International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Contemporizing Earthen Architecture: A Futuristic and Sustainable Approach

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'Earth' as a building material has a circular material flow & resource salvation Building with the earth today remains a do–it–yourself technique

Abstract
Utmost metropolises and municipalities in developing countries are passing a massive migration of population from pastoral areas. The maturity of the pastoral population migrates to civic areas hoping to find a job and an advanced income for their survival. This large affluence creates a high demand for civic casing and structure, which the maturity of the settlers cannot go. also, the inadequate use of low-cost traditional structure accoutrements and construction ways in domestic construction has redounded in precious casing stock for the maturity of the poor. That's thus a critical need to assess indispensable structure accoutrements and ways that are both affordable and sustainable. Stabilized earth is an indispensable structure material that's significantly cheaper than using conventional slipup and concrete, and is also environmentally sustainable. Earth has been used as a construction material on a global position since age.

Earth as the building material gives a lot of potential possibilities & alternative solutions, not only to the architects or the environment-conscious planners & designers, but it will encourage & respect the volunteers of commonality & make them blend towards the field of rethinking sustainable practices with their quality of living & even pave ways for skillful labors in the mainstream of the construction industry.

The objective of the study is to understand the potential of the 'Earth' as the building material & trace its evolution of construction techniques since the ages by analyzing the ecological aspect, challenges & thermal performance of Earthen Architecture to explore innovative construction techniques in the current context & future trends

Professionally architects do have the power – we must take a lead & be actively critical & analytical about the materials we choose for the design of our buildings. But innovation towards more circular material flow is already out there. We simply need to be bold enough to understand & test their potential & put them into the field of sustainable practice – the alternative & the affordable solution just lies beneath our feet – 'the Earth'.

This study is limited to the detailed understanding of building physics revolving around the Rammed Earth |RE| construction & CSEB |Compressed Stabilized Earth Block| used in the mainstream of sustainable building construction.

Keywords: Sustainable, Earth Architecture

1.0. INTRODUCTION

As a building material, EARTH is referred to by the scientific term called Loam, which has a mixture of clay, and silt (fine sand) & also occasionally consists of larger aggregates, such as gravel or stone.

Earth is one of the oldest building materials known to mankind. Earthen architecture can be defined as a building where the main constructional material is unfired earth Loadbearing walls, in the filling of walls, roof structures, roof finishes, and furniture can be constructed from the earth. It is a versatile material with many construction techniques that range from mudbrick (adobe), rammed earth, wattle-and-daub, cob walls, etc...

Handmade unbaked brick - mud bricks or adobe is the technical term used.

Compressed unbaked blocks - soil block or earth blocks is the technical term used.

Compacted with formwork - rammed earth is the technical term used in existence.

Over the centuries, many building technologies that use the earth have been developed in various regions of the world. Their variety results, among other factors, from the type of land and climate conditions prevailing in the area. Construction techniques using earth can be divided into three main categories:

1. Technique that uses earth in load-bearing monolithic constructions.
2. Techniques that use earth in load-bearing masonry structures.
3. Techniques that use earth as a non-bearing construction material in combination with a supporting structure of another material.

Today, it is well known for its good environmental properties of recyclability and low embodied energy along the production process.

If ‘Earth’ as a building material meets the requirements of a sustainable building…How its primitive techniques can be grouped & guide contemporary architecture? & ‘Buildings with natural materials are designed to be placed in the countryside, …why earthen architecture is not evident within the urban development.

Construction system: strength/deformation characteristics, aspect ratio, sound and fire performance, thermal characteristics, earthquake resistance

Fig: 1.0. Cradle-to-Cradle life cycle diagram of the earth as a building material

Pic source: *Ben-Alon w.r.t. H. Schroeder, Bauhaus University Weimar, Germany (2016)*

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PROPERTIES OF EARTH AS A BUILDING MATERIAL

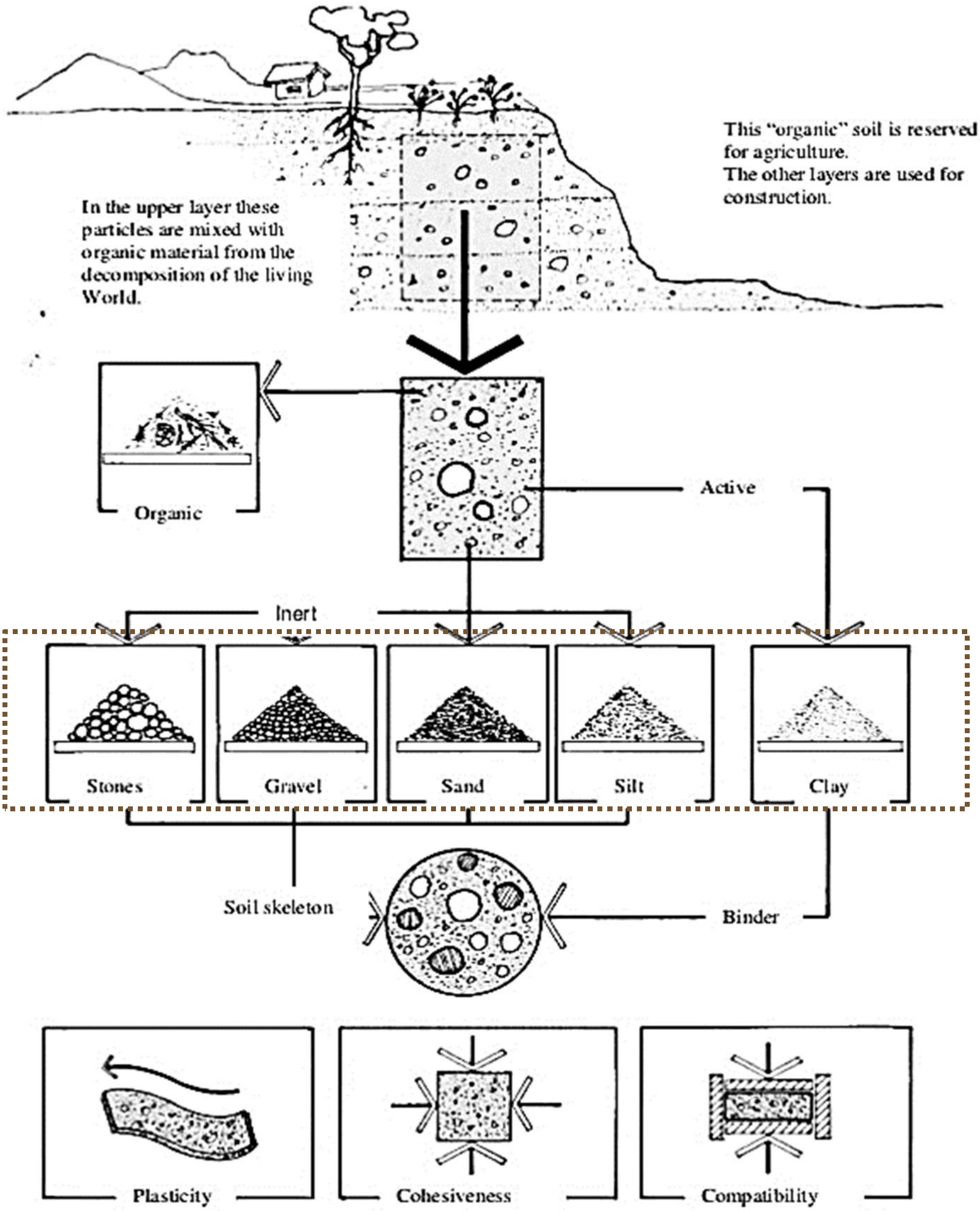

Fig: 2.0. The composition & constituents of the soil & their physical properties

Pic source: *https://ukdiss.com/examples/innovative-traditional-earth-materials-and-techniques.php*

The deterioration of earth structures is substantially due to loss, cracking, corrosion, emphasizing, and mechanical damage, the fact is it's due to direct or circular water (Hammond, 1973).

- The earthen structures successfully last for decades in nearly all types of regions and climates and also with proper care and conservation when it’s done with suitable architectural design, structural ways, and proper stabilization measures and care in sitting.
- For all types of earth construction, the important parcels are compressive strength, water immersion, and rainfall resistance.
- When compared to the numerous generally used contemporary structure accoutrements the product and construction of earth accoutrements don't have any health hazards and beget no pollution

2.0. POTENTIAL OF EARTH AS A SUSTAINABLE BUILDING MATERIAL

The term *“Carbon Footprint”* is essentially describing how much carbon is being emitted by a certain object, action, or group. It is important to keep in mind that it is also measured as a competing component to *“Ecological Footprint”*.

Being innovative and creating *sustainable building goals* is an essential part of the construction industry. The choice of materials we choose to utilize in erecting our future buildings plays a huge factor in how it plays its role in saving our environment.

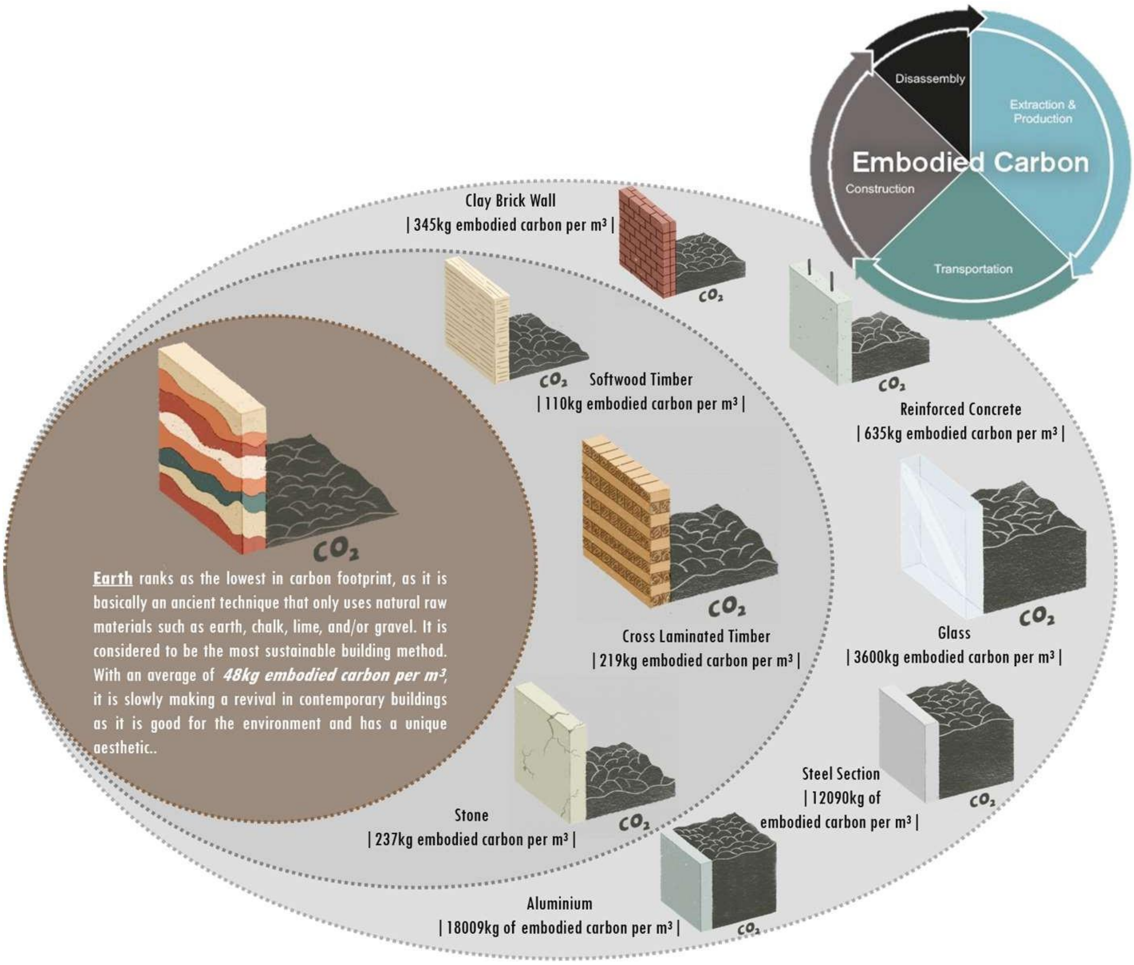

Fig: 3.0. The comparison of the carbon footprints of earthen materials to the other conventional materials

3.0. USE OF EARTH AS A MODERN BUILDING MATERIAL

The incarnation of earth as a material depends upon the kind of soil available in the region as its characteristics vary from place to place and the characteristics of available supporting accoutrements and technologies used. Some of the common uses of earth as a structure material are Adobe or Sun- dried bricks, Cob, Rammed earth, Pressed slipup, Wattle & daub, etc.

3.1 Adobe

It's a natural list material made by mixing earth with water, and some kind of stringy material like thatch, straw, and ordure. This admixture is also filled in molds. After they set are left exposed in the sun to get dry. structures made with adobe are analogous to cob and slush slipup structures. The structures made by Adobe are durable. Some of the oldest being structures are entirely made by using adobe blocks. In countries like India and West African regions, adobe construction is effective in terms of thermal sequestration due to their lesser thermal mass than that of rustic structures which are extensively used in Western countries. still, the major debit regarding adobe construction is they're veritably susceptible to earthquakes. Adobe blocks are common in practice in West Asia, Northern Africa, West Africa, South America, Spain, Eastern Europe, and East Anglia.

3.2 Rammed earth

It's a kind of unbaked earthen development used to fabricate walls by their different operations in the establishments of bottoms, and rooftops. Also, presently days have been employed for cabinetwork, theater doodads, and different rudiments. Loose soil mixed with chalk, lime, beach, and clay is filled in temporary formwork and compacted by the means of homemade or curvaceous rammer layers by layers (100 to 150 mm deep). After the admixture gets settled well the formwork is removed.

The distinctive layers can be seen in this kind of construction adding different color dies can affect in intriguing patterns on the walls.

This ramming of soil or mud technique is mostly used by all since ancient times & many developing regions continue to follow the traditional rammed earth techniques. For both ecological & economic reasons, mechanized rammed earth is preferred over conventional masonry in many places.

Rammed earth provides a much lesser shrinkage ratio & higher strength than other wet earth techniques & thus has a longer life span than adobe masonry. Rammed earth is the outer skin of a building & has a monolithic appearance with a high thickness ranging from 280 mm to 600 mm, generally involved in exterior wall constructions. The people prefer to leave the natural earthen shade of the building or might add natural pigmentation to the rammed mud to give a variety of colored finishes. Rammed earth walls control humidity, are fire resistant, act as a shield from harsh weather, store heat also resist pests & provide insulation & have seismic protection.

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Fig: 4.0. RE – historical context of the Great Wall & Mud skyscraper

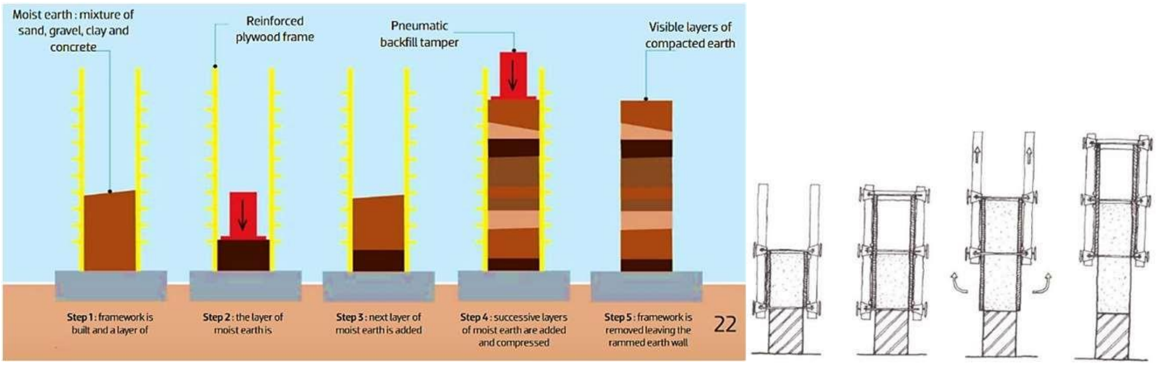

Fig: 5.0. The vertical direction of Rammed Earth formwork & steps involved in ramming

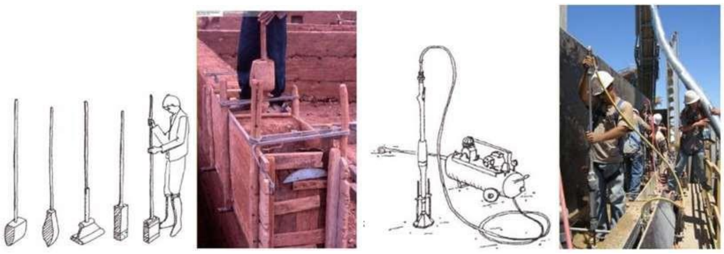

Fig: 6.0. The ramming process with the manual & the pneumatic rammers

The ramming can be accomplished manually or mechanically, that is specially shaped with long handles & a rammer has heavy heads of wood or metal to perform various forms, shapes & corners. The control of soil moisture during compaction & subsequent drying is essential in the RE construction technique

Rammed earth - foundation:

- The rammed earth walls are typically built on shallow strip footings or stiffened ground slabs & the walls are generally built on raised plinths.
- The damp proofing – 150 mm above G.L. should be able to withstand the impact of compactions & shrinkage without any damage.
- Footings are concrete.
- The ground immediately adjacent to the base of the rammed earth wall should be well drained & footings protected from water infiltration.

3.3. Compressed Stabilized Earth Blocks |CSEB|

- The first attempts at compressed earth blocks were tried in the early days of the 19th century in Europe. The architect François Cointereaux precast small blocks of rammed earth and he used hand rammers to compress the humid soil into a small wooden mold held with the feet.
- The first steel manual press which has been produced in the world in the 1950s was the Cinvaram, to improve the hand molded & sun-dried brick (adobe). This press could get regular blocks in shape and size, denser, stronger, and more water resistant than the common adobe.
- Many countries in Africa as well as South America, India, and South Asia have been using a lot this technique.
- The soil, raw or stabilized, for a compressed earth block (CEB) is slightly moistened, poured into a steel press (with or without stabilizer), and then compressed either with a manual or motorized press.
- CEB can be compressed in many different shapes and sizes. For example, the Auram press 3000 proposes 17 types of blocks.
- Compressed earth blocks can be stabilized or not. But most of the time, they are stabilized with cement or lime. Therefore, we prefer today to call them Compressed Stabilised Earth Blocks ***(CSEB)***

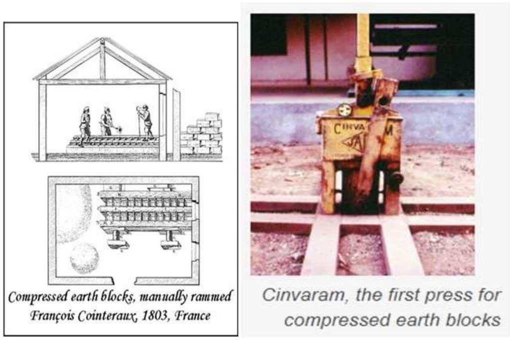

Fig: 7.0. Modern adobe technique |CSEB|

Pic source: *http://appymango.blogspot.com/2012/10/stablized-mud-blocks.html*

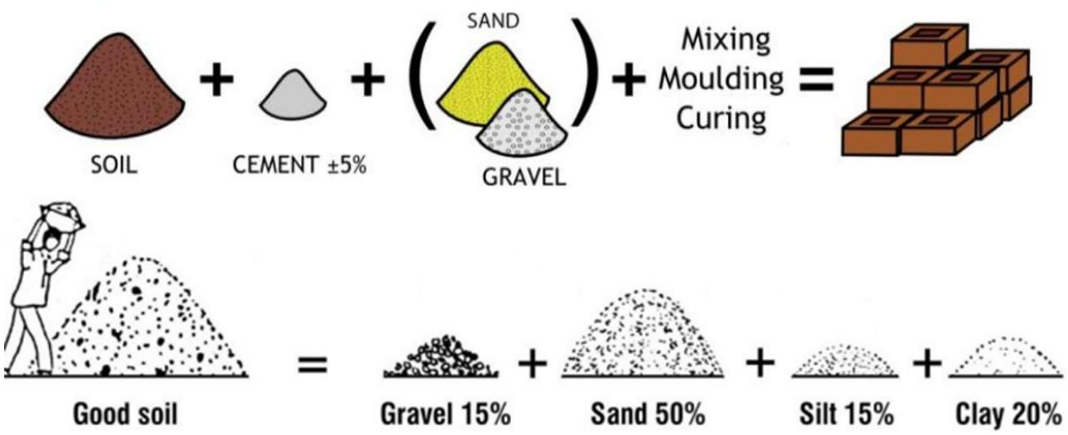

Fig: 8.0. The making process of the CSEB blocks

INITIAL EMBODIED ENERGY PER M^3 OF WALL	POLLUTION EMISSION (Kg of CO_2) PER M^3 OF WALL
CSEB wall = 582 MJ / m^3 Kiln Fired Brick (KFB) = 2,935 MJ / m^3 Country Fired Brick (CFB) = 5,090 MJ / m^3	CSEB wall = 57.1 Kg / m^3 Kiln Fired Brick (KFB) = 287.6 Kg / m^3 Country Fired Brick (CFB) = 498.8 Kg / m^3

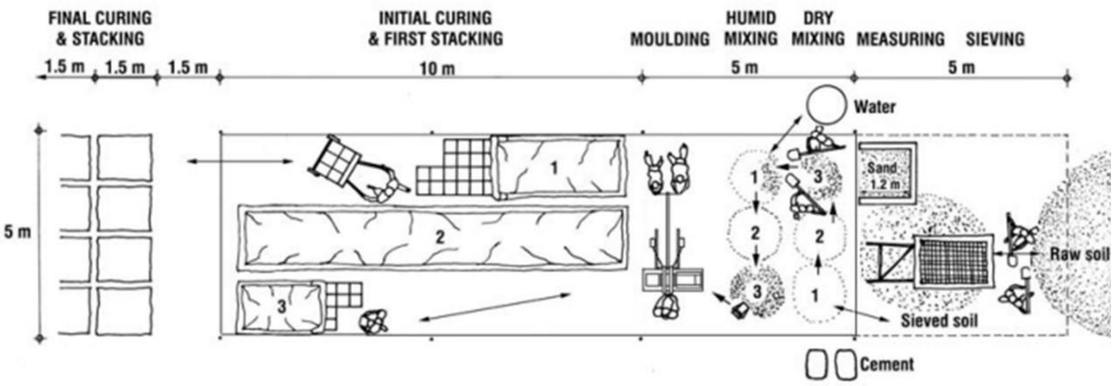

Table 1.1. Sustainability and environmental friendliness of CSEB

CSEB is environment-friendly as;

- No firing is required, but only curing **(4 weeks or 28 days approx. with cement stabilization).**
- **Less transportation** is required and production is manual.
- CSEB 7.9 times less energy than the country-fried bricks & 3.9 times less energy than the kiln-fired bricks on the Indian average.
- *Not every soil is suitable for earth construction and CSEB in particular. However, with some knowledge and experience, many soils can be used for producing CSEB.*
- *Topsoil and organic soils must not be used.*
- *Identifying the properties of soil is essential to perform, in the end, good quality products, Some simple sensitive analyses can be performed after a short training.*
- *Cement stabilization will be better for sandy soils and lime stabilization will be better suited for clayey soil condition*

Initial embodied energy (MJ/m^3 of materials)	Carbon emission (Kg of CO2 /m^3 of materials)
CSEB are consuming 4 times less energy than country fired bricks: CSEB produced on site with 5 % cement = 1,112.36 MJ/m^3 Country fired bricks = 4,501.25 MJ/m^3	**CSEB are polluting 4 times less than country fired bricks:** CSEB produced on site with 5 % cement = 110.11 Kg of CO2 /m^3 Country fired bricks = 444.12 Kg of CO2 /m^3

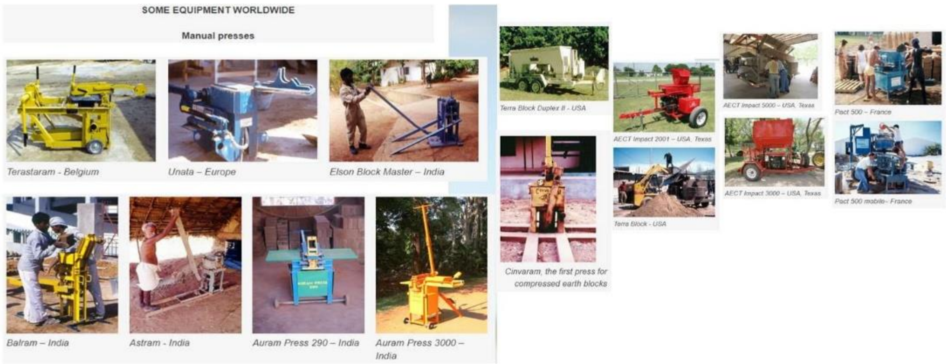

Fig: 9.0. The manual press of the CSEB blocks worldwide

4.0. COMPARATIVE ANALYSIS OF EARTH CONSTRUCTION WITH MAINSTREAM CONSTRUCTION INDUSTRY

Unlike other conventional materials, building with earth has disadvantages amongst many of its advantages in the mainstream construction industry & those three statements include:

1. **Earth - not a standardized building material**
2. **Earth - the mixtures might shrink when dried**
3. **Earth - as a material is not water-resistant**

Despite all the above earth balances the air humidity, stores the heat, saves energy & reduces pollution, is always reusable, saves the material & transportation costs, preserves organic materials, absorbs pollutants & is ideal for do–it–yourself construction.

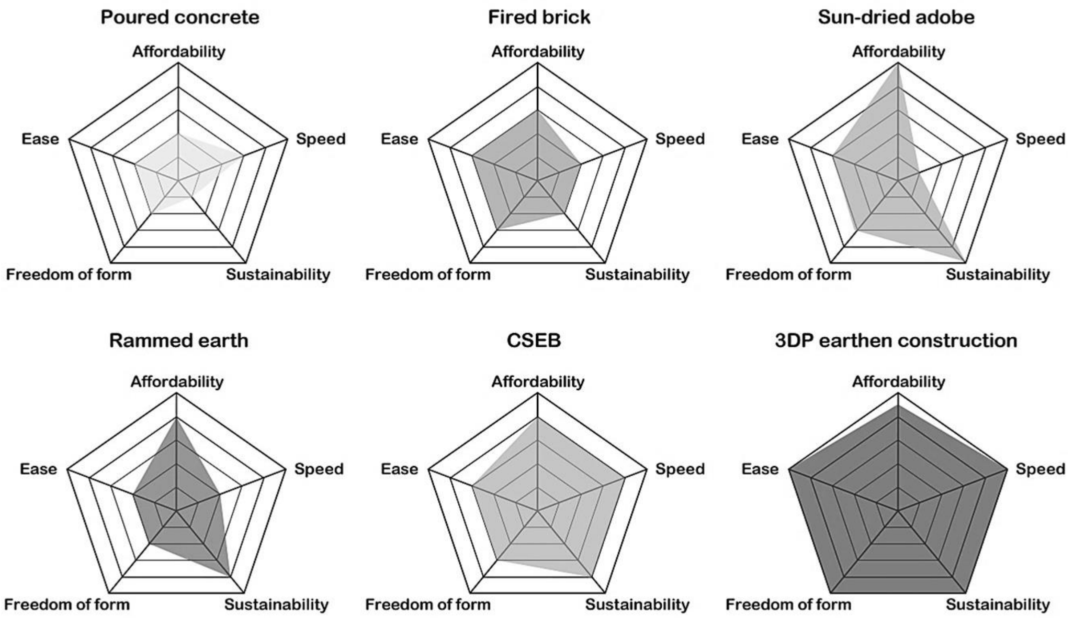

Fig: 10.0. Spider graphs showing a comparison of the five most important factors in any identical project for different construction methods of long-term building

Pic source: 3-D Printed Earthen Architecture by Paul Russell

The PEI (Primary Energy Impact) is a criterion commonly used to ascertain a rough estimation of the ecological balance of building material, allowing one to compare the energy efficiency of production processes in terms of 'embodied' energy. In the case of earth building materials, the PEI is a favorable parameter because it is extremely low: comparing the PEI of the earth with that of typical building materials such as concrete, reinforced concrete or steel exhibits a clear & significant difference.

- This is a further reason why the use of earth for construction purposes has become increasingly significant in many countries, and this new development is also reflected by a rising number of earth-building standards.
- Earthen materials help to regulate and filter the interior room climate.

Building material	PEI (kWh/m^3)
Earth	0–30
Straw insulation panels	5
Timber, home	300
Timber materials	800–1,500
Fired bricks	500–900
Cement	1700
Concrete, 'normal'	450–500
Lime sandstone	350
Glass panes	15,000
Steel	63,000
Aluminium	195,000
Polyethylene (PE)	7600–13,100
Polyvinylchloride (PVC)	13,000

Table: 3.1. PEI of typical building materials compared with earth building materials

Dry density ρ_d [kg/m^3]	Thermal conductivity λ [W/mK]	Earth building materials
2,200	1.40	RE
2,000	1.10	RE
1,800	0.91	RE, EM, CP
1,600	0.73	C, EI, EM, EB, CP
1,400	0.59	C, EI, EM, EB, CP
1,200	0.47	LC, EI, EM, EB, CP
1,000	0.35	LC, EI, EM, EB, CP
900	0.30	LC, EI, EM, EB, CP
800	0.25	LC, EI, EM, EB, CP
700	0.21	LC, EI, EM, EB, CP
600	0.17	LC, EI, EM, EB, CP
500	0.14	LC, EI, CP
400	0.12	LC, EI, CP
300	0.10	LC, EI, CP

Earth building materials in comparison to: polyurethane, 0.02 W/mK, aluminium, 200 W/mK.

Table: 4.1. Thermal conductivity values for the earthen building materials

Pic source: L Ben-Alon et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 323 012139

The comparison between the earth building techniques |RE| & conventional building techniques, their better performances based on thermal conductivity, tensile, compressive & shear strength |BUILDING PHYSICS|.

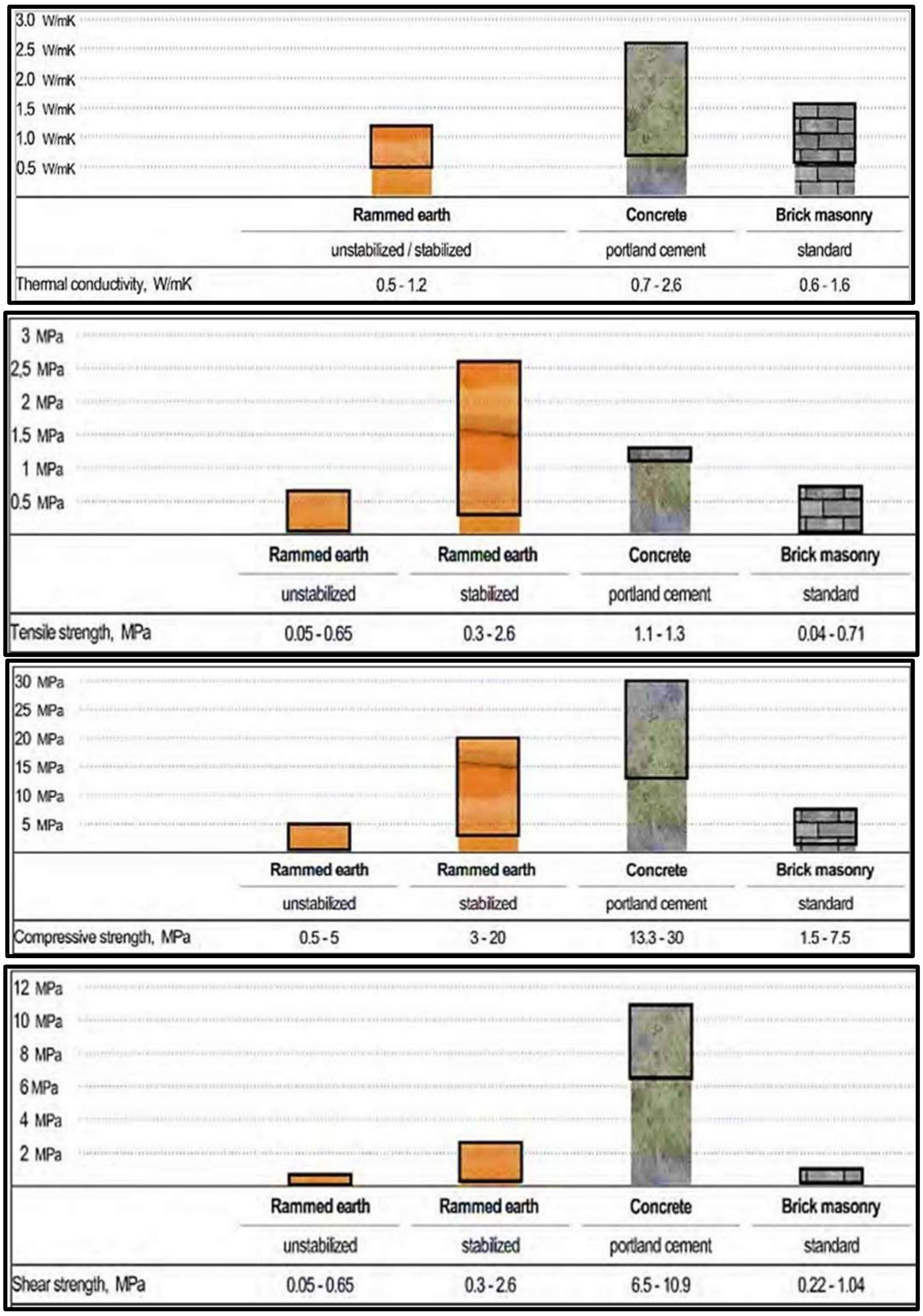

Fig: 11.0. The earth material being compared to other conventional materials

5.0. DISCUSSION & CONCLUSION

From the above find out about and assessment of the earthen architecture, we can conclude how useful Earth can be in conceiving sustainability thinking about its a number factors and how vital it is to introduce some of these strategies to frequent residents to obtain a sustainable surroundings in cutting-edge times. Following are some of the inferences made thru our study:

1. As 'earth' is ecofriendly in nature it can make a contribution to sustainable architecture.

2. Considering the current component of architecture, the modern methods developed for the development of earthen structures must be delivered to the frequent public via applicable and formal talent training.
3. As it is primarily based on the nearby availability of substances and sources it additionally helps aid the neighborhood economy.
4. Promoting earth structure will be extraordinarily useful in growing low-priced and less expensive housing for low
5. income team and economically weaker section.
6. Professionals like architects and engineers ought to promote these development strategies and substances to keep ecology and the environment.

Despite their many advantages & technical advancements, they still have not been implemented broadly in the construction mainstream & also been rejected in large-scale urban-level projects, be it particular low-cost residential prototypes or the community that completely focuses on the goals of sustainability & affordability, even several projects of the schools & other institutional buildings, might probably be evident in public gathering buildings too, all these typologies amidst the urban region can be perfect for the experts to spread the knowledge on the revival or reinvention of the earth based construction techniques to the public.

The study also speaks about the quality of life & choice - based living inside the earthen building where it maintains a comfortable temperature tackles the external harsh weather factors in geographical extremes & is a disaster-proof structure, also maintains healthy indoor environmental quality & has a lower environmental impact proving the material and technique in the circular economy.
It is evident from the above literature assessment that the financial advantages of affordable earth building in growing nations are radically based onthe value of components that are used to manufacture the constructing units, and that of transportation of uncooked substances or completed merchandise to the building site. Further, there is a power value related with the manufacturing of anything, and this can furnish an approximate usual measure of environmental impact. Building with earth is viewed as a splendid and value and energy-effective technology. However, one has to apprehend the fabric and grasp its disadvantages, which generally are structured on the soil quality, and which, negatively, can adversely have an effect on the block quality, motive shrinkage cracks, and decrease wall power in contrast with remarkable fired bricks or concrete.

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