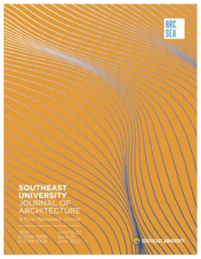

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# Unfired Earth: A comparative analysis for finding appropriate earthen construction technology as an alternative to kiln-burnt bricks

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ABSTRACT

*Most of human civilization was once sheltered by earthen structures. Even today, approximately 1.7 billion people worldwide reside in earthen structures [1]. In the developing world, the raw earth is being replaced by its fired counterpart - the brick. But making fire mostly involves burning of fossil fuel – a non-renewable source that pollutes. In the age of standardization and rapidly evolving technology, the malleable and organic raw earth cannot compete. But perhaps the same ingenuity that gave us the brick can transform earth into something new that is fit for construction in the 21st century. This paper evaluates all the existing earthen technologies available; in an effort to determine the most practical unfired counterpart of the modern-day clay bricks.*

## 1. Introduction

Brick is a truly versatile material. It is durable, cheap, easy and quick to produce and is aesthetically pleasing. But brickmaking requires a lot of energy – which causes massive carbon emission and pollutants. In developing countries, energy is scarce. In Bangladesh, for example – natural gas is increasingly being used in kilns, a resource in such dire scarcity that it is being regulated for residential use.

Replacing brick is a challenge, not only because of its physical properties; but because of the confidence it demands. Oppositely, earthen construction evokes an image of poorly constructed crumbling village huts – which discourages the urban population to even consider it. Even in rural areas, earthen architecture is losing its prestige. Raw earth is bio- degradable, requires a fraction of the embodied energy of bricks, and has hygric properties that can regulate humidity in a space and produces little to no pollution in construction. It is considered short- lasting by the masses, yet structures of mud-brick over 3000 years old still stands in Egypt[2].

In Bangladesh, over twenty-three billion bricks are produced per year emitting over 15.67 million tons of $CO_2$ in the air [3]– contributing to climate change. In Dhaka, kilns account for an estimated 40% of the total air pollution – which causes approximately 750 premature deaths annually [4]. In the light of this condition, the pursuit of finding alternatives to kiln-bricks in order to reduce its production is an urgent issue.

## 2. Process of Determination

To determine an earthen alternative to kiln-burnt bricks, the study requires the following steps:

1. Identifying all available earthen construction techniques.
2. Sorting suitable earthen construction techniques in relevance to the study.
3. Determining the indicators required for the qualification of the techniques.
4. Analyzing and comparing the sorted earthen construction techniques based on the determined indicators.
5. Determine the best alternative to fired bricks based on the findings.

### *2.1. Construction Techniques*

The following earthen construction technologies have been practiced around the world in the course of over nine thousand years [5]-

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1. **Dug-out Earth:** The earth is excavated to create living quarters underground or on a hillside, forming a cave-like structure.
2. **Cut-blocks:** In regions where the soils are cohesive and contain concretions of carbonates - the soil is cut in the shape of blocks and used like bricks. The soft soil hardens when exposed to air due to a chemical process called 'induration.' Sometimes the soil had already hardened naturally over time, and then cut and used like stone blocks. Burkina Faso in Africa and Orissa in India has such earthen cut- blocks.
3. **Earth-bags:** Dry soil is poured into long plastic tubes, which are then stacked on top of each other. Cal-Earth (The California Institute of Earth Art and Architecture), an institute founded by the architect Nader Khalili - uses this technique extensively. Here, tubular rolls of sandbags are filled with soil to produce domical structures. Barbed wire is used in between the tubes to hold them together. The tubes are then plastered with stabilized earth plaster.
4. **Covered Earth:** Soil is used to cover roofs for insulation in various parts of the world.
5. **Rammed Earth:** Wet earth is poured in a formwork in thin layers and then rammed to increase its density.
6. **Compressed Earth Blocks (CEB):** The soil is slightly wetted, poured into a steel press and then compressed. Compressive strength and water resistance of these blocks can be improved with the addition of lime or concrete. After stabilizing them with concrete, the blocks have to be cured for four weeks. After which they can be used like common bricks.
7. **Shaped Earth:** Plastic earth is molded without formwork, similar to pottery- making. This technique is still being used in the Sahel (the belt between Sahara and Sudanian savanna) as well as in the equatorial regions.
8. **Stacked Earth (Cob):** Plastic soil is formed in balls and then stacked upon each other. This technique has been used in medieval Europe, and is still used in Africa, Saudi Arabia, India and Bangladesh.
9. **Adobe:** Adobe or Sun-dried clay brick, is one of the oldest building materials used by man. The earliest found Adobe structures were built over ten thousand years ago in Dja' De El Mughara in Syria.
10. **Extruded Earth:** Earth is stabilized with concrete and extruded through a machine to form a shape. The blocks are often hollow and are cut to the desired length.
11. **Wattle and Daub:** A lattice made of reeds and sticks is plastered with soil to create panels. These panels are then held together by a wooden frame.
12. **Straw Clay:** Clayey soil is poured over straw in a muddy consistency. Blocks are formed with the resulting mix, which are used for light, non-loadbearing partitions held together by a wooden frame.
13. **Poured Earth:** Soil is mixed with sand, gravel and water to form a concrete-like slurry and then is poured in a formwork. The mixture is often stabilized with cement.
14. **Projected Earth:** Muddy soil is sprayed with a high-pressure pump onto wooden or steel lattice. The earth here, much like poured earth – also require sand, gravel and cement to avoid shrinkage.

### *2.2. Selection of Construction Techniques for Study*

It is clear that there are many available earthen construction techniques. However, the purpose of this study is to determine the best alternative to kiln-bricks among them.

Dug-out Earth, indured Cut-blocks are too site-specific to be applied elsewhere. Earth-bags, Shaped Earth, Cob, Wattle and Daub, Straw Clay, Poured Earth and Projected Earth aren't suitable for most modern construction due to their lack of standardized properties such as compressive strength and water absorption rate. Covered Earth is simply a secondary roofing insulation. This leaves rammed earth, Adobe bricks, extruded earth and stabilized (CSEB) or non-stabilized (CEB) compressed earth blocks as contenders.

## 3. Methodology

The study is based on literature review, as very few local studies exist, even fewer have quantitative documentation. The paper uses general information from various reputed research practices.

The factors to be considered while examining preference of a particular construction system can be divided into two categories – qualitative and quantitative. Some of the factors however – such as economy and speed of construction may seem quantitative in nature if put in terms of cost per sft and hours per cft, but in reality, external factors make it qualitative in nature. For example – rammed earth construction can be economic to a company that has the expertise and the machines for it from a previous project, but introducing this technology in a new locality would cost several times over.

Even quantitative values such as dry and wet compressive strength, water permeability, average life cycle has a varying degree of results in various parts of the worlds – due to variation in soil composition and techniques. These data therefore have to be presented in ranges and then compared as an average of the variation.

Therefore, the indicators to be discussed are –

1. Qualitative -
   a. Economy
   b. Speed and ease of construction
   c. Aesthetic value and public image.
2. Quantitative -
   a. Compressive strength
   b. Water absorption
   c. Durability against weather conditions

### *3.1. Comparative Discussion*

#### *A. Economy*

Economy in construction system in earthen concerns not only cost of installation, but the cost of infrastructure, equipment, training, labor, maintenance etc. Common costs, such as cost of procurement of good quality soil – need not to be discussed.

Traditional rammed earth construction is slow, labor-intensive and forms cracks at edges. However, modern construction involves using steel formwork, pneumatic rammers and stabilizing agents that takes care of it all. But the new equipment and chemicals increase cost significantly - and requires a high degree of expertise in both production and installation. Actual production costs cannot be compared due to the fact that no example of modern rammed earth construction exists in this part of the world and labor and consultancy costs vary wildly here from the west. Few examples of traditional rammed earth construction exist – a technique which has become virtually obsolete.

Extruded earth construction can be characterized as machine-made hollow sun-dried bricks. But the machines used for the process erode rapidly, due the abrasive nature of the high sand content required [5] – rendering it economically impractical.

Non-stabilized compressed earth blocks (CEB)are quite cheap both in production and installation, whereas stabilized compressed earth blocks (SCEB)are relatively more expensive. This is due to the added cost of stabilizers such as cement or lime and its longer production process. But once the blocks are produced, installation is similar to traditional masonry construction.

#### *B. Ease and Speed of Construction*

Modern rammed earth construction can be as fast as or even faster than brick masonry construction using state-of-the-art methods, but requires use of specialized equipment and advanced training, which leads to specialization – a factor that creates high quality output but renders universal availability impossible.

Both extruded earth and CEB has the same speed of construction as a masonry wall and requires no additional training for masons. But both has to be cured for up to four weeks, which is considerably longer than production of kiln-bricks [5,6].

#### *C. Aesthetic Value and Public Image*

Architects have loved traditional clay bricks for thousands of years. It comes in varying sizes and colors, glazed or unglazed and can be given numerous textures. It's flexibility as a module allows an immense variety in form-making as well.

Rammed earth has an exotic tactile quality to it when kept exposed but is limited in terms of form- making. Vaults, arches, corbelled or fluid forms and perforated screens are either difficult or impossible to produce in this method.

CEB, SCEB and extruded earth blocks can be used similarly as brick construction – but due to their lower compressive strength its scale and scope is limited. None can compete with the variety of colors and tactile quality of bricks, as the color of earth blocks depend heavily on the color of the soil - which in turn is dependent of its context. Only SCEB, made with a silt of high iron-oxide content, comes close to the strength, flexibility and tactile quality of modern gas burned red bricks [7], but still fails in terms of variety in color and texture. It also cannot be used as aggregate for RCC construction or for brick soling, paving and road construction – which accounts for a major portion of brick uses.

Public image; however, is even more challenging. General consensus currently does not accept any earthen construction as 'standard.' Even Auroville Earth Institute, an institution dedicated to research on earthen construction technologies, forbids using terms such as 'mud blocks' while describing SCEBs due to the negative image it provokes. It falls under a vicious cycle – if only a large number of good earthen construction is made, the consensus will change, the very consensus which prevents construction in such a scale. It seems convincing the government to adopt such techniques could be the answer.

#### *a. Compressive Strength:*

The following data may vary if compared to other sources due to a variety of technique & composition –

**Table. 1**. Compressive strength of various earthen medias, higher is better [7,8,9,10,11,12]

| No | Construction Technique | Dry Compressive Strength |
|---|---|---|
| 1 | Rammed Earth (Stabilized) | 1.48-2.45MPa |
| 2 | CEB | 2-3 MPa |
| 3 | CSEB | 3-7 MPa |
| 4 | Adobe | 0.25-1.25 MPa |
| 5 | Extruded Earth | 3.5 MPa |
| 6 | Brick | 10.3-24 MPa |

The data reveals that CSEB is strongest among these earthen construction techniques, but still falls behind brick.

#### *b. Water Absorption*

The following data may vary if compared to other sources due to a variety of technique & composition-

**Table. 2.** Water Absorption of Various Medias, lower is better [7,11,12,13,14]

| No | Construction Technique | Water Absorption (Percentage in Weight) |
|---|---|---|
| 1 | Rammed Earth (Stabilized) | 13-17% |
| 2 | CEB | Up to16% |
| 3 | CSEB | 8– 15% |
| 4 | Adobe | Up to 23% |
| 5 | Brick | 10-20% |

#### *c. Durability against Weather Conditions*

Without the use of stabilizing agents, raw earth performs very poorly against rainfall. Not only water reduces its compressive strength, but the continuous process of wetting and drying that occurs throughout the year slowly erodes it until its completely destroyed.

Adobe, Compressed Earth Block, extruded earth, Rammed Earth all perform poorly if not stabilized with cement, lime, manure, rice etc. with cement being the most effective for water-resistance [15]. Once stabilized, however – all except extruded earth perform fairly well, with CSEB coming up slightly better.

### *3.2. Limitations*

There is a distinct lack of practical comparative study on various earthen techniques in a particular region. Due to this, the data cannot account for multiple variables such as difference in regional soil composition and manufacturing practices. More research is needed in this field.

## 4. Findings

Along the shortlisted techniques, Rammed earth requires training and specialized equipment in all new sites – making it impractical to adapt widely. Extruded earth suffers from the inconvenience in terms of cost-effectiveness, due to the fact that its production machine has a very small life cycle. Adobe and Compressed Earth Block is similar in nature if left un-stabilized – is brittle and has low durability against rain [15,16].

Considering all of these factors, it appears that stabilized compressed earth block (SCEB) is the most suitable alternative to kiln-bricks when compared to other earthen construction technologies currently available. It is strong, durable, water resistant and appears almost identical to fired bricks.

But it can only suitable to be used as partition, as it cannot replace brick use as an aggregate in Reinforced concrete construction (RCC), or for paving and brick soling. Natural stone aggregates and concrete blocks can be a more sustainable alternative in these scenarios.

## 5. Conclusion

SCEB is not without its limitation. It requires a full 30 days to produce[7], is heavier than bricks and cannot be made into various colors and textures as fired bricks. The biggest challenge, however, is the fact that there appears to be no incentive for brick producers to switch to CSEB.

In Bangladesh, 60% of all bricks produced is used by the government – mostly for infrastructure purposes [4]. Fortunately, the government has decided to phase out clay bricks in public construction by 2025 [17]. Currently, the alternative chosen is concrete blocks, which poses its own environmental concerns due to its high carbon footprint for production. Earthen construction can be a more sustainable option in some cases.

Bangladesh has a long tradition of earthen construction. Advent of modernism and globalization has made it scarce – which in effect has bought upon an era of unsustainable growth and a loss of identity. In remembrance of the past and in consideration of the future – the practice of earthen construction demands a revival.

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