to access. Therefore, it may be unwise to promote the reuse of these materials for these communities, especially if the reintroduction of these building elements has a high social and economic cost.

4. CONCLUSIONS

"…Disasters are not only caused by the destructive action of natural phenomena forces, but also include changes in the behavior patterns of our communities"

(Ferrigni et al., 2005, p. 25).

The Chilean LSC Atlas project seeks the ultimate goal of reducing vulnerability of earthen architecture to seismic risks, also providing other results, such as:

- Documenting the use, development and presence of vernacular seismic resistant building systems of earthen architecture in Chile.
- Identifying different LSCs.
- Defining the terminology of "know-how" in relation to seismic resistant vernacular techniques, as well as understanding the loss of legitimacy of these.
- Valuing the logic of architectural knowledge (construction and urban) and local materials, its evolutionary spirit, and how that tradition is established.
- Developing a critical view of the use of foreign techniques and the introduction of industrialized materials and building systems into vernacular architecture.
- Establishing a reflection on reinforcement methods and/or structural stabilization (seismic retrofitting) for the interventions proposed for existing earthen buildings, promoting less invasive techniques that maintain the building's authenticity (and especially its original construction logic).
- Introducing the concept of "social cost" for interventions, both in terms of heritage and civil construction (social housing, public infrastructure, among others).
- Encouraging a sense of long-term reconstruction and post-emergency projects, in contexts with a strong LSC presence.
- Enhancing local emergency plans, based on the autonomy of the people and the characteristics of the towns, being that communities are the main actors responsible for their dwellings.

By overlapping the background identified in the Chilean LSC Atlas and its results, sufficient tools to identify the degree of relevance and appropriateness of proposals to rebuild or reinforce earthen buildings can be obtained. Similarly, the necessary background for the evaluation and implementation of emergency or preventative plans against new earthquakes in a specific location will be established.

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A RESEARCH AGENDA FOR CLIMATE AND CLIMATE-CHANGE IMPACTS ON EARTHEN STRUCTURES

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Theme 2: World Heritage Earthen-Architectural Sites, Natural Disasters and Climate Change
Keywords: Climate prediction, damage functions, documentation, test wall

Abstract

Climate change is likely to affect earthen-architectural heritage because the materials are sensitive to many aspects of weathering. Both gradual changes and an increase in the frequency of extreme events seem likely to be important in the future. Both represent threats to earthen materials, which can be especially sensitive to alterations in humidity and water. At the moment there is little research on the mechanisms of damage that might change over the next century. While there are many general questions that relate to future damage to our heritage, research has to be more specific.

The authors examine the potential for a five-year test-wall project to explore climate-change issues. Walls would be designed to facilitate ease of repeat documentation using conventional and 3D methods. These qualitative and quantitative observations would be compared with measurements gathered through an on-site weather station and wall sensors (recording temperature and humidity). This in turn would be compared to the high-resolution climate models. The analysis would, we argue, start to give an indication of observed change, quantified change and the relationship with climate over five years, which in turn could be related to the longer-term climate models.

1. INTRODUCTION

Relatively little research has been undertaken on the impact of climate change on heritage. This is to be compared with the extensive study of climate change on the global environment, human wellbeing, and agriculture. Such topics are widely researched and, furthermore, appear within IPCC reports. The modest number of publications on climate change and heritage are frequently desk studies, interviews or opinion pieces, rather than carefully framed research projects that utilize the vast amount of work that has been done on future climate. Exceptions to this have been projects funded by the European Commission (e.g. Noah's Ark, and Climate for Culture) or that of a small number of publications from individual scientists (such as Lankester and Brimblecombe, 2011; 2012).

The issue of climate change was raised at the Terra 2008 conference in Bamako, Mali (Brimblecombe, Bonazza, Brooks, Grossi, Harris, and Sabbioni, 2011), but even here opinions were mixed about its significance. Although the importance of weather as a factor in the deterioration of earthen structures was clear, not all felt detailed climate-change research was needed. Some thought that enough was already known about climate change to gain a good picture of how earthen heritage might degrade, and others drew attention to the fact that the weathering of earthen structures is rapid anyway, so careful maintenance is an effective approach to the preservation of such heritage.

While acknowledging the wisdom of the comments above, we present a case for more detailed research. The discussions in Mali had an understandable focus on impacts of desertification, and impacts of wind-blown (or aeolian) sand on earthen structures. However, threats to vernacular heritage are much wider. In the years since 2008, we have seen a number of climate phenomena that have been of concern for heritage structures, such as flooding in Pakistan (2010), dry aridity in Central Europe and Russia (2010), and more locally in the UK, flooding, and during a cold winter (2010-11), pipes froze in historic buildings and heavy accumulations of snow caused the roofs of heritage buildings (such as chalk barns) to collapse under the weight of snow.

Earthen architecture has been promoted as an environmentally friendly, responsive and sustainable building material, and the UK and Europe as a whole has seen a revival in the craft sector utilizing earthen-building materials. We have scientific data to show such buildings are environmentally sustainable (such as the various research projects undertaken at the University of Bath by Peter Walker, and at the University of Nottingham by Matthew Hall, amongst others), but we have little scientific data to prove the hypothesis that such buildings are adaptable to climate change. A method of assessing the performance, survival and deterioration of earthen structures in relation to climate parameters is proposed, to enable us to establish a real understanding of earth structures. It is not until such data is collected that we can better understand the performance and survival of earthen structures in the 21st century. This might also require critical reflection on the heritage values of earthen heritage, and how these values may be impacted by physical change.

2. HERITAGE AND CLIMATE

Although the survival of earthen buildings is influenced by local climate, climate change poses a new and pressing threat to this aspect of cultural heritage. Data generated by climate-change scientists indicate that the average rate of warming over the next 100 years will probably be greater than any that has occurred in the period over which civilization developed. Increases in the global averages of evaporation and changes in precipitation are expected, and extreme events, such as heavy rains and droughts, are likely to increase as the climate continues to change. Although changes of a few degrees in temperature are unlikely to have a damaging effect on earthen heritage, changes in the relationship between earthen materials and water seem a potential threat. Extreme rainfall events and long periods of wetting or drought can enhance the rate of weathering of these materials.

Recently, the impact of climate change on Europe's built heritage and cultural landscapes was considered through the Noah's Ark Project (Sabbioni, Brimblecombe, and Cassar, 2010). This project used modeled output extracted from climate models at the Hadley Centre to examine climate parameters (precipitation, frost, wind and wind-driven rain). It also established heritage climatologies (Brimblecombe, 2010a) that looked at salt crystallization, wet-frost, biomass accumulation, and lichen to produce damage and risk maps. The work has identified the meteorological changes critical to built heritage, highlighting factors, such as changes in precipitation patterns, salt damage, freeze/thaw, changes in groundwater levels, and inundation. The project examined materials rather than separate heritage entities. However, the project would imply a range of changes that affect cultural heritage, deterioration phenomena, heritage structures, and infrastructure that could have significant impact on earthen architecture. It becomes apparent that the material properties of earthen heritage make it particularly vulnerable to these threats.

The potential impact of climate change on earthen heritage raises concerns nationally and internationally (for example by ICOMOS and ISCEAH), but detailed studies of the specific effects of climate on earthen structures is largely absent. Only a vague and general picture of impact upon earthen materials can be surmised, such as the dramatic physical loss of landscape components (i.e. structural loss of buildings and archaeological sites as a result of inundation), the acceleration of more gradual decay factors (i.e. as greater presence of fungi and salt), alongside impacts on values and societal relationships with earthen-building technologies related to increased frequency of maintenance cycles. Such general viewpoints can raise awareness, but are hardly a guide to action. These offer little understanding of the mechanisms or rate of damage. It is unclear which fungi or salts might be damaging or where the problems will be most serious. It would be hard to justify expensive and difficult interventions without a better understanding.

3. RESEARCH AGENDA

There are a range of questions that can add to research projects on climate change and earthen-architectural heritage. Such work will need to consider the physical aspects of a changing climate and its impacts with a number of objectives such as:

- Identification of the climate parameters most likely to affect earthen-architectural heritage and highlighting of those most likely to change over the next century;
- Identification of likely mechanisms and damage forms to arise under a changing climate that would most affect earthen-architectural heritage;
- Understanding how each of the separate components of earthen-architectural heritage may be affected by climate parameters by gradual long-term change as compared to extreme events.

These scientific questions cannot be addressed in isolation, so it is important to consider management and social aspects, such as:

- Development of a methodology for documenting and proactively monitoring earthen architecture that will be applicable in an international context;
- Reflecting critically upon the values of earthen-architectural heritage, and how these may be affected by future climate change;
- Making recommendations concerning how tangible and intangible values can be preserved using traditional and modern conservation techniques;
- Development of an understanding of how heritage values of earthen-architectural heritage may be transformed in response to physical change.

4. PROJECT METHODOLOGY

The broad research agenda above is often too vague for an individual research project, which needs to be more focused in its specific objectives. Many projects center on monitoring of the climate and the change to materials at heritage sites. Such an approach leaves us with an immediate question: How is it possible to monitor long-term climate change within the confines of a short-term project? It raises further issues, like the fact that monitoring necessarily addresses the present, while the records of such exercises tell us something of the past. Issues such as these have been addressed in a paper concerned with the problems of monitoring the future (Brimblecombe, 2010b),

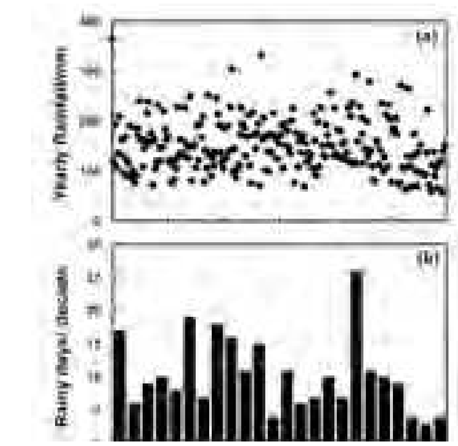

Fig.1 Modelled rainfall in the Timbuktu region of Mali: (a) annual precipitation and (b) the number of rainy days (rainfall>10 mm). Note: the estimates are derived from the HadCM3A2 output for a cell 2.5°×3.75° centred close to village of Araouane on a key Saharan trade route.

but typically, climate-change research has relied heavily on models of the future world, rather than monitoring. This is not without its scientific problems, but has also fuelled public skepticism about the existence of climate change. In addition, specific problems exist for earthen architecture because it is associated with dry climates where there are issues with climate data and how climate models are generated (as precipitation is used to downscale such models).

However, smaller scale projects with a well-defined methodology and relevant monitoring can contribute to a broader set of questions. The example below was derived from some ideas developed for an application to the UK Arts and Humanities Research Council (AHRC)-led Science and Heritage program called Identifying, Modeling and Predicting the Impacts of Climate and Climate Change on Earthen Heritage. Under the AHRC call, projects had to be multidisciplinary, meeting a set of objectives already defined by the Science and Heritage program, primarily the application of scientific techniques to heritage, which in this case is to understand the significance, vulnerability, resilience and conservation of earthen heritage in the 21st century as a result of climate, climate change and extreme climate events. It was suggested that the available climate data would allow the assessment of the results of monitoring of conditions over a period of time that enables the relationship with climate, climate change and earthen-architectural heritage to be explored and better understood.

This project envisaged a series of earthen 'test walls' that would be monitored and compared to climate factors. It was seen as necessary to build new walls for this project rather than use historic walls for several reasons. First, the exact composition and construction of the walls will be a known factor, whereas historic walls may have a particularly complex history of repair and maintenance that may impact the quality of results. Second, temperature and relative-humidity sensors can be embedded into and outside the walls during construction using techniques developed by Dr. Mike Lawrence at the University of Bath (Lawrence, Heath, and Walker, 2009).

New walls were also necessary as the design and location of the walls can be controlled to ensure exposure to climatic effects and facilitate photographic-recording and 3D-scanning. As such, this project envisaged the design and construction of two sets of test walls on the site, composed of cob, adobe, rammed-earth, wattle and daub, turf, and chalk. With one set protected via a simple inverted V-shaped roof capping, while the other will be unprotected. An additional pair of walls will facilitate analysis of the effect of maintenance cycles and alterations. One of these would have been maintained throughout the course of the project, while the other will be coated in a cement-based render, reflecting one of the most problematic and damaging methods used for earthen walls in the UK. To eliminate variation in groundwater movements, the walls would be constructed on concrete-block footings. The walls would also incorporate right angles in order to be resistant to weather in all directions, and this will allow an analysis of the influence of different aspects (windward, high and low areas, corners) and microclimate on the walls.

The project built upon existing research carried out in the UK concerned with the construction and monitoring of test walls (for example, the Scottish ESRP project (undertaken by Becky Little and Arc Architects), alongside experimental archaeology projects, such as Overton Down (Bell, Fowler, and Hillson, 1996). Internationally, a number of earthen test-wall projects have been undertaken, such as those undertaken by CRAterre-ENSAG, and the Getty Conservation Institute (Cooke, 2010); these have primarily been concerned with researching methods of construction, repair and conservation treatment, rather than monitoring conditions in relation to climatic factors.

In addition, it was possible to identify a site that had existing meteorological data from the last 50 years, and a weather station, which records data at sub-hourly intervals. This existing meteorological data can be used to identify longer-term climatic change, as well as to place the project data in a wider context. Finally, the site would have to be located to allow easy access to document wall conditions during and immediately after extreme climatic conditions.

The project required a comprehensive documentation and monitoring system. It was envisaged that the test-wall materials would be analyzed both for construction and on an annual basis, through the collection and analysis of soil samples, thin sections and strength tests in order to detect and quantify change both within, as well as on their surfaces. The surface condition (e.g. physical loss, biological phenomena) of the walls would also be monitored through the use of conventional documentation (drawing, photography, surface-condition assessment), and through repeat 3D-scanning at regular intervals throughout the project.

The documentation of the physical condition of the walls would be supplemented by the continual logging of RH/temperature from sensors embedded within the test walls. These data will be analyzed via WUFI software for calculating the coupled heat and moisture transfer in building components, as well as relate conditions recorded in the walls to long-term predictions. A database would also be developed for logging long-term monitoring attributes (condition reports, climate data, microclimate data) and photographic records.

The analysis of monitoring and climate data collected through the project would enable the relationship with climate, climate change and earthen-architectural heritage to be explored and better understood. Where damage could be expressed in terms of damage functions, the potential damage in the future could be determined by coupling these to the likely future climate at the site.

This project also wished to move beyond the data to carry out qualitative analysis of the test walls, in order to understand earthen-architectural heritage and climate change in relation to the philosophical and reflexive context of heritage values. For example, recording of thoughts and opinions concerning the physical appearance of the test walls provides opportunities to reflect upon and document reactions to the varying conditions of the test walls, to understand how rates of transformation impact upon physical conditions and heritage values of earthen structures.

A key problem for such research is how to transform the very large quantities of data gathered into coherent research outcomes. It is easy enough given modern recording techniques to gather large amounts of data. However, this can become a descriptive end in and of itself. An important element of this research was to isolate key parameters such that they would be useful in understanding the types of change likely to occur into the far future, as well as to provide guidance for the management and protection of earthen-architectural heritage.

5. CONCLUSIONS

Earthen architecture is of significance to a wide range of policymakers, businesses, practitioners and individuals. Earthen architecture has been promoted as an aesthetic, healthy, environmentally friendly, responsive and sustainable building material. There has been a revival in the craft sector utilizing earthen-building materials. The construction industry is also interested in the utilization of earthen-construction materials as environmentally friendly and economically more viable materials (due to reduced carbon-dioxide emissions as a result of the omission of cement-based materials or reduction in firing temperatures) in otherwise more 'conventional' building developments. In the long term, by providing information and a scientific rationale for monitoring earthen structures in relation to climate parameters, this research is of importance to all involved in planning for sustainability in the 21st century, not just from a heritage perspective, but also from the industry concerned with adopting more environmentally friendly materials and technologies, alongside communities and individuals involved in sustainability, local distinctiveness and craft-skill training.

Earthen architecture is affected by climate, and will be increasingly threatened by climate change. If there is a need to adapt to climate and climate change, and plan strategies to minimize harmful effects on important earthen structures, it is required a better comprehension of the mechanisms of weathering. There is a need to need to be proactive, in order to better understand the likely impacts and adaptations necessary to assure the survival of earthen-architectural heritage. It seems unfortunate, given the sensitivity of earthen structures to climate, that there is so little focused research in this area.

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CHALLENGES IN PRESERVING THE WORLD HERITAGE EARTHEN SITE OF CHAN CHAN, IN PERU

Mariana Correia

Theme 2: World Heritage Earthen-Architectural Sites, Natural Disasters and Climate Change
Keywords: Chan Chan, World Heritage site, conservation, management plan

Abstract

Chan Chan is an archaeological site in Trujillo, on the north coast of Peru. The archaeological complex is the largest earthen site in the world and has been on the World Heritage in Danger list since being inscribed in 1986, following its classification as a UNESCO World Heritage site.

The aim of this paper is to address the state of the art, regarding the challenges and the current preservation status, and to understand why the site has been on the list for last 25 years. This paper also discusses the architectural and archaeological significance of Chan Chan, its assessment as a World Heritage site, the management-plan development, the conservation state of the site, the conservation practice on site, the conservation philosophy, reasons for conservation failure, key issues emerging from qualitative analysis, and finally, in conclusion, recommendations to consider.

1. INTRODUCTION

Chan Chan is an earthen archaeological site located in the Moche Valley, 5 kms northwest of Trujillo on the north coast of Peru. It is situated 600 km north of Lima. Chan Chan is considered to be the largest World Heritage site built of earthen materials in the world, and the largest pre-Columbian city in the Americas.

The inhabitants of the Moche Valley were the Mochica and Huari, when the Chimú culture arrived around the 9th century AD. In 1100 AD, following the collapse of its economy resulting from "el Niño phenomenon, as well as several tectonic movements" (Castellanos, 2000, p. 69), the Chimu state directed its attention to military activities "to conquer and dominate the neighboring valleys … consolidating Chimu power" (INC, 2000, p. 5, Executive Abstract). It was in 1300 AD that the Chimú culture initiated the dynasty of the Chimor Empire (Briceño Rosario, 2004, pp.13-15).

Chan Chan became the religious and administrative capital of the Chimor Empire during the reign of the ten rulers, reaching its maximum splendor in 1450 AD, with an estimated 35,000 inhabitants living in the citadel (INC, 2000, p. 5, Executive Abstract). This empire extended throughout an area of 1,000 km, on the north coast of Peru (Valle Alvarez, 2004, p. 9) and fell under the Inca conquest between 1462 and 1470. Chan Chan was then almost abandoned as a living city and was again conquered by the Spanish, approximately 60 years later (Briceño Rosario, 2004, p. 15).

According to several authors, the meaning of Chan Chan in the autochthon Yunga language is "City of the Sun" or "Warm City" (Pinillos, 1995, p. 24). At the present time, the complex has an area of 14.14 km²; however, its original area was about 20 km² (Valle Alvarez, 2004, p. 9).

The complex is comprised of nine walled citadels, known as townships or palaces. There are also "thirty-five architectural units and semi-monumental ensembles, six huacas, ceremonial roads and four extensive popular neighborhoods" (INC, 2000, p. 6). The huacas were built as pyramidal-type structures dedicated to sacred ceremonies, related to the concept of transcendence. According to Campana, a huaca represented the idea of an ancestral power, which explains in certain cases the burial of men at huacas (2000, p. 120). Within the citadels, there were autonomous units containing ceremonial squares, temples, reservoirs, gardens, burial places, storehouses of the aristocracy, but also labyrinths and blind alleys (Pinillos, 1995, p. 15). Some authors believe that most of the population lived outside the citadels.

2. ARCHITECTURAL AND ARCHAEOLOGICAL SIGNIFICANCE

The citadels were built in different historical periods with similar architecture typologies. The overall complex emerged as a metropolis, and followed an outstanding method of town