Construction and Building Materials 29 (2012) 512–519

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

Earth construction: Lessons from the past for future eco-efficient construction

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ARTICLE INFO

Article history:
Received 24 June 2011
Received in revised form 3 October 2011
Accepted 4 October 2011
Available online 3 December 2011

Keywords:
Earth construction
Rammed earth
Adobe
Cob
Energy
Wastes
Indoor air quality

ABSTRACT

Earth construction has received in the last decade an increased attention by the scientific community illustrated by a tenfold increase of the published research articles when compared to the previous decade. Earth construction has a major expression in less developed countries, however, the mimetic temptations towards more polluting construction techniques based on reinforced concrete and fired bricks are likely to favor a change towards a clear unsustainable pattern. In order to disclosure and highlight the importance of earth construction, this article reviews some of the environmental benefits associated with it. It includes an overview about its past and present. It also includes a review about economic issues, non-renewable resource consumption, waste generation, energy consumption, carbon dioxide emissions and indoor air quality.

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1. Introduction

Unlike other species who seek a balance with nature that will ensure their survival, mankind concerns only with the immediate satisfaction of their "needs" regardless that they may cause the exhaustion and the collapse of the ecosystem which they are an integral part, and this despite the fact that scientific community have been alerting for some time to the urgency of this problem [1–4]. The construction industry is one of the largest and most active sectors throughout Europe representing 28.1% and 7.5% of employment respectively in the industry and in the European economy. With an annual turnover of 1200 billion euros, this sector represents 25% of all European industrial production, being the

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doi:10.1016/j.conbuildmat.2011.10.054

largest exporter with 52% market share. In world terms the construction industry will keep on growing at a fast pace. For instance China will need 40 billion square meters of combined residential and commercial floor space over the next 20 years – equivalent to adding one New York every 2 years or the area of Switzerland [5]. Environmentally speaking, this industry accounts for 30% of carbon dioxide emissions; in addition the global construction industry consumes more raw materials (about 3000 Mt/year, almost 50% by weight) than any other economic activity, which shows a clearly unsustainable industry. The foreseeable increase in world population (by 2030 is expected to increase by more than 2000 million people) and the needs in terms of buildings and other infrastructure, would further increase the consumption of non-renewable materials, as well as waste production. Therefore, the use of more sustainable construction materials and construction techniques represent a major contribution to the eco-efficiency of the construction industry and thus to a more sustainable development. In the last decade almost one hundred research articles related to this subject have been published in Scopus journals mostly related to rammed earth. This is just a small fraction (less than 10%) of the research articles published about Portland cement concrete in the same period (the largest-volume manufactured product on earth [6] and responsible for 5% do world CO_2 emissions), but it represents a tenfold increase compared to the research articles concerning earth construction publish in the 1990s. This means that more and more research efforts are being dedicated to transform the current building industry into a more sustainable one. Earth construction assumes in this particular context, an environmental advantage that makes it extremely competitive when compared to conventional materials and construction techniques. The majority of investigations carried out in this field are mostly related to the seismic response of earth buildings, mechanical properties of earth masonry and more recently about thermal and hygrothermal performance. The authors only found one review paper about the selection of soils [7]. The present manuscript reviews important aspects related to earth construction. It addresses economic advantages, non-renewable resource consumption, waste generation, energy consumption, carbon dioxide emissions, toxicity and indoor air quality.

2. Earth construction

2.1. The past

There is no consensus about the date when man began to use earth construction. Minke [8] mentioned this may have happened over 9000 years ago, basing its beliefs on the fact that earth blocks (adobe) based dwellings discovered in Turkmenistan dated from a period between 8000 and 6000 BC. Other authors [9] mentioned that the use of earth for construction purposes dates from the period of El-Obeid in Mesopotamia (5000–4000 BC). According to Berge [10] the oldest adobe blocks, which were discovered in the Tigris River basin date back to 7500 BC so earth construction could have been used for more than 10,000 years. It is not very relevant, whether the earth construction began more than 9000 or over 10,000 years ago but its not far from the truth that the earth construction begin with the beginning with the start of early agricultural societies, a period whose current knowledge dates from 12,000 to 7000 BC. There are countless cases of earth buildings which were build 1000 years ago and made it to the XXI century. Even the Great Wall of China whose construction began about 3000 years ago has extensive sections built on rammed earth. Evidence show the use of earth construction by the Phoenicians in the Mediterranean basin including Carthage in 814 BC. The Horyuji Temple in Japan has rammed earth walls built 1300 years ago [11]. This author refers the existence of rammed earth based buildings in the Himalayan region built in XII century. Adobe based buildings structures are common in Central America. The ruins of the city of Chanchán in Peru are among the most ancient earth based constructions [12]. The village of Taos in New Mexico is another example of ancient earth constructions (1000–1500 AC). Another good example is the city of Shibam in Yemen with earth buildings up to 11 floors that were built 100 years ago [13].

2.2. The present

Currently almost 50% of the world's population lives in earth based dwellings [14]. The majority of earth construction is located in less developed countries, however, this kind of construction can also be found in Germany, France or even the UK that has an excess of 500,000 earth based dwellings. Earth construction has also increase substantially in US, Brazil and Australia largely due to the sustainable construction agenda, in which the earth construction assumes a key role. The French laboratory CRATerre, founded in 1979 and linked to the School of Architecture in Grenoble, which acquired an institutional dimension in 1986 through the recognition of the French Government, was capable to maintain a strong and steady action in the promotion of earth construction. Houben et al. [15] mention the success of an educational project undertaken in CRATerre, consisting of a scientific workshop with over 150 interactive experiences that in just 4 years had been attended by 11,000 visitors. As for Germany, Schroeder et al. [16] report the existence of vocational training on earth construction as well as courses that confer the Expert title in this area. Three universities offer earth construction courses respectively the University of Kassel, the University of Applied Sciences in Potsdam and the University of Weimar (Bauhaus). Earth construction is not only dependent on adequate training but also on specific regulations.

Several countries already have earth construction related standards. In Germany the first Earth Building Code dates back to 1944, but only in 1951 with DIN 18951, these regulations have been put into practice. In 1998 the German Foundation for the Environment disclosed several technical recommendations known as the "Lehmbau Regeln" [17]. Over the years they have been adopted by all the German states with the exception of Hamburg and Lower-Sáxony. A revised version of the "Lehmbau Regeln" passed in 2008. Australia was one of the first countries to have specific regulations on earth construction. The Australian regulations were published in 1952 by the Commonwealth Scientific and Industrial Research Organization (CSIRO) under the designation of "Bulletin 5". This document has been revised in 1976, 1981, 1987 and 1992. In 2002 this document has been replaced by the Australian Earth Building Handbook [18]. In 1992 the Spanish Ministry of Transport and Public Works published a document entitled "Bases for design and construction with rammed earth" to support not only rammed earth but also adobe based buildings. Recently Delgado and Guerrero [19] stated that earth construction is not yet regulated, posing several drawbacks such as the need to contract a building insurance during the 10 year warranty period. The United States has no specific regulations related to earth construction; but seismic regulations must be addressed by these constructions. Since 1991 New Mexico has a state regulation concerning rammed earth and adobe based constructions. New Zealand has one of the most advanced legal regulations on earth construction which is structured in three distinct parts:

NZS 4297:1998 – engineering design and earth buildings – establishes performance criteria for mechanical strength, shrinkage, durability, thermal insulation and fire resistance;
NZS 4298:1998 – materials and workmanship for earth buildings – defines requirements for materials and workmanship;