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USE OF RAMMED EARTH IN ABORIGINAL REMOTE COMMUNITIES OF WESTERN AUSTRALIA: A CASE STUDY ON SUSTAINABILITY AND THERMAL PROPERTIES

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Abstract: The Department of Housing of the Government of Western Australia, acknowledging the benefits of using rammed earth in remote areas, has recently decided to use rammed earth to build around 300 houses in the next 3 years in remote Aboriginal communities of the Kimberley, northern territory of Western Australia. This paper assesses the social, economic and environmental benefits of this project. It also discusses the possible thermal behaviour of a rammed earth house in the Kimberley and how the restrictions on the insulating properties of the walls of a residential house dictated by the Building Code of Australia currently represent an obstacle for the use of rammed earth.

Keywords: Rammed earth, sustainability, remote areas, thermal efficiency

1 INTRODUCTION

Three main first-necessity goods are probably required to establish a human settlement: potable water, easily-accessible healthy food and a house for each family of the community. In a remote area, kilometers and kilometers far away from any well developed metropolitan region, are these first-necessity goods still easy to obtain? The viability of potable water and healthy food is beyond the purposes of this paper, but the affordability of a house in a very remote zone is discussed in the next paragraphs, with special emphasis on the Aboriginal communities in the north of Western Australia.

In general, the cost of a house is mainly determined by: 1) the cost of the construction materials and 2) the cost of the labor force working on the construction site. In a remote community, it is often the case that neither construction materials nor skilled labor are readily available on site. For this reason, two more expenses must be added to the list: 3) the transportation of the materials from the closest supply centers to the remote community and 4) the accommodation of the skilled labor force brought on site. In light of this analysis, it is reasonable to state that the overall construction cost of a house in a remote area is always higher than the cost of the same house built in a metropolitan zone. For this and other reasons, in many Aboriginal remote communities of Australia, Aboriginal families that cannot afford the expenses of building their own house find themselves in an endless waiting list to obtain a house from the state governments.

But construction cost is not the only issue with housing in remote zones. The most preferred construction technique in Australian remote areas is the *steel framed* house. The advantages and disadvantages of this type of construction are exposed in Section 2. Here it is anticipated that the steel framed house has bad thermal efficiency. In the hot climate of the north of Australia (where the majority of the Aboriginal communities concentrate), generally the comfort of this type of house depends on an air-conditioning system installed inside. If it breaks, the comfort of the dwellers relies on the availability of an air-conditioning technician willing to make a potentially long journey to reach the house and fix the problem. In the likely event that the air-conditioning unit is not fixed, the house becomes a hostile home and eventually it is abounded. This leads to further deterioration before the house can be repaired and occupied again. In 2006, 30% of the total permanent dwellings (mainly steel framed houses) in Indigenous communities required major repair or replacement. In that same year, according to the Australian Bureau of Statistics, AUS$37.4 million was spent in the repair and maintenance of Indigenous Housing (Australian Bureau of Statistics, 2006). The Sydney Morning Herald reported in 2009 that in another occasion the Australian government spent AUS$80 million to inspect or fix 2,900 houses in the Northern Territory alone (see ref by Korff). It is clear that not only construction but also maintenance costs must be considered when assessing the cost-effectiveness of any housing scheme.

Recently the University of Western Australia has established a partnership with the Department of Housing of the government of Western Australia with the goal of improving the housing program in remote Aboriginal communities in the Kimberley, northern part of Western Australia (WA). This research project, partially funded by the State Government of WA and partially by the Australian Research Council, is motivated by the recognition of the potential benefits of using rammed earth as a construction material in remote areas.

This paper discusses the motivations behind the choice of rammed earth as a construction technique in the Aboriginal housing program in Western Australia, in terms of social, economical and environmental sustainability (Section 3). It also presents some recent results on the thermal properties of rammed earth (Section 4). Some concluding remarks are finally offered in Section 5.

2 SITUATION IN THE KIMBERLEY (WA)

The majority of new and existing homes in the remote communities of the Kimberley have a concrete ground slab, steel framed walls and a steel or timber truss roof. Contrary to rammed earth (Ciancio and Jaquin, 2011), the steel framed construction technique is well known and well regulated. For this reason, steel framed houses are often preferred because their construction procedure is very straightforward. Other building techniques such as bricks and timber are equally well understood and established in Australia. However, steel panels are much lighter than bricks and timber to transport, making the use of steel panels more financially competitive in remote and rural areas of Australia. This explains why currently the steel framed house is the most cost-effective option in many remote Australian communities.

Even though this type of construction is very popular, the 'Kimberley' style house presents some significant drawbacks:

- Durability. When the communities are located on or near the coast, salty air can accelerate rusting of the steel components of the house leading to a need for large scale maintenance or complete demolition. In some instances, wet areas of a house that have not been water proofed properly have also seen rusting of the steel frame. The cladding, especially the interior cladding, is susceptible to impact damage. Damaged or broken cladding can be expensive to repair, even if it is only a small area. In remote areas, where it is common to have long delays in maintenance, the internal steel frame exposed to the elements is highly susceptible to rust.

- Thermal efficiency. From a solar passive design point of view, this type of construction does not perform well. It provides little insulation or thermal mass. Even though the wall cavity does allow for the addition of insulation, this represents an extra cost that is not always included in the budget.

- Cost. Materials are not locally sourced and need to be transported. Even though steel framed panels are cheaper to transport than bricks or timber, the impact of the transportation cost remains significant in remote areas.

3 USE OF RAMMED EARTH IN REMOTE COMMUNITIES

Rammed earth is a building technique where moist earth is compacted into rigid formwork in successive layers. Traditional, or unstabilised, rammed earth is composed of varying proportions of clay, sand and gravel (Easton, 2007; Middleton and Schneider, 1987; Walker and Standards Australia, 2002). Nowadays, the addition of cementing materials is becoming a common practice to improve strength and durability performances. In this case, the material is known as stabilised rammed earth (SRE). The social, economic and environmental benefits of rammed earth in remote communities are presented in the following Sections.

3.1 Social Sustainability

In 1933, as part of the National Industrial Recovery Act in USA, a total of 7 rammed earth houses were built in Gardendale, Alabama. Architect and engineer Thomas Hibben successfully taught unskilled laborers to build a rammed earth house. Fourteen men needed 5 weeks to build the walls for the first house, but only 5 days to build the last of the 7. The original houses are still occupied today (Easton, 2007). In a similar way, in June 1997, the Arrillhjere house project in the west of Alice Springs, Australia, was successfully completed. Aboriginal unskilled laborers were employed to build the rammed earth foundation and the mud brick walls of the Arrillhjere house. Aboriginal people gained knowledge of appropriate technologies and building techniques through participation and hands-on involvement, taking those experiences and utilizing them back in their own communities (Hueneke and Wright, 2004). The bulk of rammed earth construction is very straightforward. It is necessary to have only one experienced rammed earth contractor on site during construction when sufficient (even semi-skilled) labor is available. As a result, local jobs can be created and the laborers/dwellers can develop a sense of ownership that should help to reduce the rate of abounded houses.

3.2 Economic Sustainability

Following from what presented in the previous Section, the overall cost of the construction may be reduced by eliminating the need for expensive accommodation for labor brought in from outside. Additionally, since soil can be sourced on-site at zero or almost zero cost, the transportation cost of the construction materials (on-site sourced earth) is significantly reduced. Furthermore, rammed earth walls do not require painting or other wall treatments resulting in minimum ongoing maintenance cost. Rammed earth seems to provide a solution to the above mentioned problems of expensive housing in remote areas.

3.3 Environmental Sustainability

Rammed earth is an environmentally sustainable building material (Bahar et al, 2004; Jayasinghe and Kamaladasa, 2007; Reddy and Jagadish, 2003). This assertion is realistic where little or no cement is used and there is no reinforcement. However, this argument is diminished by the addition of cement and steel in modern rammed earth.

In this work, “environmental sustainability” is used as a term to indicate the environmental impact of the material. The amount of embodied energy, or emergy, of a material is often used to give an indication of this type of impact (Boyle, 2005). Ciancio and Boulter (2011) have recently compared the production energy – i.e. the energy required to produce the materials from which a building is constructed (Harris, 1999) - of a 1m long and 2.4m high wall made of *i)* 10% cement-stabilised rammed earth and *ii)* steel framed panels, hypothetically located in a remote community of the Kimberley. The comparison showed that the 10% cement stabilised rammed earth wall has 75% lower production energy than the steel-framed wall. The same paper compares the transportation energy of these 2 walls. The analysis assumes that the soil used for the cement-stabilised rammed earth wall is sourced on-site but not the cement. The transportation energy for the steel-framed panels was found to be 35% higher than that of the rammed earth wall.

4 THERMAL EFFICIENCY

The first of the 300 houses to be built by the Department of Housing of WA will be in a community called Fitzroy Crossing. An assessment of the thermal performance of this rammed earth house is currently in progress. There has been much debate about whether rammed earth thermally performs well as a building material. This represents an ongoing issue for the rammed earth industry and one main concern for the success of the rammed earth housing project in the Kimberley. It is generally well established that rammed earth has a high thermal mass. Therefore it has the potentialities to perform satisfactorily in climates where there is a large difference between daily average maximum and minimum temperatures like in Fitzroy Crossing, as presented in Figure 1.

However, it is also well understood that insulation plays an important role in the thermal performance of a house. The ability of the material to resist heat transfer (i.e. to insulate) is called resistance. Thermal resistance is more commonly known by its alternative name, the R value, defined as: $R = t / k$, where t is the material thickness [m] and *k* is the thermal conductivity [W/(m K)]. Different thermal resistance values of rammed earth can be found in literature, as shown in Table 1.

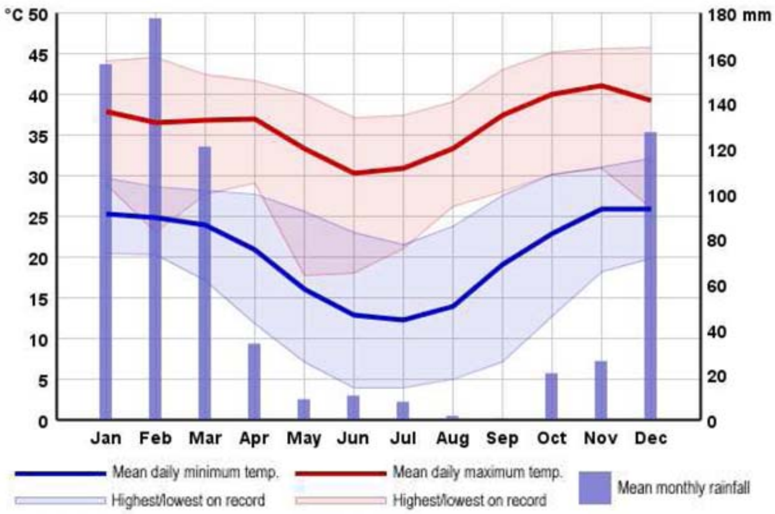

Figure 1: Mean, highest and lowest daily temperatures and the mean monthly rainfall in Fitzroy Crossing, WA.

Table 1: Rammed earth *R* values from different sources

Source	t [mm]	*R* value [m^2 K/W]
Bulletin 5 (Middleton et al, 1987)	300	0.391
HB 195 (Walker et al, 2002)	300	0.35-0.7
CSIRO Press Release (Clarke, 2010)	200	0.4

The building code of Australia (ABCB, 2010) requires that all external walls of a residential building must have a minimum *R* value of 2.8 [m^2 K/W]. It is evident that, even though not much research has been carried out to investigate the *R* value of rammed earth and even though the few values available in literature are not unique, it is generally well established that rammed earth has a poor thermal conductivity that can potentially reduce its thermal performance.

4.1 Improving R-value of Rammed Earth

Minke (2006) proposed a wide range of porous materials that can be added to a rammed earth mix to reduce its thermal conductivity. Some of them are: straw, reeds, seaweed, cork, plant matter, pumice, lava, expanded clay, foamed glass and expanded perlite. The general principle of decreasing density (and hence increasing insulation) through the addition of a porous lightweight material is applied in his work. Hall & Allinson (2009) looked at the effect that soil grading and moisture content has on the thermal conductivity of rammed earth. Results found a proportional correlation between moisture content and thermal conductivity.

In the presented study, the effect of perlite as admixture in a cemented stabilised rammed earth mix was investigated. Perlite is an amorphous volcanic glass material that when heated to high temperatures softens and expands creating a material with air voids. Due to its low density and air voids, perlite has very low thermal conductivities of around 0.039 W/(m.K) for density of 30 kg/m^3 and 0.061 W/(m.K) for 180 kg/m^3 (ASHRAE, 2009).

The soil used is a 10mm crushed limestone mix, commonly used in Perth (WA) for the majority of rammed earth constructions. The particle size distribution of the crushed limestone mix is presented in Figure 2. The aim of the investigation is to find out if the addition of perlite significantly improves the thermal resistance (or decreases the thermal conductivity) without drastically diminishing the compressive strength of rammed earth (due to its high porosity, perlite is quite weak and brittle). To achieve this goal, five rammed earth batches were used in the experimental program, as reported in Table 2. The water content was obtained by using the drop test and consequentially measured by oven drying some mix samples, as reported in column 5 of Table 2. For each batch, the thermal conductivity and the unconfined compressive strength (UCS) were measured. The thermal conductivity *k* was obtained from the Hot Wire method, in accordance with ASTM C1113-09 (2009) and BS 1902-506 (1985). The *R*-value was then calculated with reference to a wall of 300mm of thickness. The UCS was obtained as the average strength of 5 cylindrical samples (diameter = 100mm, height = 200mm) per batch.

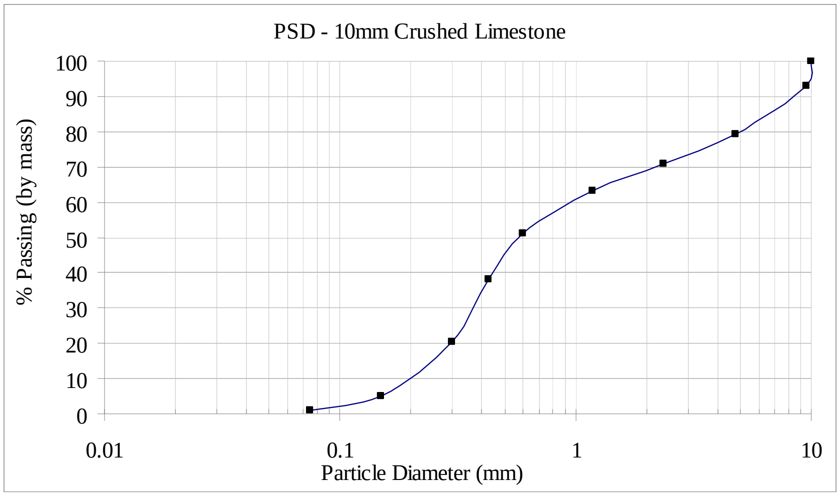

Figure 2: Particle size distribution of 10mm crushed limestone

Table 2: Characteristics of soil mixes used in the experimental program

Batch	% Limestone (by limestone and perlite vol.)	% Perlite (by limestone and perlite vol.)	%Cement (by limestone mass)	% Water (by limestone, perlite and cement mass)	Dry Density (Kg/m^3)
1	100	0	7	8.92	1893.7
2	90	10	7	9.12	1857.5
3	80	20	7	9.38	1813.7
4	70	30	7	9.95	1814.0
5	60	40	7	10.92	1781.3

The results presented in Figure 3 show that the reduction in strength due to the addition of 40% of perlite is less than 6%. The same Figure also shows that the addition of perlite into the mix enhances the thermal performances by increasing the *R*-value of 12.8%. Nevertheless, the obtained results cannot be considered satisfactory.

The improvement in terms of *R*-value is not very significant considering the addition of perlite of 40%. The dry density of the batch of pure limestone is 1893 kg/m^3. The dry density of the perlite used in this study is 56 kg/m^3. Contrary to the numbers reported in column 6 of Table 2, it was expected a more significant decrease of dry density from batch 1 to batch 5. The explanation for this behavior is found in the brittleness of perlite. It seems reasonable to think that the mixing and/or ramming process might have crushed the very porous but also very brittle and weak admixture. By being crushed into a powder, the benefits of the low density of the perlite are lost and this explains why only a small decrease in density was recorded. Evidence of crushing is seen in Figure 4 below. This sample is from Batch 5 and therefore has 40% perlite by volume. By visual inspection it is clear that the perlite content (white particles) is not 40% by volume when considering the surface area exposed.

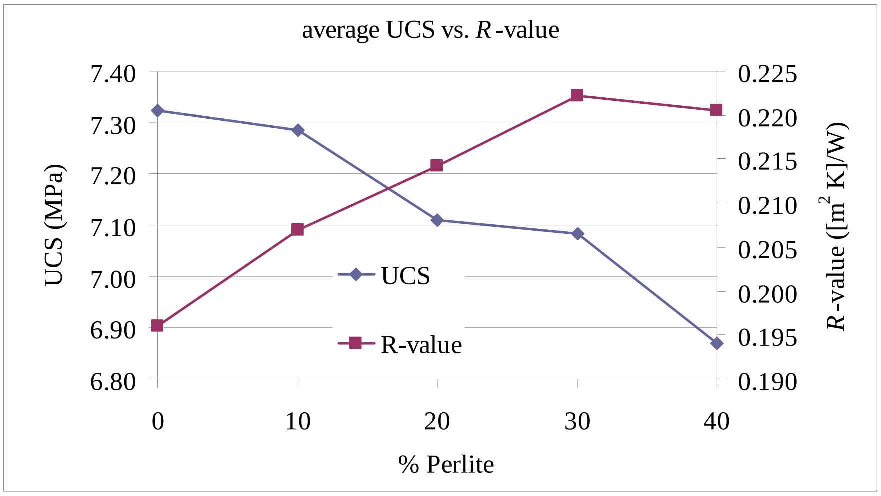

Figure 3: Average UCS and *R*-value of the 5 batches of rammed earth with different perlite contents.

Figure 4: Batch 5 sample after being tested to measure the unconfined compressive strength (UCS). The white particles represent the intact perlite grains.

Another unsatisfactory performance concerns the range of the obtained *R*-values (between 0.18 and 0.225 [m^2 K/W]) that not only are far below the limit imposed by the Building Code of Australia of 2.8 [m^2 K/W], but are also notably less than the existing data in literature (Table 1). The high thermal conductivity of Batch 1 was further investigated through an X-ray diffraction (XRD) analysis. From this test, the approximate percentages by weight of crystalline and amorphous material were found to be 80% and 20% respectively. Crystalline materials have a higher structural order than amorphous materials and this improves the materials ability to transfer heat through conduction. As the degree of crystallinity increases so does the thermal conductivity (Assfalg, 1975). This finding concludes that crushed limestone is not suitable as a base component of rammed earth mixes aiming for good thermal performance.

5 CONCLUDING REMARKS

Rammed earth was identified as a construction method with significant advantages over the typical steel framed houses that are currently built in remote Aboriginal areas of the Kimberley, north of Western Australia. The advantages were considered in terms of social, economic and environmental sustainability. The environmental benefits are always valid in any remote communities where the impact of the energy of transportation of the construction materials significantly affects the environmental analysis. On the other hand, some economic benefits (i.e. reduction of the cost of accommodation of labourers brought in from outside the community by using local labour force) and the social benefits strongly depend on the level of engagement of the Aboriginal communities participating in the project and their willingness to be actively involved in the house construction process. It is crucial for the success of the project to build a relationship of trust and communication with the communities to avoid some mistakes done in the past.

Due to its high thermal mass, a rammed earth house might be adequate in some areas of the Kimberley with a large difference between daily maximum and minimum temperatures. However, due to the restrictions of the Building Code of Australia, the insulation properties of this material remain the main obstruction for its use as an alternative solution in remote communities if further studies are not conducted. This paper showed that it is possible to improve the *R*-value by using appropriate admixture. Nevertheless, the *R*-value of the pure soil without admixture must not be excessively low (as the crushed limestone used in this investigation). Further studies are needed provide suitable recommendations for the right choice of the admixture. The perlite used in this experimental program showed to be not effective for rammed earth.

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