Affordable sustainable earthbag housing; achieving indoor thermal comfort in low cost housing in Egypt.

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ABSTRACT

Housing demand for the low/moderate-income majority in global south creates potential and need for several housing types. Currently, one-sixth of the world's population lives in urban slums in emerging and developing countries. In addition net growth of 2.6 billion in world population between now and 2050 is projected to occur in these cities. The paper is discussing a real living lab test for construction of an affordable earthbag experimental model. Projected a new concept of low cost housing in Egypt. Economical yet rich in values integrated in it, with the objective to develop innovative, economical, viable, reproducible and affordable residential houses, using low-tech solutions. The discussion will show a room sample using earthbag technique over training workshop in a farm land in the outskirt of greater Cairo. Thermal comfort and health benefits will be discussed for this model example. The paper will discuss the construction techniques and building phases together with the method applied for thermal comfort assessment. The results from this pilot trial gives a clue that it is possible to contend against slum dwellings by introducing low cost earthbag housing. This experiment shows that an earthbag building built with available local materials can incorporate essential life necessities and at the same time is affordable to construct.

KEYWORDS: Affordable housing, Low-tech, Earthbag, Thermal comfort, Egypt

1. INTRODUCTION

According to The Egyptian Centre for Housing Rights (ESCR), it is mentioned that millions of citizens in Egypt lack proper shelter (ESCR, 2012). Rapid urbanization and economical problems in Egypt resulted in urban poverty and the spread of informal slum dwellings (Aref., 2004 & Abdel Halim, K., et al., 2009). To cope with such problems several architects and building engineers in Egypt tried to think of alternative solutions for low-cost housing that are currently being researched and tested (see Aref., 2004, Gelil, 2011 & Ibrahim, 2011, Dabaieh, 2012). In the same time research to reduce energy consumption in the building sector through climate responsive strategies without compromising human comfort was and still a vital concern in research and practice (Fathy, 1973 & 1986, Harris-Bass, 1982 & Hanna, 2011). In Egypt recently there are several implementation for low-tech and low-cost building construction aimed at pushing for sustainability concepts in the energy-intensive building sector (Ghorab et. al, 2007, Dabaieh, 2011 & Ibrahim, 2011). Such initiatives works in conjunction with measures to minimize resource consumption in residential building construction as an essential part in achieving energy efficiency of buildings national goals in Egypt (UNDP, 2010). One of those initiatives are building with earthbag techniques. Earthbags are gradually becoming recognized as a practical, example for energy efficiency and low-cost housing solution.

Generally, many academics and architects mentioned that between one third and a half of the population of the world lives or works in earth construction buildings (See Dethier, 1983, McHenry, 1989, Warren 1999, Elizabeth, 2000, & Rael, 2009). Rammed earth, soil blocks, mud bricks or adobe are various applications for earth or clay soil (Minke, 200&2006). In Egypt earth was one of the main
building material in ancient time and till recently is still a main building construction material in rural areas (Houben & Guillaud, 1994). The earthbag method exploits the ancient technique of rammed earth in combination with woven bags to create sustainable housing structures.

Looking at the history of using earthbag technique, it was used basically for military purposes, and has long been used for disaster and hazards relief such as flood barrier (Kennedy, 2000). Also it was used for replacing demolished houses after earthquakes with temporary earthbag shelters (Barnes et. al, 2009). Nader Khalil in 1990 started leading the movement of sustainable earthbag buildings in residential projects (Khalil, 1990). Other several architects have practical experience in building with earthbag like (Otto & Rasch, 1995) and (Minke, 2000). They used earthbag building technique for housing application units and other architectural purposes. The main aim of earthbag techniques is the use of local available material and applying inexpensive construction methods together with offering trouble-free maintenance methods that can be easily done by local building owners. All these allow applying sustainable and affordable building system for low income citizens.

A recent example in Palestine built early in 2013 with total cost of 35 thousand dollars which is 50% less than conventional building with the same size in the same town of Ariha in Palestine. The building is equipped with like mail life necessities electricity, water feeding and sanitary infrastructure. The building was built with minimal energy consumption and CO2 emission.

![Figure 1. Building with earthbag in Palestine, 2013. Source: ShamsArd Design Studio](image)

![Figure 2. The building is equipped with life necessities. Source: ShamsArd Design Studio](image)

This paper is discussing a living lab experiment in constructing a model from earthbags through a training workshop. It is an initiative started by a non profit organization in Egypt with the help of architects and building engineers interested in sustainable building solutions. The main goal was to start testing building with earthbags and provide practical training for new sustainable and low cost housing solutions to solve the problem of slum dwellings. It was necessary to look beyond conventional construction materials and methods which proved failure in solving the problems of low income housing and informal settlements in Egypt. Looking at this experiment from environmental sustainable concerns, all basic materials selected for construction were naturally available and could safely return to nature after use. The selection to use earthbag was not only because it is an affordable and low cost technique but it also saves wood as a structure element. So it helps preventing deforestation in a country like Egypt with sacristy of wood. The objective of this paper is also to show the possibility and applicability of building with earthbag. The idea of earthbag training workshops that involved over 25 participants including architects and building engineers had proved the interest in adopting building with such techniques.

2. METHODOLOGY

This paper applied a descriptive explanatory approach to document and explain an urban living lab co-creation experiment for earthbag training workshop. The paper explained the different workshop phases and showed how this training can be further applied and used to help solving informal housing problem in Cairo, Egypt. While the method adopted at the workshop itself are derived from the
concept of learning by doing. The participants had the chance to experiment and test by themselves all the building phases. The workshop started with theoretical seminar giving a background on earthbag technique then followed by on-site tests for the soil which will be used as filling as shown in Fig. (1&2). Then the work started from foundation digging till layering the earthbags courses until the final plastering phase. The outcome of the workshop was a building guide and manual illustrating all the building steps and documenting the participants experience during the workshop.

A qualitative questionnaire survey was done to evaluate the experiment and measure the thermal comfort level for the built room out of this training workshop (which was used as a guard rest room and storage) and another shack room in a slum area (used as a shelter) with almost the same size. The questionnaire was mainly targeting the users' thermal comfort and feeling inside the two rooms. The survey was done for three consecutive days in late June and early July 2013. The users were asked the same questions to measure their comfort level over the three days. The outcome of the survey was a qualitative description for thermal satisfaction inside the rooms.

![Figure 3. Squeeze and drop tests to check the type and strength of the soil.](image1)

![Figure 4. Ribbon tests to check the elasticity of the soil.](image2)

![Figure 5. The mixture of sand, gravel and lime used as filling for the earthbags.](image3)

![Figure 6. Weighing the mixture of sand, gravel and lime on site and deciding the percentage of each component.](image4)

### 3. EARTHBAG BUILDING TECHNIQUE

Earthbag construction depends on earth as primary structural element, which is flexible and helps to create different shapes to form earthly architecture. It is in the same time providing structural safety and offer internal stability (Hunter & Kiffmeyer, 2004 &2005). The monolith structure of earthbag building technique creates the whole building structure with the same material from foundation to walls to roofs. Earthbag techniques demand very basic construction materials like strong sacks filled with inorganic material which normally could be available on site. For a compact cohesive mixture inside the earth sacks, moist subsoil that contains enough clay is recommended to be added to the earth filling mixture to become cohesive when tamped. Also gravel or crushed rocks can be added. Walls could be gradually built up by laying bags in courses and forming a staggered pattern like brick laying. The basic procedure to induce an earthbag building simplify in rammed earth conjunction with cloth
bags or woven polypropylene bags to act as a flexible form. Building procedures can be summarized as:

First: Filling the bags with suitable pre-moistened earth. The fill material optimally consists of 10% clay, 30% gravel, 30% sand and 30% lime.

Second: Closing and folding the bags to create neat square shape.

Third: Laying the finished bags in the required shape for the building like a masonry running bond.

Fourth: After the rows have been laid, compact the bags with hand metal tampers.

Fifth: Fixing the bags from the four corners and laying the form structure, generally two strands of four point barbed wire, then push down every two rows.

Sixth: Binding the bags in place with wires using tensile strength effect.

Seventh: After allowing the rows to be stepped, create the building shape like domes, rectangular or any shape else.

Eighth: Sticking the exterior and interior plasters, and coating earthbag with appropriate material. The Plasters mixture includes mud, clay, sand and fibres. Plastering serves as pest and UV protector.

Walls can be shaped in any form whether linear, free-form or circle. Openings like windows and doorways could be built around temporary arch forms till the keystone bags are positioned in place. In case of wood unavailability, steel wire can form the doors and window frame structures before bags are impeded. In humid environment, a good percentage of lime, cement is recommended to be added to adjust chemically the mixture of the earth and to make it more resistant to water absorption. Also if earthbag will be used in the foundation and for the first few courses near the ground, lime should be added to the filling mixture to avoid underground water or moist soil.
Earthbag building system align with sustainable building principles. That is not only by offering an affordable construction method but by mainly using local available materials, and following sustainable principles of building throughout the design and construction process. Earthbag techniques is easy and that is an advantage as no labour skills are needed. So one can build an earthbag home with minimal cost. Adaptability and durability are the main key words of earthbag building system, as the technique may be modified several times and in different ways and means to suit any environment.

From a cradle to cradle perspective, earthbag buildings can be recycled once it is no longer in use. Time wise, construction takes a considerably shorter time compared to other natural building techniques like building with earth bricks or rammed earth techniques. In addition to durability and adaptability, environmental and health wise, earthbag buildings allows the air exchange from interior to exterior and vice versa, provides a good thermal insulation through the walls thermal mass and also maintains regular indoor humidity levels.

4. SUSTAINABLE CHARACTER OF EARTHBAG HOUSING

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5. EARTH BAG AND ENVIRONMENTAL BENIFTS

As Macias and his colleagues discussed in the outcome of their research that the low energy approach should be the key concept in any long-term strategy aiming to build sustainable building future (Macias et al., 2009). Earthbag is considered one of the building techniques that has low embodied energy. Earthbag buildings minimize impact on building lot and reduce water use in construction phases. For the Egyptian hot climate, earthbag can reduce local heat effects, provide comfortable indoor thermal environment, protect occupants from indoor chemical pollutants and helps in air filtration. Earthbag buildings encourages the notion of constructing smaller homes for plot areas consumption and at the same time promote for using local material and reduce waist generation of
building. In general in terms of energy and environment sustainable aspects, earthbag minimize thermal bridging, unnecessary energy consumption, and optimize performance of heat in terms of windows, HVAC, insulation, and water heating system. In addition the building technique reduce the demand for non-renewable energy sources and help basically to incorporate green design and construction strategies.

6. EVALUATION OF THE LIVING LAB EXPERIMENT

As mentioned in the methodology section, a comparative study was conducted using qualitative survey questionnaire with users in the two room units. One is a shack shelter unit in one of the informal settlements in Cairo and the shelter units build with earthbag during the workshop. The questionnaire with users aimed at investigating the comfort level inside both units. The user of the earthbag room mentioned that it is comfortable to stay inside the room especially during midday. The temperature inside the room is better than outdoor temperature. The user mentioned that it feels humid and cool inside the room. While the user in the slum dwelling indicated in the questionnaire survey that it is unbearable to sleep at night inside his shack during July and August in summer time and from December till February in winter time. That is due to using improper building materials with poor thermal properties together with unsealed walls and ceilings with no insulation. The result of the questionnaire gives an indication that earthbag techniques provided adequate comfort level compared to other shacks in slum areas built with tin, metal sheets and cardboards. It can be a drawback in this study that there are no thermal measurements for indoor temperature and humidity to be able to have accurate results to assess indoor thermal comfort. It is recommended to conduct further survey using qualitative measurements to assess and evaluate comfort level inside earthbag buildings.

![Figure 15](image15.png)

**Figure 15.** The shack room built from wood, cardboard and tin.

![Figure 16](image16.png)

**Figure 16.** Unhealthy and inhuman shelters in slum dwellings in Cairo.

7- DISADVANTAGES AND LESSONS TO LEARN

Generally during the workshop some difficulties were observed. The tamping down of bags is the hardest part; it needs strength to left a heavy metal plate. Also it gets difficult after several hours of lifting the heavy bags, it needs muscles to lift and carry each bucket filled with earth. Workers should be careful as it’s hard on man back, feet and hands. In addition, during the work, earthbags appeared not to be flexible in construction in case of multi-storey buildings; it is more applicable for one story building. It is a labour intensive technique and it might cost in that scene if external labour is needed other than the building owners. Moreover rodents are considered a threat but with proper thickness of external and internal plastering layer it will be hard to scratch the cloth bags. As for insulation and mass of earthbag, generally the soil is a very good thermal mass material and very poor at insulating. The exception in this case is that earthbag walls are thick walls and can reach up to 60 cm. They do provide insulation from the outside temperature. However it is recommended to add insulating materials to the filling mixture for better thermal performance and indoor thermal comfort conditions during both hot and cold seasons. Also unsealed doors and windows sometimes case infiltration; all
gaps should be filled with mortar or other filling materials to avoid indoor discomfort due to air leakage.

8. CONCLUSIONS

This paper showed by a living experiment that with barbed wire rolls, a bale of bags, and a shovel one can build a decent, low cost and comfortable shelter. As the famous architect Hassan Fathy used to say you do not need more than earth underneath your feet to build your house. This paper attempts to address an idea to assist housing the urban poor in informal settlements and the challenge of providing low cost and environmentally friendly shelter through using earthbag construction.

The earthbag building experiment discussed in this paper showed an example of using locally available materials and inexpensive construction, maintenance and use of a low-tech and self help building model. This experiment not only showed a possibility to help solving the problem of affordable housing but also housing solutions with low embodied energy and lower carbon footprint. Earthbags do not require much time and attention compared to other earth building construction. Since the bags act as a form, the mixture is put directly into them and in same place on the wall. One of the most important aspects of building with this technique is that it helps in empowering communities.

Thousands of poor Egyptians who survive in slum areas are left on their own to deal with extreme heat in the summer or rain in winter. Due to the fact that the Egyptian government couldn't cope with the rapid increase in population and housing demands, this idea of this training workshop need to be spread in a wider scale and involve laymen to train them on self help housing techniques. That could help in eradicating the phenomena of unhealthy and uncomfortable slum housing that is spreading like cancer tumours in the urban fabrics of the majority of Egyptian cities. Economical wise, this workshop experiment proved that building one room with earthbags costs four times less compared to a room built with conventional techniques as materials for earthbag construction are in most cases inexpensive, abundant, and accessible. However this technique had proved over the years that it is suitable for arid and semi-arid area like the Egyptian climatic context, one of the challenges that might hinder this notion from realisation on a wider scale is basically getting earthbag technique approved by building code associations in Egypt. It is still hard to get permission or gain fund for projects built by such technique.

The results from this pilot trial proved that is possible to build an affordable house with available local materials, and at the same time can incorporates essential life necessities. Moreover the thermal comfort and health benefits can be achieved as well.

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