MUD ARCHITECTURE PRACTICES IN INDIA AND IT'S USE FOR PASSIVE COOLING AND HEAT INSULATION

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ABSTRACT

Mud is one of the oldest building materials which has been used for thousands of years. Unlike bricks or other construction materials which need huge amounts of energy to be manufactured, mud is directly available in nature and is ready to be used for construction making it ecofriendly. Unlike the false notions which present day people carry mud is a durable and long lasting material and structures constructed using this material last for more than a century. Therefore I am going to explore all the possibilities for the use of mud in building construction as a building construction material . In my study I will emphasize the use of mud as a mud wall and How can we strengthen the mud wall by using different material with mud as a mixing element. How can we strengthen the mud wall in context of compressive strength. And how it works as a heat insulator.

KEYWORDS: Mud Walls, Mud Architecture, Passive Cooling, Heat Insulators, Passive Cooling Technologies

Manufacture of building materials consumes huge amounts of energy and at the current rate of energy consumption we will soon run out of fossil fuels. Present day constructions use reinforced concrete, cement blocks, burnt bricks etc. But we tragically don't realize the amount of energy they consume to be manufactured. An ordinary middle class house made of brick needs two or three trees to be chopped to fire up the bricks. Other building materials like concrete consume further more energy to be manufactured. Natural materials like stone are not available in all parts of the country, they need to be transported over large distances again consuming energy and money. Further more, tremendous amounts of energy is spent in quarrying.

Mud is a soft sticky matter resulting from mixing of earth and water, it is available almost anywhere and does not need to be manufactured. One doesn't need to spend enormous amounts of energy and money on manufacture and transportation as it is available on the site itself and can be constructed by the residents themselves.

Although mud by itself cannot be used to construct a strong and durable house it can be stabilized by mixing it with various other materials to create a material that is strong enough to stay stable for over a hundred years. Archeological excavations reveal mud buildings that are over a thousand years old.

Many rural families and many of the poorer people still build with mud but official or government housing schemes rarely use it and our growing middle class also rarely uses it. One of the main reasons behind this is because people are class conscious and people assume mud to be a material used by the poor. Although mud may be old fashioned it has been used for thousands of years and could be used to make one of the best houses.

Poverty in India is another major issue of concern, many people both in the rural and urban areas have no shelter above their heads, if used wisely mud can be used to provide homes for millions of people who sleep on the streets and eradicate slums.

AIM

Through this study I seek to explore mud as a building material, understand the construction techniques and expound the same through illustrations.

OBJECTIVES

- To provide a basic understanding of what mud is and expounds reasons to use it for wall building.
- To understand the properties of mud as a building material.
- To explore the drawbacks of mud architecture and expound ways to curtail the same.
- To identify various techniques of construction with mud.
- To illustrate mud construction techniques.

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METHODOLOGY

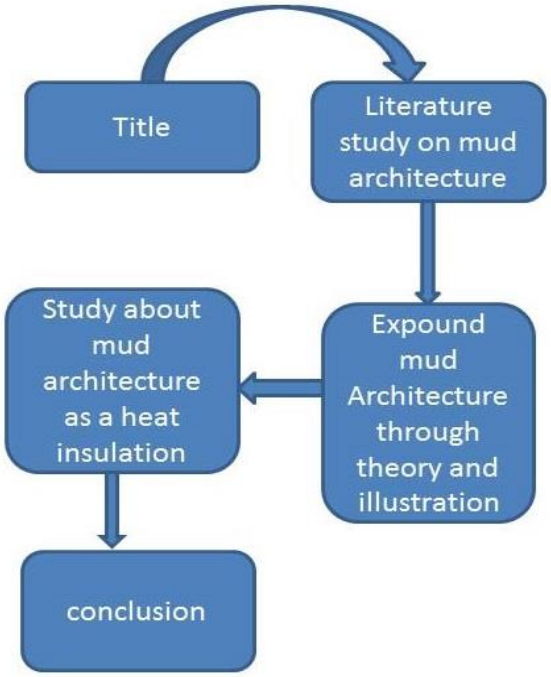

Figure 1: Methodology Chart

LITERATURE STUDY ON MUD ARCHITECTURE

What Is A Good Building Soil And Where Can We Find It?

Soil a mixture of sand, silt, clay, gravel and a small proportion of water. The proportion of the aforementioned constituents plays a major role in deciding weather the soil is good for construction or not.

We thus observed the characteristics of a few constituents of soil. Through years it has been observed that soil with a proportion of 5%-15% clay, 65%-75% sand and 20% silt is perfect for mud house construction. Usually the topsoil which we find right beneath our feet consists of organic matter as mentioned earlier in this chapter, the presence of organic matter makes the soil good for plant growth but it is not ideal for building walls. But if we dig deeper we can observe that the characteristic properties of soil vary with depth, at a certain depth we no longer find organic matter, this layer of soil which lies beneath the top soil is called sub soil.

Figure 2: Perfect Building Mud comprises of 6-755% sand, 20% silt and 5- 15% clay

Soil Tests For Determining The Perfect Building MUD

As we have studied the characteristics of various constituents of soil and how their proportion can affect the suitability of the soil for construction, we know look at a few tests which can help us determine if the soil we have beneath our feet is suitable for construction.

The Cigar Test

For this test we pick a handful of mud and mould it into a cigar or a sausage shape by rolling it, it must be noted that the soil must have just enough water content to enable it to stick together. Once we have a cigar shaped piece of soil, we squeeze the end of the cigar until the thickness of the cigar is about a quarter of an inch, we continue the process of squeezing and note how long it takes for it to break off and fall to the ground.

- If it is too sandy with very little or no clay content it would just fall to pieces and cannot be shaped or pushed. This type of soil would need a stabilizer to

make it usable or would require one to add clay and mix it with this soil.

- If the soil has an excess amount of clay we can go on squeezing it out until it is eight or nine inches long. Such a soil is again not ideal for wall construction as it wil have cracking or shrinking problems.
- The soil can be identified as an ideal building soil if we can squeeze it about two or three inches before it drops off.

As gravel does not stick together we naturally cannot make a cigar out of it, organic soils similarly are no use for building work and thus any tests with such a soil is in vain.

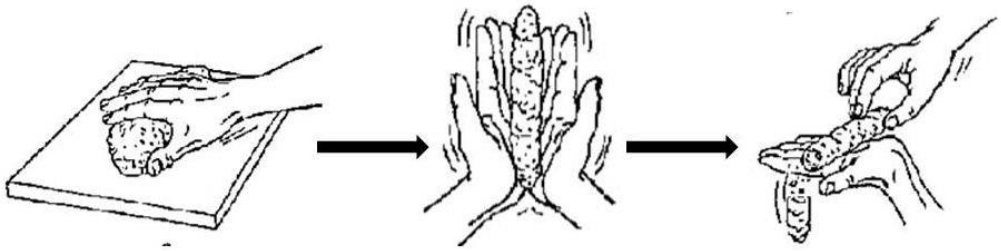

Figure 3: Cigar Test

The Biscuit Test

For conducting this test we need to make a small flat biscuit with about ¼" thickness and 2" diameter with a suitably moistened soil and dry it thoroughly in the sun.

- If it consists of excess sand it would crumble to pieces and can hardly be picked up once it is dry. Such a soil would need stabilizers or should be mixed with a suitable amount of clay to make it ideal for construction.
- If the biscuit is hard to break, or if it breaks with snap like an over baked biscuit and it cannot be powdered it has excess clay content. Thus it would require stabilizers to make it suitable for wall building, or would require one to add a suitable amount of sand to it.
- If it can be broken into pieces with the application of some pressure but without much difficulty, it can be identified as a good wall building mud.

Figure 4- Biscuit test

The Hand Washing Test

This test would require us to spend some time with our hands in the moistened soil until they are thoroughly dirty. We then note the effort we need to put into washing our hands clean to determine the suitability of the soil for wall building.

- If we are quickly clean with no effort it means that we were playing with loose sand, which is not suitable for wall building by itself.

- If it is difficult to get rid of it and we need to use a soap and our hands are slippery the soil has excess clay content and thus needs sand or a suitable stabilizer to make it ideal for wall building.
- If it takes a little time for us to get clean and it feels like we are getting rid flour accompanied with a powdery feel, then the soil is silty and would be ideal for wall building with the addition of a suitable stabilizer.

Figure 5- Hand washing test

Stabilisers

Stabilizers used in rural areas are usually locally available materials or waste products, thus one need not spend as much money, time or energy in implementing these techniques.

Straw

This stabilizer doesn't have any specific chemical characteristics, but it helps in minimizing cracks and the presence of straw in blocks tends to make the damp blocks more handlable. Chaff and various other fibres could be used similarly. It is widely used for stabilizing mud used for cob wall construction. The addition of this stabilizer adds tensile strength to the mud.

Figure 6- Straw

Cow Dung

It often consists of fibrous components and helps in imparting tensile strength. Further it is easily available in rural areas and can be used for all sorts of mud work.

Sugar and Molasses

The crude waste jaggery is a binder and it contains fibrous materials which inundate the mud with tensile strength.

Figure 7- Cow dung

Figure 8- Sugar and molasses

OIL

Oil when used as a stabilizer imparts the mud with a water proofing quality.

Coconut oil is used in Kerala. Almost any oil can be used for this purpose, waste engine oil or sump oil are used as a modern counterpart.

Figure 9- oil

Plant Juices

A sticky white sap can be found in most plants, like poinsettias, various cactus plants, sisal and so on. This white sap acts both as a binder and imparts a water proofing quality when mixed in mud, but this sap doesn't mix with water making it difficult to mix with mud, some local techniques in rural areas provide suitable answers for this problem.

Quite often the most effective stabilizer for soil is soil itself. Clay can be added to the soil if it consists of excess sand and similarly sand can be added to the soil if it consists of excess clay. In most parts of India the soils or mixture of soils as we find them are satisfactory and are ideal for construction without the use of any aditional stabilizers.

Figure 10- Plant juice

Source- https://www.naturalhealers.com/wp-content/uploads/2016/10/aloelatex.jpg)

Various Technoques Employed for Construction with Mud as a Material

COB

It is the simplest and oldest mud construction technique which has been employed for thousands of years and is still in use to date. The oldest cob house has been found in an archaeological excavation in Jerusalem which is a stunning 10,000 years old.

Cob is basically subsoil mixed with straw, it is moulded in the form of an elongated egg, usually 12 to 18 inches long and about 6 inches in diameter. Three parts of sand, one part of clay and one part of straw would make the ideal cob needed for costruction. Straw inundates tensile strenght to the cob. Lime could be addded for imparting extra strength to the cob.

Figure 11: Cob is a combination of three parts sand, one part clay and one part straw.

Figure 12: Cob can be used to make buildings upto two stories in height like the cob home we see above. Source- (https://tinyhousetalk.com/incredible-cob-house-tour-2-story-cob-cottage-originally-built-in-1999/)

COB Wall Construction

- A row of these cobs of mud are laid neatly side by side – preferably some what pressed together. Then another row is laid on top. This second layer obviously lies in the depressions between the lower row of cobs.
- When three or four courses have been laid, one above the other, the sides are smoothed over so that the holes and cracks disappear.
- With care and experience and perhaps the use of a sharp knife like instrument a very smooth flat surface can be acquired.
- Mud must be kept stiff, too much water and the wall as it grows, bulges or slumps and is likely to fall down or subside into a heap of mud.
- The wall building must be done slowly, after laying two or three courses of cobs all round the house one must wait until it hardens and set a little before carrying on with the next two or three rows.
- Another cob problem is to keep the walls straight and vertical. The easiest way to overcome this problem is to stand astride the wall while you are working.
- The surface of the walls will be somewhat rough if only the hands are used to smooth over the holes and crevices. Soon after completing the wall you can smooth its surface by using a mammatty or an adze or a sharp knife or trowel. Such instruments will slice off bumps and give lumps a clean smooth surface.
- Once you have obtained the feel of the right consistency of mud, this cob method is a very simple, straight forward, uncomplicated way of building a wall and almost anyone can learn quickly how to do it.
- If you wish to build curved or circular walls, "Cob" is the ideal system for doing it.
- Openings for doors and windows are a problem which can be solved by using temporary vertical planks or shuttering.
- Another very simple shuttering for openings is to use empty kerosene tins.
- Cob is easy work and can be constructed by the residents themselves without the use of any special tools or moulds.

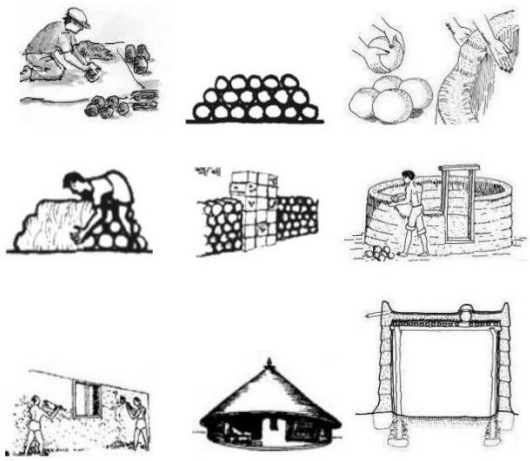

Figure 13- Cob wall construction technology Source-(http://www.earth-auroville.com/compressed_stabilised_earth_block_en.php)

Figure 14: Temporary wooden planks or shuttering can be used to leave space for windows
Source-
https://www.google.co.in/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwjOuLPZnuPeAhUGsI8KHRTSDtIQjRx6BAgBEAU&url=https%3A%2F%2Finspirationalvillage.me%2Ftag%2Fcobbing-around-windows%2F&psig=AOvVaw1ooEMlogO9p2xcWRP0nuH-&ust=1542812523696747)

Rammed Earth

Rammed earth is a type of earth construction in which gravel, sand, silt and a small amount of clay are rammed into place between flat panels called formwork until it becomes rock solid. Rammed earth constructions can last for hundreds of years if constructed properly. Subsoil is compressed over hundreds of years to form rock the same process of compression is executed by using rammers and formwork to compact and stabilize mud in a few days or weeks to make a rammed earth construction.

Rammed earth is a construction technique that has been employed for over two thousand years and has been used all over the globe. The Great Wall of China has various sections built in rammed earth and has been standing sturdy for 374 years.

Rammers

Once the formwork is assembled and the mud is filled in it, we need to start the process of compaction and to achieve this we need rammers.

Rammers are of Three Types

- Wooden rammers
- Metal rammers
- Mechanical rammers

Furthermore the above mentioned rammers come in different surface areas. Rammers with greater surface area enable larger portion of the filling to be rammed but it is more. efficient to use rammers with lesser surface area as they enable deeper compaction with every blow and they work well with portions that are closer to the edge.

Figure 15- Manual rammers

Figure 16: Electronic Rammer

Construction Technique of Rammed Earth

As aforementioned there are two types of form work, hence there is a slight difference in the procedure of construction depending on which formwork is used.

Rammed Earth Wall Construction Using Movable Formwork

- As the form work is assembled stiff mud is thrown into it.
- It is rammed using either wooden rammers, metal rammers or mechanical rammers until the mud becomes rock solid and a ringing sound can be heard.
- The two boards are dissembled as this section is complete and are moved along and the process is repeated until the whole plan is completed.
- The formwork is lifted up and a second course of rammed earth is made over the first course; the same procedure is repeated until the whole wall is completed.
- If the sections are aligned one above the other it could lead to a long vertical crack along the joint. Thus the sections must be rammed such that the vertical joints between one section and the next section are not vertically one above the other, thus a bonding pattern as used in brick work is to be followed.

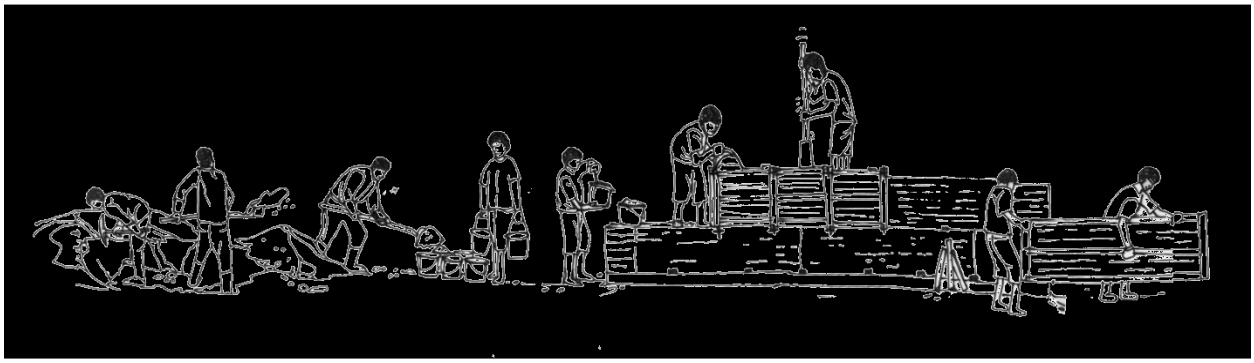

Figure 17: Rammed earth wall construction
Source- (www.madeonearth.com)

Compressed Stabilized Earth Block

Architect Francois Cointereaux attempted to precast small blocks of rammed earth for which he used hand rammers to compress humid soil into a small wooden mould held with the feet which resulted in a compressed earth block. If we relate to the aforementioned techniques of mud construction we can observe that this technique has been inspired by rammed earth.

Unlike sundried bricks which are moulded and dried, compressed eart blocks are compacted, thus they have higher compressive strenght; furthermore they use lesser amount of water and thus do not need to be dried for long. As compared to rammed earth in which larger units are rammed together in a formwork, compressed earth blocks are compacted in machines which are manually operated and form smaller units, enabling easier transportation after manufacture.

Once the blocks are compressed we can use bonding patterns similar to brick masonary. In addition since the soils are compacted and dense termites and insects are left with no scope to dwell within these walls.

Compaction of MUD

Compressed earth blocks are basically blocks of soil with increased density achieved by reducing air voids by applying static or dynamic loads. Loose soil has a dry bulk density ranging from 1.0-1.3 gm/cc. The density is increased to density values like 1.8-1.85 gm/cc when subjected to compaction.

The compaction energy per volume of the soil and the moisture content, for a given compaction energy affect the density that can be achieved in a given instance. The compaction energy per volume is the effort of compaction applied to the soil per unit volume and is determined using the weight, height of drop, and number of blows of a hammer to compact a volume of soil placed in layers into a mold.

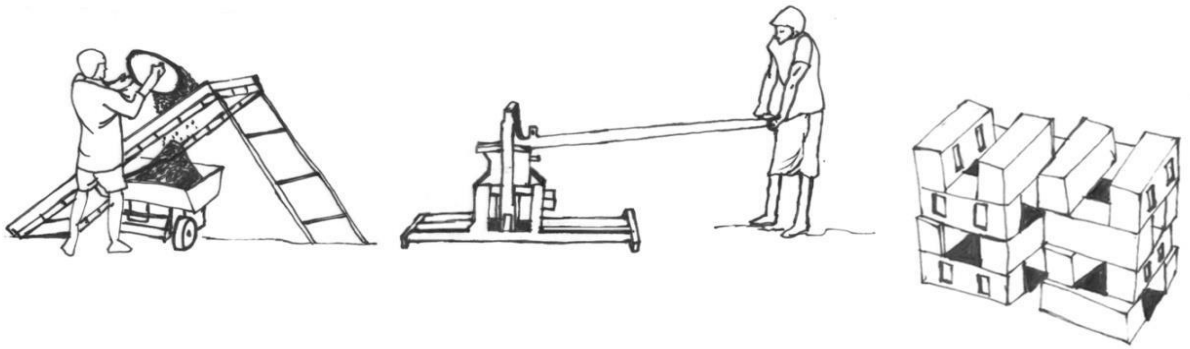

Figure 18: Compressing the mud blocks to make it more strong

Machines for Compaction of MUD

- CINVARAM was the first CMB machine developed in Columbian the year 1959 by Raul Ramirez. The machine was manually operated and used a toggle mechanism to generate a force of the order of 10 tons to act on the loose mud mass to compact it.
- Ellson Block Master originated from Africa, was under manufacture in Rajkot, Gujrat since 1959.
- ASTRAM was the first machine developed by The Department of Civil Engineering, IISc in the year 1979.
- In 1987 a new machine was developed at IISc called ITGE VOTH to improve the compaction.
- In 1994 a machine called MARDINI was developed by making modifications to CINVARAM.
- BALRAM was developed by a Delhi based NGO called development alternatives around 1994.
- In 1989 The Center for Scientific Research, Aurovile developed a machine called AURAM.

Among the machines mentioned above MARDINI and AURAM are the most widely used for block making at present day.

Wall Construction Using Wattle And Daub

- Firstly a timber frame structure is made.
- Within this structure in each frame the upper timber is drilled such that a series of holes are made along the middle of its inner face, then the lower timber is cut such that a groove is made along its inner surface in the middle.
- Secondly vertical members called staves which are basically slender timbers are inserted into the holes of the upper timber and the grooves on the lower timber.
- Thirdly the wattle is woven through these staves as shown in the figure.
- A mixture of mud straw and animal dung is then daubed into the wattle.
- Holes are made into the mud that has been daubed to hold the plaster.
- As the daubed mud sets, lime with a mixture of mud and jute thread is used to plaster the walls such that the mixture settles into the holes made on the mud daubing.

Figure 19: Source- (https://madeinearth.in/wp-content/uploads/2018/02/wattle-and-daub-sketch.jpg)

Figure 20: Source-
(https://www.google.co.in/url?sa=i&source=images&cd=&ved=2ahUKEwjNnKDusuXeAhVZWX0KHc30CqkQjRx6BAgBEAU&url=https%3A%2F%2Fmadeinearth.in%2F2016%2F03%2F1038%2F&psig=AOvVaw1kvR3fGclVL4Pup-9m2Kcu&ust=1542886578459702)

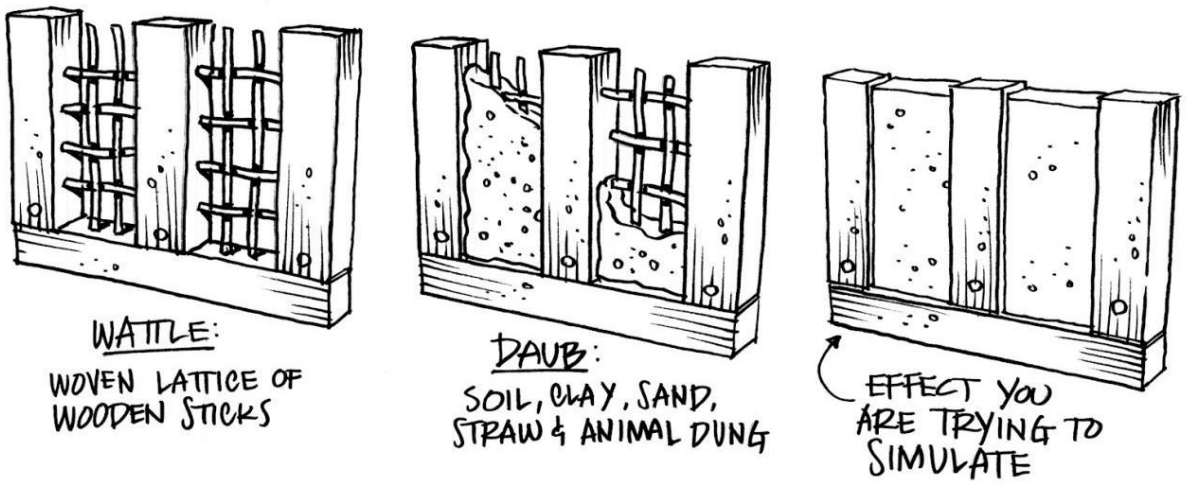

Figure 21: The figure above throws light on the construction of a wall using wattle and daub technique
Source-
(https://www.google.co.in/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwjslZqIreXeAhVDeH0KHdTBCxcQjRx6BAgBEAU&url=http%3A%2F%2Fthemedfairedesign.blogspot.com%2F2012%2F06%2F&psig=AOvVaw12fBQ7rvjxXqTeHCzlZORI&ust=1542883747780625)

Figure 22: The figure shows portions of wall with exposed wattle weaved into staves and portion of the wall with a daubing

Source- (www.researchgate.net%2Ffigure%2FTimber-framed-building-with-panels-at-various-stages-of-wattle-daub-infill-17_fig6_307995450&psig=AOvVaw1kvR3fGclVL4Pup-9m2Kcu&ust=1542886578459702)

Mortars for Adobe and Stabilized Earth Blocks

Adobe and stabilized mud blocks need a mortar to to hold them together as a wall. The following are a few mortars which are used for wall building:

- Cement mortar (1:6)
- Cement-lime-mortar (1:1:6)
- Cement-soil-mortar (1:2:6 or 1:2:7)
- Cement-pozzolana-mortar (1:1:6)
- Lime pozzolana mortar (1:2:9)
- Mud mortar

MUD WALLS WORKS AS A HEAT INSULATOR

When we practicing in mud architecture, first of all we prepare the mud for the construction by mixing some elements in it. Which are as follows:

- Good quality mud which will useful for construction.
- Wheet straw
- Cow dung
- Slurry
- Clay

As we know that all of the above are porous materials. And when we mix all of them with appropriate ratio of water it will be stiffer than the previous and the tendency of the mixture is porous.

Therefore, because of their porous tendency when we make a wall with that mixture the wall will be the porous and it helps to stop the outer heat outside and make the inner environment cooler than outside the room or house. Therefore the mud walls or mud architecture acts as the heat insulator.

CONCLUSION

Through the study we conducted we can understand that a building material that lies right beneath our feet could be used to create wonders. Mud is often mistaken for topsoil which is organic and doesn't hold together like other construction materials, but the mud used for construction demands a certain proportion of mixture of soils and this proportion is quite often found in the subsoil

which lies just a few layers beneath the topsoil. This false notion that people carry is what which sparks the imagination that mud abodes are fragile and would disintergrate with time, while on the contarary mud dwellings last for centuries and have in some cases for many millenia. Through the ages different construction techniques emerged which use the same material for construction. Each of these techniques inundate unique qualities in the buildings they help manifest, many historic examples exist which explore usage of more than one of the aforementioned techniques. Depending on the complementary raw materials available and the climatic conditions of the region any of the techniques which proove to be most suitable can be used for construction. Furthermore the origination of these techiniques has made it possible to construct with mud in a wide range of climatic zones ranging from desserts to foothills of snow capped mountains.

Mud is an omnipresent material, unlike other materials which need to be manufactured and transported over large distances to the site, it is already available in a form which can be used to construct. As mud is available almost anywhere it not only saves energy but also stands as a cost effective material for providing dwellings for the poor. A wise architect, who has a sense to conserve the natural resources which are used up for manufacturing and transportation of these materials for the future, would implement the usage of this material.

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