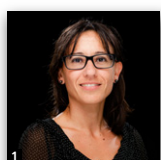


First International Conference on Rammed Earth Construction: report

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In February 2015, the University of Western Australia organised the First International Conference on Rammed Earth Construction. The event was a major success with participants from 11 countries. The participants were representatives from the research (scientists, professors, students) and industry worlds (engineers, architects, builders). The conference provided the unique opportunity to present recent advances in rammed earth research, innovative construction practices and sustainable projects in different countries. It also provided the opportunity to discuss the current issues experienced by the rammed earth industry around the world and to create collaborations between research institutions. This paper presents a summary of the discussions held at the forums of the event. It aims to disseminate the priority research topics identified at the conference and to increase awareness of the difficulties currently experienced by the rammed earth industry and by academia.

1. Introduction

In recent years, together with the growing interest in the use of earth as a construction material, the world has seen an increasing number of national and international conferences offered on this subject. Frequently, these conferences cover all earthen construction techniques, including rammed earth, mud bricks, cob, adobe and so on. One of the most commonly discussed topics at many of these conferences is the conservation and rehabilitation of historic earthen structures.

Rammed earth has been used for thousands of years and many historic buildings exist around the world, some of which need special care to be conserved and maintained. Nevertheless, rammed earth is also widely used as a modern construction technique. Many builders and engineers in different countries have been experimenting with new construction practices and design methods for rammed earth. At the same time, scientists and engineers have begun to focus on their research activities to understand the mechanical, structural and thermal performance of this material. The time was

therefore right to hold a conference in 2015 exclusively for rammed earth construction where industry and academia could meet and exchange ideas, concerns and research outcomes.

The First International Conference on Rammed Earth Construction (ICREC2015; see <http://www.ecm.uwa.edu.au/business/icrec2015>), organised by the University of Western Australia in February 2015, brought together researchers, engineers and practitioners to communicate the latest developments in the design and analysis of rammed earth structures. The event comprised a 2 d workshop held in Perth and a 2 d conference held at Margaret River, both in Western Australia. The invited speakers were internationally recognised leaders and national experts on rammed earth. The conference delegates were representatives of industry and academia from 11 different countries (Australia, USA, Brazil, Canada, South Africa, India, China, UK, France, New Zealand and Italy) and, in this respect, the event was a rare opportunity for real interaction between these two worlds.

This paper presents a report on the outcomes from ICREC2015. It does not aim to review current rammed earth literature, but instead to share the discussions that took place during the event and to review the identified priority research topics. The paper offers a brief summary of the workshop and conference keynote presentations in the following two sections. The four keynotes covered the majority of the key research topics. The priority research topics are discussed in detail in Section 4 of this paper and Section 5 presents the concluding remarks.

2. Keynote workshop presentations

The workshop keynote speakers were Stephen Dobson, owner of the first rammed earth building company in Australia founded in Perth in 1979, and David Easton, author of the definitive text *The Rammed Earth House* (Easton, 1996). Both have nearly 40 years of experience in using and adapting rammed earth to fit the needs of the construction market. Their presentations highlighted the development of the rammed earth industry in Western Australia and California, respectively.

Dobson kindly shared with the audience his pictures of rammed earth structures collected from his trips around the world, emphasising the use of unstabilised ('traditional') rammed earth in Austria and the emerging technology of pre-cast rammed earth panels (Dobson, 2015). He also discussed the difficulties that the rammed earth industry in Australia is currently facing due to the thermal assessment procedure regulated by the Building Code of Australia (BCA). According to this, the quickest and cheapest way to assess the thermal performance of a new building is by using one of the three pieces of BCA accredited software (NatHERS, 2012). The software calculates a 'star rating' for the building, based on the energy consumption (heating and cooling) required to maintain comfortable indoor temperatures for given times of the day. A new building needs a minimum of six out of ten stars to be deemed energy efficient; many rammed earth houses in colder climatic zones of Australia fail to achieve this. This requirement affects the rammed earth market as owners are reluctant to spend more money to perform an alternative thermal assessment, or to install insulation panels to increase the thermal resistance of the walls (rammed earth insulated panels are discussed in Section 4.3). Two workshop speakers further discussed this topic on the first day of the event: Peter Hickson and Dong Chen. Hickson is the president of the Earth Building Association of Australia and is an advocate of the excellent thermal properties of rammed earth buildings. He stated that mass is essential in moderating and balancing both indoor temperature and humidity. He also argued that the accredited software do not model buildings as they are operated in reality and do not allow the use of appropriate ventilation logic to

maximise efficiency. Chen, who currently leads the development of one of the three pieces of accredited software ('AccuRate'), showed that thermal mass is in fact correctly implemented in the software, but that occupancy-related variables (like ventilation) do not necessarily represent the real situation in an earthen building. He cited recent findings (Daniel *et al.*, 2014) according to which the front end of the BCA software AccuRate 'in its current regulatory form does not allow the user to take into consideration occupancy-related variables'. Section 4.1 further discusses this point.

Easton spoke about his 30-year career experience with rammed earth structures in terms of construction and development costs and environmental impact. He shared his memories of the first houses built in California using local soil and little cement. He argued that government regulations and clients' requests pushed his practice towards the use of more engineered soils, with more cement, more attention to finishing details and a more experienced, and hence more expensive, labour force (Easton, 2015). Easton is, however, a supporter of the reduction of rammed earth's carbon footprint and is currently developing a low-carbon high-strength compressed earth block. The evolution of rammed earth, in his experience, has followed a path of increasing financial and environmental costs. Government regulations, costs and environmental impact have been recognised as critical issues for rammed earth's future. A lack of standards might also discourage the construction of new houses. On the other hand, overly conservative regulations, dictated by the lack of research on the material and structural performance of rammed earth, can be detrimental to the rammed earth industry.

3. Keynote conference lectures

The conference keynote speakers were Charles Augarde, Professor at the School of Engineering and Computing Sciences at Durham University (UK), and Rongrong Hu, Associate Professor at the School of Architecture of Xi'an University of Architecture and Technology (China).

Augarde highlighted the recent advances made in understanding rammed earth's material behaviour through his talk 'Earthen construction: a geotechnical engineering perspective' (Augarde, 2015). He discussed the use of unsaturated soil mechanics principles to study and understand the strength of rammed earth materials. He also presented some studies on reinforced rammed earth specimens, using natural fibres and geogrid sheets. The topic of this presentation was recognised as a priority research area (discussed in Section 4.2). Should rammed earth be treated as a strong soil or as a weak concrete? Is the research needed to better understand the mechanical performance of rammed earth already available in the literature? In other words, how much of the research conducted by

our geotechnical colleagues can be applied to rammed earth (Gallipoli *et al.*, 2014)?

Hu's contribution focused on the use of rammed earth for the sustainable development of remote Chinese rural areas (Hu, 2015). China has a long history of rammed earth construction that has been widely used for centuries to build, not only houses, but also a key symbol of the country, the Great Wall of China. Hu (2015) presented several successful programmes of construction in remote rural areas in which the occupants (mainly farmers) built their own rammed earth homes. She discussed issues faced by the leaders of these projects, for instance, gaining the trust and acceptance of the local people and learning and preserving the traditional building techniques from the few still-living elders. Hu's (2015) presentation highlighted the two faces of the rammed earth coin: on one, this building technique can be used to produce expensive architecture and design award-winning structures that are displayed in commercial magazines and are often owned by rich and extravagant individuals; on the other, the same technique can be used in developing countries and in remote areas of developed countries to build affordable, low-cost and sustainable houses (Beckett *et al.*, 2014).

4. Priority research topics

This section presents the priority research topics identified at the ICREC2015. These topics, as agreed among the delegates of the conference, need further research and development to promote the acceptance and use of rammed earth.

4.1 Thermal assessment

Given their background, the majority of the concerns described in Section 2 might be predominantly related to the Australian market. Nevertheless, they still describe some problems that are relevant to all earthen buildings worldwide. In particular, two issues deserve further attention: (a) the thermal comfort perception of occupants of earthen houses and (b) the lack of information on the thermal properties of rammed earth mixes. Regarding the first, there is an increasing awareness of the fact that people living in earthen houses do tend to have a perception of thermal comfort that differs from the criteria used to define the 'comfort theory'. These criteria are based on assumptions of average human characteristics such as occupants' metabolic rates and clothing levels (to mention a few), but also on assumptions of average environmental variables such as humidity and air movement. These assumptions lead to the definition of some threshold temperature limits for the use of artificial heating and cooling. An accurate thermal assessment should, however, consider that the thermal perception of occupants of earthen houses might differ from average conditions (Williamson *et al.*, 1995). Regarding the second point, it can be stated without any doubt that an accurate

numerical simulation must be based on accurate input parameters. Hence, the use of correct values of thermal resistance and heat capacity is crucial. Although these parameters are well known for more traditional construction materials such as concrete, steel or glass, they are still not well defined for rammed earth. It is important to carry out more research to evaluate the thermal properties of different soil mixes in order to get a wide database of values.

4.2 Soil mix

Although a significant number of papers exist that describe the mechanical properties (e.g. compressive and tensile strength, elastic modulus, etc.) of different rammed earth soil mixes, the nature of rammed earth makes it impossible to obtain a universal formula that deems a certain soil suitable and accurately predicts its mechanical behaviour. Each soil mix is different from another and although some existing guidelines are useful to estimate preliminarily soil suitability, testing is still needed to satisfy strength and durability requirements. In his presentation, Augarde discussed the use of soil mechanics principles to understand the mechanical behaviour of rammed earth. Some laboratory procedures in existing rammed earth standards refer to geotechnical laboratory methods. However, when the soil is stabilised with cement and/or lime, these tests might become inappropriate (Beckett *et al.*, 2015). Should the laboratory procedures used to characterise a soil mix represent onsite procedures or should they be carried out under controlled environmental conditions? In the latter scenario, samples would be manufactured at their optimum water content and controlled density; they would be cured in an environment with controlled temperature and relative humidity and in the case of stabilisation, this would be accurately controlled by the measured mass percentages. In the former scenario, the water content at manufacture might differ from the optimum, the density would vary from sample to sample, the curing conditions would strongly depend on site practices and the cement content would be estimated by rough volume percentage. Clearly, such an approach is not appropriate for reliably characterising the material, but these are the conditions under which site samples are made to judge the performance of a chosen soil mix. Reconciling the two approaches is essential if rammed earth materials are to become standardised.

4.3 Insulated rammed earth walls

As mentioned earlier, one solution to improve the thermal resistance of rammed earth is to insert an insulation layer into the wall. This practice preserves the aesthetics of rammed earth walls, but at the same time creates a structural element that significantly differs from the monolithic wall. In Australia, this system is only used in cold regions, where the mandatory 'six star' rating is not achieved by monolithic walls. However, it is a common practice in Canada where the very low



Figure 1. ICREC2015 delegates

temperatures would not allow for the use of non-insulated walls (Krayenhoff, 2015). The design of these walls often involves a highly conservative approach, that is to neglect the presence of the insulation sheet and the inner rammed earth wythe (i.e. the internal face of the insulated wall), and to rely exclusively on the structural capacity of the monolithic external wythe. Sometimes builders insert steel ties between the rammed earth wythes through the insulation layer to enforce the composite action (Krayenhoff, 2015). The structural contribution of these ties, their thermal impact and the overall strength capacity of the composite wall (rammed earth layer–insulation sheet–rammed earth layer) to resist out-of-plane loads is not well understood and needs further research.

4.4 Design methods

Several delegates expressed their concerns about the lack of standards and guidelines available for civil engineers. The presentation by Bill Smalley, a chartered engineer and director of an engineering firm in Perth with several years of experience in designing rammed earth buildings, showed that it is possible to treat cement-stabilised rammed earth with a compressive strength of $\sim 5\text{--}8\text{ MPa}$ as weak concrete for design purposes. He discussed the design of structural elements such as walls, lintels and columns, using the guidelines in the Australian standard AS3600 (AS, 2009), and showed examples of award-winning rammed earth buildings built using this approach. Nevertheless, the question remains about the structural design of traditional (unstabilised) rammed earth structural elements. Should they be designed using the recommendations for

masonry or concrete blocks? Or do they need an approach specifically suited for rammed earth?

4.5 Standards

The importance of government regulation for the growth of rammed earth and its acceptance as a standard construction technique attracted diverse comments. On one side, it was agreed that standards containing design regulations would improve uptake of rammed earth by offering well-accepted and accredited design methods to engineers. Furthermore, standards to refer to would allow rammed earth-based courses to be taught at universities. However, those opposed to standardisation saw their creation as a set of rigid rules that might constrain design creativity and freedom, leading to overconservative and cost-ineffective structures. Where art ends and engineering begins is an age-old question that will not be answered here; however, it is clear that the ideal solution lies between these two extremes.

5. Conclusions

ICREC2015 achieved a rare environment where industry and academics were able to engage each other directly and positively to identify and address the key issues facing rammed earth construction. Despite its millennium-spanning history, it is clear that significant issues still exist, several of which were discussed in this report. Although the conference focused on thermal assessment and material regulation, leading issues in Australia, conference outcomes and ideas (Ciancio and Beckett, 2015) will influence rammed earth research and will be used globally. There was a unanimous agreement to run the

second ICREC in 2017, and the delegates of the conference (in Figure 1) are now members of an online forum where post-conference conversations are kept alive.

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