placed the buttons, which were had cut 75mm in diameter using a piece of thin piece of wood approx 7mm thick. These buttons, along with supporting washers and bolt could later be removed along with the actual thread, and reused. The buttons etc were placed at 300mm horizontal intervals. The Spacing was determined from out prototype as the best spacing to create enough support, least uncontrolled bulging, without over restraining the structure.

This added the restraint of the wall, the crafting of curvaceous shapes and ease of removal of components. The making of the wall comprised of adding earth the earth then ramming and repeating this process until 350-400mm height was achieved, then addition of the threads and buttons and repeating again until we reached 2m height. All the while we also were constantly

maintaining and controlling the earth consistency by turning, adding moisture and regularly testing as explained earlier. As we reached higher – more people were required to aid the steering and supporting of the pneumatic rammers, but as we had less soil we were able to sacrifice people from this.

In reality on a larger scale project this may not be a solution that could work, however as our means of reaching higher and higher was a series of standing on chairs and then tables and even some risque chairs on table, this would definitely not happen on a real site as it would most certainly be violating all sorts ofhealthand safety rules, adequate scaffolding would be used and people the people working on ramming and earth maintenance would remain constant. Once the wall had been rammed until the top and almost all of our soil supply had been used, we were able to take down the fabric formwork, which took comparatively little time to assembly and construction. We unscrewed the buttons removing them which care... just in case.... hey had in the same way with the prototype buckled under the strain and had curved round so once removed left a beautiful perfectly ball like shape, and we quite easy to removing, causing no damage to the structure, after that we cut the fabric to remove it, it was very easy on the side with the wood, coming away leaving a very flat surface, on the other side, some more care was taken not to damage the imprint of the sewing, though more care was taken than was probably needed- the deceptively soft look of the wall made one think it might just crumble away, which was of course not the case, it was more delicate at edges such at the ends that were sewn, but very durable. The only part of the wall which really presented any issues

when removing the fabric was the bottom, of course the fabric pinned beneath could not be removed, but as the wall had bulged over the wooden base trapping fabric below, we had to cut around the bulges leaving fragments of the fabric stuck beneath- it was just impossible to remove, but they were not noticeable after edges were trimmed, and neither affected the strength or overall appearance of the wall.

The only implication if would have in real building sites would the amount of fabric salvaged from each construction would be less , and whilst it could be reused, the size of fabric over time would shrink and shrink. [pic] The changes to the design we did make from our previous prototype were: • We discarded the idea of incorporating the curve as in every attempt so far had been unsuccessful, having no affected on the shape of the wall. So we simply cut a straight rectangular shape into our baseboard. • Rather than having two pieces of wood either side of the fabric then bolted together and the piece of timber then placed inside the piece, we used the one piece of wood at one end and attached the fabric to that. As the wall was going to be longer we would be using 3 button / threads per row and having 4 rows We stuck with the method of sewing up the other side as it had been quite successful in the last wall, however in the final wall throughout the process of ramming it became apparent that it was leaning quite a bit particularly at the top of the wall- as can be seen in the final photograph.

Conclusion

During the course of construction we learned a lot about building with rammed earth. Before this week I believed that building the wall would be a lot more complicated than it actually is, and I found it fascinating at how

much could be achieved with some Fabric, thread, very little wood, some buttons and some earth!

It was interesting the affect that the stitching, buttons and wood had on the wall- a very unique finish could be achieved and the structure was so strong and solid despite of it looking much like a giant cushion. The first thing we did in preparation for construction week was our risk assessment- however despite highlighting various precautionary measures we should take – in reality we took almost none. However I think that the risk assessment was still quite accurate in assessing the risk it was wrong not to observe the suggested measures. We did at times wear goggles when the dust simply made it impossible to see what we were doing when ramming, and we did take great care when using the ramming equipment as its use carried the most danger. But in the end I think fashion won out over the use of goggles, masks, boots and gloves.

The Buttons which we used were probably the most successful thing that came out of our construction week. Although by complete accident. Because we had used a thinner piece of wood for our buttons in the final prototype when we rammed the wall – the buttons buckled under the pressure and at first we thought that this was another failure, but in the end it turned out this worked in our favour- they were easy to remove without damaging the wall, but also gave a very clean nice rounded indentation- success!

The Rammed Earth wall and construction methods we used differs from the conventional way in which a rammed earth wall is made by using fabric as formwork as opposed to wood or metal as is the norm.

Within UEL the students and staff are pioneering the use of fabric formwork with rammed earth – which has otherwise been left unexplored as a method. In previous year in UEL students and staff have also experimented with fabric to make rammed earth columns. The use of fabric in other construction methods such as concrete has been successful, well received and used more and more in various new and innovative ways. The wall which we built was largely a success in all aspects of shape, height, strength and texture. Making it very possible that this project, could lead the way for further use of fabric formwork within the field of rammed earth constructions.

It has been proven successful and there is no reason that this method could not be adopted as a viable means of construction in mainstream rammed earth constructions. The Reasons why constructing a rammed earth wall using fabric is better than current method are numerous: ? Sustainability ? The use of low embodied energy rammed in conjunction with fabric resulted in an ultra ecological combo. ? The fabric can be used and reused, as can the buttons and threads ? Beauty ? Sculpted texture created when using fabric can be quite desirable, and will be depending upon specific fabric choice ? The Positioning of the buttons will also impact upon the finished appearance. The effect achieved with our wall was that of a large cushion As there are fewer limitations on the size of fabric which can be used as there are when using wood – where marks from joints are unavoidable. ? Rapid construction and deconstruction of formwork. ? Fewer things are needed to construct a wall when using fabric, so in principle this method could be used in obscure locations where communications are poor, as transpiration would not pose as

much of a problem as it would if using heavy –bulky formwork, provided of course the earth could be found on site. ? Expense –Fabric is less expensive than conventional formwork, fabric formwork is approx 1/25th [5] the cost of dimensional lumber ? Less Weight- weighting approx 1/300th[6] of rigid formwork. There are too, reasons why using fabric formworks may not be favoured. ? Manpower The way in which we constructed our wall required people to do various different things simultaneously, ramming, holding the fabric to keep it tense, shovelling the earth into the wall, turning the soil to maintain moisture consistency. In general at any one time we required 7-8 people so building on a larger scale could present issues of number of people required. Although alternative method of turning the soil or holding the fabric could be adapted. ? Appearance ? The fabric restrained appearance may not be appropriate to the design and desired look. ? Height restrictions ? Whilst there are no specific height restrictions associated with fabric form work- it is an aspect of this construction method- yet to be explored fully- our wall was just less than 2m, what would happen when the height would be increased?

Would there be significant implication affecting thickness of the wall? Budging is not as controlled with fabric as with wooden formwork. One of the great things I saw from our construction week was working together with a set of people for one week for a common goal- we achieved so much, learning from each other sharing ideas and testing them, One can really see how this is in some small way how the builders yard idea must function, and therefore I would believe it to be a really successful idea. If a small group of people in one week can create this unique rammed earth wall- then communities of people working together on projects of greater long-term

significance to them i. e. heir homes their neighbourhood the places they will spend their lives, with such vested interested interests, and working on larger scales over longer periods should be creating all sorts of innovative building techniques, materials and components.

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