International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 6 (2016) pp 4628-4633

Sun-dried Clay for Sustainable Constructions

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Abstract
Sun-dried clay is one of the oldest building materials that has been used for more than 10.000 years to build houses, mosques, churches, palaces and cities. Currently one-third of the global population lives in this vernacular architecture made with the man-made stone-like construction material. This building material, commonly made from a mix of clay and organic materials, is resisting the long span of time and weathering. Used correctly, the clay making technology has many benefits: the technique used is very simple with zero maintenance cost, local availability and affordability, and has a good thermal and acoustic insulation. Because of this, earthen architecture has many advantages from a sustain ability perspective. The use of this eco-friendly construction material nowadays could be a viable alternative to solve our 21st Century big concerns of energy and climate change. For this reason, it is important to understand this material characterization, diagnosis and suitability in construction, and to understand how can it be a good construction material for a particular site. This paper discusses earthen material and construction techniques, and their important contribution to sustainable development.

Keywords: Earth architecture, Sun-dried clay, Adobe, Rammed earth, Sustainable architecture, Eco-construction material.

A Global Interest in Vernacular Architecture

According to the International Energy Agency (IEA), global energy consumption is set to increase by 37% in 2040 [1]. The effects of climate change (such as environmental pollution, increasing sea levels, ozone depletion, global warming, deforestation and desertification), and pressures related to development are all facts that pushed scholars to direct their thinking towards eco-friendly technologies, sustainable economy, societal sustainability and reducing greenhouse gas emissions [2].

There has been a growing interest in the promotion of earthen architecture as the most insightful and sagacious means to stop threats from nature and the environment. Indeed, the topic of sustainable design today is highly ranked and so are the researches on developments in technology, architecture and construction materials. The researches nowadays are directed towards earthen architecture and its development in different parts of the world.

The indigenous people with their different landscapes, climates and cultures around the globe achieved "sustainability" thousands years ago: from the great wall in China, to the Djingueréber Mosque of Timbuktu in Mali, to the Ramasseum in Egypt, to the ancient towns in South America or the 10.000 years old Catahyouk site located in Konya province in Turkey.

Figure 1 is an illustration of the Turkish proto-city that has been founded around 7500 BCE and lasted for almost 1700 years. It is one of the oldest sun-dried clay architecture dwellings known today [3].

Figure 1: Catalhoyuk proto-city [4]

Sun-dried clay architecture allowed these populations to live in harmony with nature as they developed different construction techniques and methods to build their dwellings. Figure 2 shows how earth architectural constructions are distributed around the world.

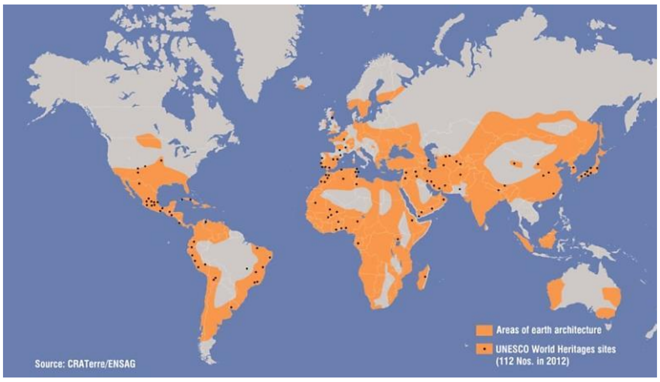

Figure 2: Earthen construction around the world [5]

In the early 1980s, the world population living in an earthen habitat was evaluated by 30%, which is nearly 1.5 billion of human beings [6]. Figure 2 helps to visualize earth

architecture distribution areas and earthen heritage sites according to UNESCO (CRATerre/Ensag, 2012) [5].
In recent decades, studies on clay architecture have undergone an undeniable acceleration, hence the interest in the renovation of vernacular architecture spread in all continents. There are numerous international conferences, exhibitions and publications that highlight the importance of resurrecting a savoir-faire almost forgotten and almost overwhelmed by the conglomerate concrete and the current forms of building production. Concrete production was also responsible for 12.94% of global CO^2 emissions during 2014 [7].

A Contemporary Housing Solution

In the late 1940s, Hassan Fathy was able to prove that solving social problems is possible through low-cost housing for low-income societies; he proposed to use traditional clay architecture. The self-sufficient sustainable village "New Gourna" was built in the famous archeological Egyptian site in the Luxor using traditional techniques and local materials in harmony with both the environment and the rude local climate conditions.
After 64 years of this successful experimental eco-village in Egypt, Professor Richard Economakis has revived the same idea of sustainable vernacular Mediterranean architecture for the sake of sorting out the challenge of hosting the Syrian refugees and decrease the pressures on many Mediterranean sites. This researcher proposed to UN Habitat a semi-permanent refugee settlements for Syrian refugees in the Greek Islands as humanitarian refugee village solution to the actual European migration crisis (Figure 3); an idea which can be re-purposed for an eventual profitable use in the future [8].
The refugee village, consisting of 800 dwellings, would be constructed of sun-dried bricks, for an affordable, rapid and easy local construction. If each housing unit can accommodate up to 10 people, each village will be receiving up to 8000 Syrians [8].

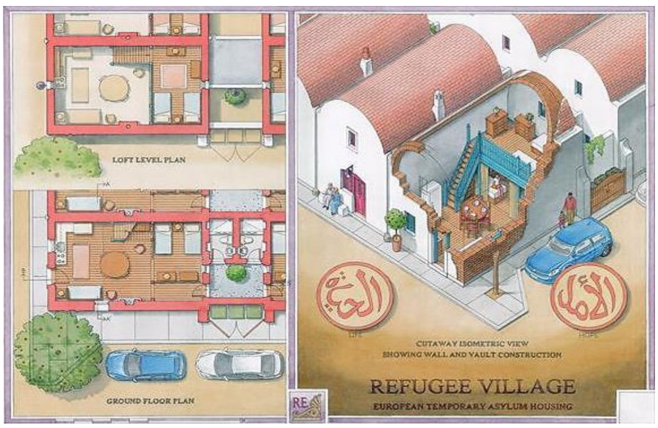

Figure 3: Economakis refugee housing floor plan proposal [8]

Thermal Performance Comparison of Unfired Clay-Brick and Precast Concrete:

In 1964, Hassan Fathy conducted comparative measurements about indoor and outdoor air temperature fluctuation using different construction materials. The research was located in the Cairo Building Research Center (CBRC) in the Giza district in Cairo (Egypt). The latter lies in a maritime desert region with only few meters above the sea level at a latitude of 30° north. With hot days and cold nights the comfort zone of this region is between 18 and 27° C [9].
The experiments intended to prove the thermal performance of the sun-dried clay-brick, i.e., a local traditional building material, against the precast concrete; a conglomerate widely used construction material. Fathy used two different test rooms: the first one was built similar to the local traditional housing type using a 50 cm thick mud bricks walls covered with a dome and the second one was built using a 10 cm thick precast lightweight concrete blocks and prefabricated concrete roof panels [10] Figure 5.
The air temperature fluctuation performance was monitored during the 24 hours as shown in Figure 4.

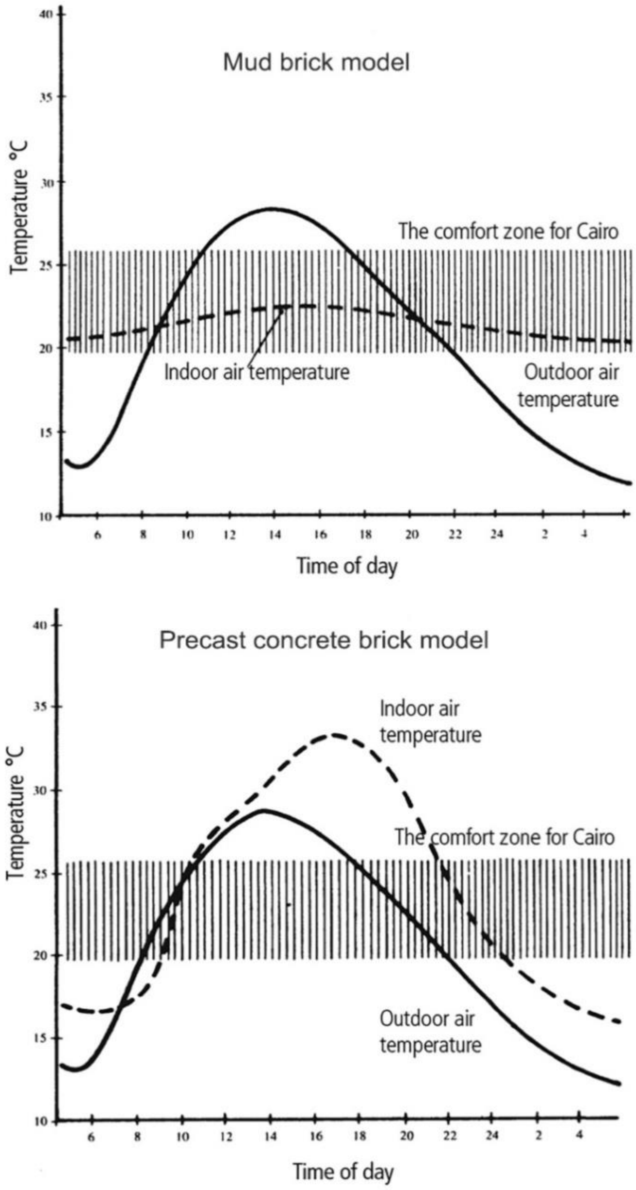

Figure 4: Hassan Fathy air temperature fluctuation experiment [10]

Figure 4 shows that the precast concrete brick model was outside the comfort zone for most of the day, 19 hours and 20 minutes against the mud brick model which was within the comfort zone during the whole 24 hours cycle as summarized in Table 1.

Table 1: Thermal performance tests on concrete and clay (Adapted from : Fathy, 1986) [10]

	Time outside the comfort zone	**Time within the comfort zone**	**Thickness**	**Thermal conductivity**
Precast concrete	19h 20mn	4h 40mn	10 cm	0.9kJ/m^3 ℃
Adobe	0h	24h	50 cm	0.34kJ/m^3 ℃

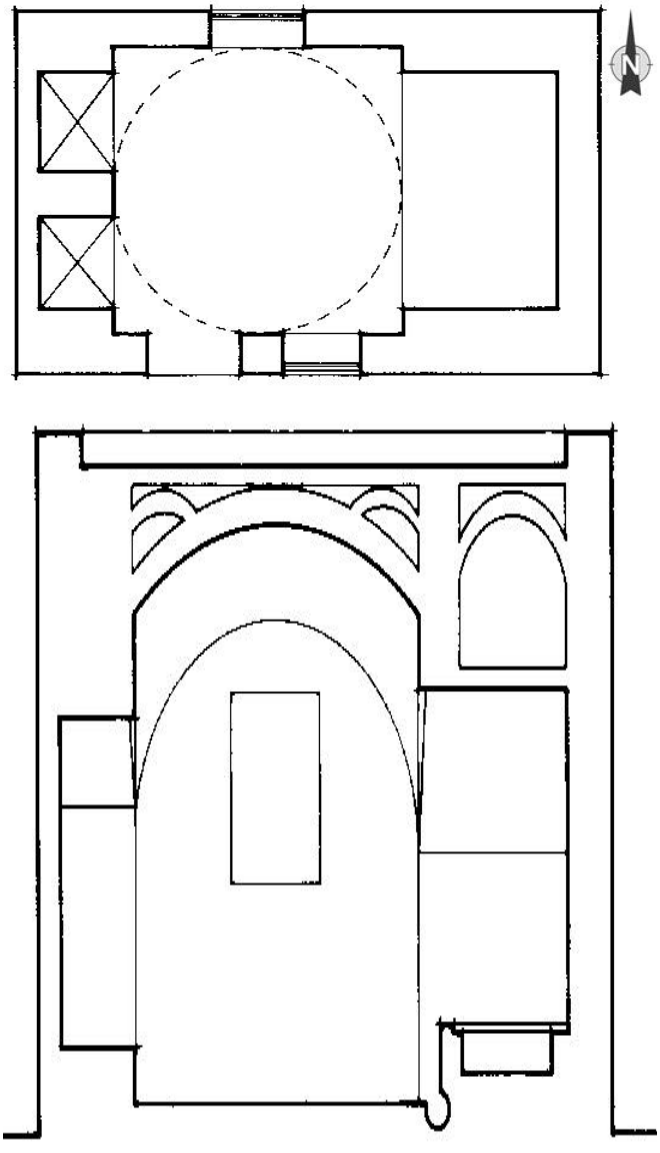

Figure 5: Plan and section of the sun-dried mud-brick vault-and-dome test model [10]

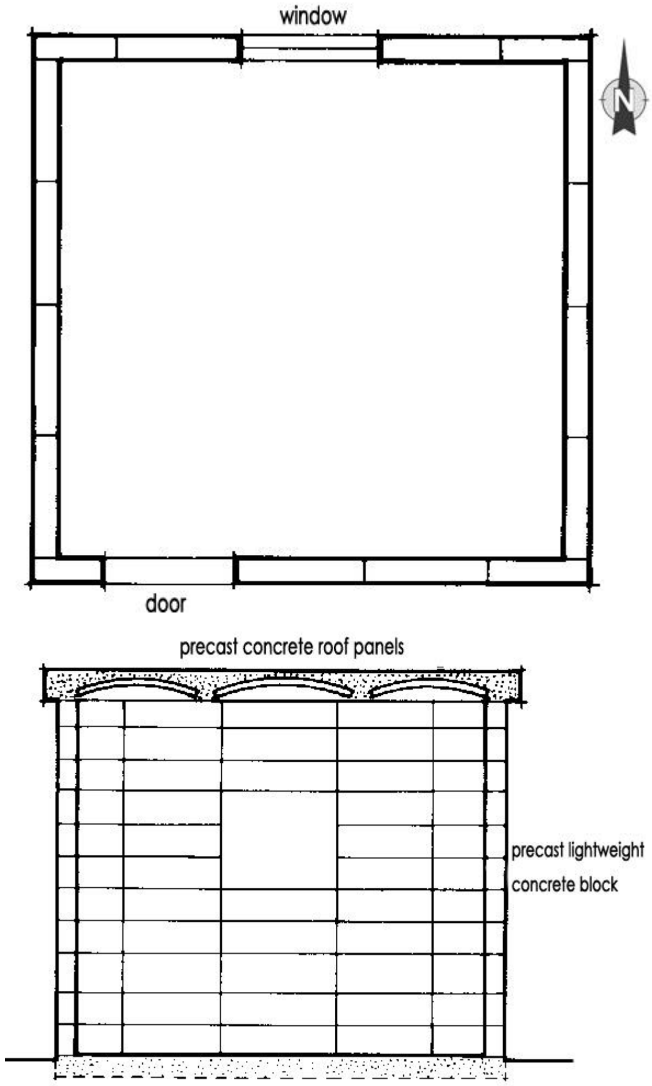

Figure 6: Plan and section of the precast concrete test model [10]

In fact, the precast concrete brick test room was within the comfort zone only 1 hour during the day from 9 am to 10 am and 3 hours 40 minutes during the night from 8:40 pm to 12:20 pm.

The indoor air temperature fluctuation of the clay-brick test room varies from 21 to 23° C, not exceeding 2° C allowing an interior thermal stability. On the other hand, the indoor temperature of the concrete test room is greater than the outdoor temperature by 9° C reaching 36° C. It is 13° C warmer than the indoor mud brick test room.

The instability of the indoor temperature of the concrete test room is due to the high thermal conductivity 0.9 in comparison with the mud brick wall 0.34 as shown in Table 1, beside the fact that it is five times thinner than the last one.

The traditional sun-dried mud-brick test room has a thermal resistance thirteen times higher than the precast concrete test room.

Embodied Energy in Clay

Figure 7, shows the energy amounts consumed by different construction materials expressed by kWh per cubic meter, reinforced concrete embodied energy is 99.5 times higher than the raw earth embodied energy.

As a matter of fact, steel in the reinforced concrete is using a large energy amount for its manufacture and transportation. However, raw earth has a very low embodied energy since it is an in-situ material and 100% reusable when it is stabilized with natural materials. Clay is a cost-effective construction material with only 30kWh/m^3.

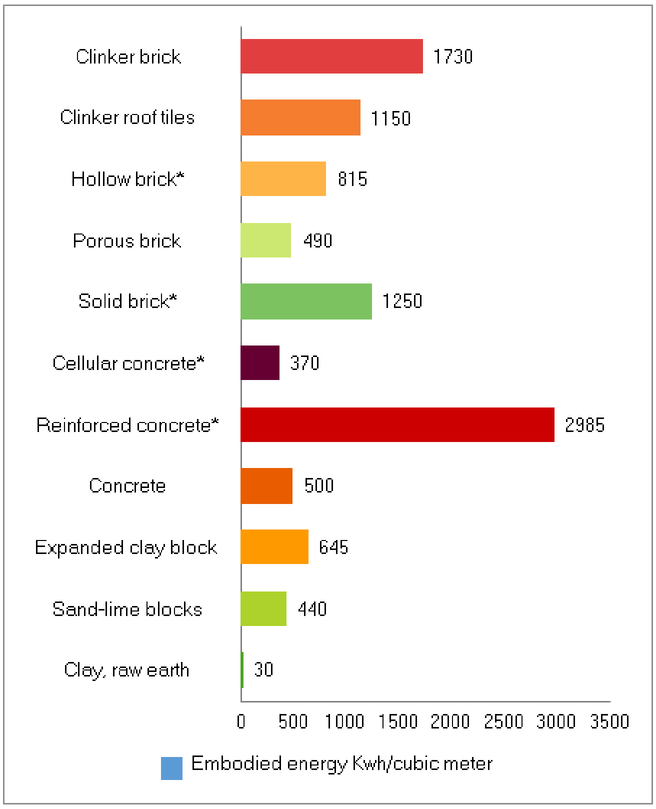

Figure 7: Embodied energy for different construction (*. Average value) [11]

Unbaked Clay Architecture: Strength and Weakness

Because of its low-cost and earth construction composition, mud is wrongly perceived as a sign of poverty [12]. Consequently, it receives a low acceptability by owners as an alternative building material to the concrete or the fired bricks. It also has a low popularity by the industry due to its low economic profit. Conceptually, the mud can be used to combine traditional elements in contemporary contest to create pleasant aesthetical contemporary buildings with high thermal comfort, low energy consumption for winter heating or summer cooling [12].

Figure 8 shows an excellent example of an earth-brick yet an ultra-modern residence made with a mixture of local building materials. This earth building is the result of research collaboration between universities, corporations and specialists (2008-2011).

Figure 8: The Earth Brick Residence in Chiba, Japan, Atelier Tekuto.[13]

It is known that clay buildings are subjected to deterioration by weathering, especially by wind and moisture (either from excessive rain water, rinsing ground water or high humidity). The durability of clay structure will depend on its compressive strength, thermal conductivity, and most of all its porosity [14].

Table 2: The strength and weakness of clay [15]

Strength	**Weakness**
Suitable for hot dry climates	Not suitable for Humid climates (moisture absorption)
High compressive strength	Low tensile strength
High thermal resistance	Low response to weathering: shrinkage cracks & erosion
Global availability	Low acceptability: perceived as a sign of poverty
Zero waste	Low aesthetic value
Fireproof& Vermin resistant	Labor-intensive
Cost-effective	Low financial industry profit
Soundproof & Non-toxic	Needs constant maintenance
Low embodied energy	Low governmental incentives

Main Construction Techniques for Clay Architecture

Rammed Earth (Pisè)

The rammed earth involves the construction of formwork within which the earth is compacted. Such formwork, which must be strong enough to withstand the pressure of compaction are traditionally constituted by sections of piles held together and made to slide along the wall after it is compacted. Approximately 10% of its total weight consists of water. Figure 9 shows a rammed earth home example.

Figure 9: Aerecura Rammed Earth Home Revisited [17].

Wattle and Daub

It is a plaster-based earth obtained by mixing fine earth, fibrous material (like straw, mud, clay, animal manure or sand) and lime. It seals any spaces between the wood wall sections. Figure 10, shows a timber-framed building using the wattle and daub technique.

Figure 10: Timber-framed building with panels at various stages of wattle & daub infill [17]

Adobe

It is a very old technique of earth blocks construction made from a mixture of earth rich in clay and a sufficient amount of sand to allow adequate compressive strength and reduce cracking. The liquid mixture is to be poured into molds in order to shape the bricks in the desired size. The mixture is allowed to cure until it is possible to remove it to let it completely dry in the sun.

Figure 11, is the famous New Gourna, a village made entirely of adobe designed by Hassan Fathy.

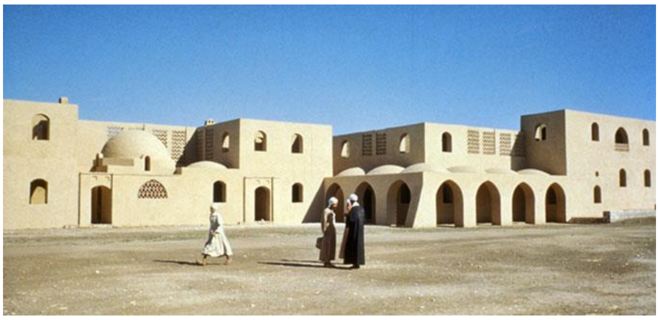

Figure 11: New Gourna Village is located in Luxor, Egypt, Hassan Fathy.[18]

Cob

This system uses a combination of clay, sand, straw and water to create rigid blocks shaped loaf of bread that are placed in the wall and then "woven" together to create a consolidated mass. Blocks allow the creation of curved shapes thanks to their malleability, but require a lot of straw as shown in figure 11. The straw works for the "cob" such as steel for the cement: the wall gives higher tensile strength, especially when the various blocks are machined between the one and the other with the "cobber's thumb" or with his own hands and fingers.

Figure 11: Interior of a cob house [19]

Conclusion

Despite the fact that earthen architecture being massively replaced by the conglomerate concrete since the Second World War, it has remained a valuable building material due to its structural capacity, durability, energy performance and environmental impacts. The durability and versatility of earth constructions is an undeniable fact demonstrated by both traditional and modern high-tech earth buildings from all over the world. This study recognizes the significance of earth building materials.

Building with earth is definitely an appropriate and cost-effective and energy efficient technology that reflects the “green” contemporary concerns. By using appropriate structural techniques and stabilization methods, earth

architecture is a climate responsive way to build constructions that can be used in almost all climates and last for decades.
In terms of sustainability, earthen architecture offers several advantages that can be summarized in two points:

- The building materials derived from soil, water, clay, etc. have a lower cost than any other materials.
- Earthen construction needs low energy input in processing, manufacturing and handling soil.

With its low environmental impact, sun-dried clay could be a global affordable solution for low income societies.

Acknowledgement

This work was supported by the Dong-A University Research Fund.

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