ISSN: 1999-1630

SEU Journal of Science and Engineering, Vol. 12, No. 1, June 2018

A Study on Feasibility of Super Adobe Technology –An Energy Efficient Building System Using Natural Resources in Bangladesh

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Abstract: The inspiration and concept for the Superadobe system originates not from the modern architecture design experience, but from the influence of traditional rural buildings and landscape, together with a 13th century Persian poet named Jala Ad-Din Muhammad Balkhi, Rumi. The poetry spirit of Rumi, connects and enlightens the architectural theme of Nader Khalili with natural resources that anybody in the world should be able to build a home for his or her family with the simplest of elements: Earth, Water, Air and Fire. Therefore, to build a human shelter that will give maximum safety with low financial budget and minimum environmental impact with natural disaster resilient a Superadobe Technology has been adopted. The Superadobe, a form of earth bag construction using sandbag and barbed wire technology, is an economical, time efficient, energy efficient and ecologically friendly system developed by Iranian-born architect "Nader Khalili". The system connects the natural materials and rural traditions to create a new way to use natural materials such as mud, water, air and fire which can be finished in a short time without any large construction equipment. The goal of this study is to introduce the building system, analyse the ventilation, lighting and insulation of the prototype of Superadobe system replacing the contextual earth house in Bangladesh.

Keywords: *Barbed Wire, Climate Resilient, Energy Efficiency, Earth Bag,Super Adobe.*

I. Introduction

The global need for housing includes millions of refugees and displaced persons - victims of natural disasters and wars. Iranian architect Nader Khalili believes that this need can be addressed only by using the potential of earth construction (L. M. Surhone *et al.*, 2010; M. T. Timpledon *et al.*, 2010; S. F. Marseken *et al.*, 2010). After extensive research into vernacular earth building methods in Iran, followed by detailed prototyping, he has developed the sandbag or 'superadobe' system. Superadobe is a super long sandbag, a super long adobe to construct a compression structure which uses layered long fabric tubes or bags filled with clay (T. Katauskas 2007). The system connects traditional and natural resources such us mud, water, air and fire creates energy efficient houses in an effective way for an individual in a very short period of time .This concept was originally presented by architect Nader Khalili to NASA for building habitats on the moon and Mars, as "Velcro-adobe" however, the patented and trademarked (U.S. Patent # 5, 934,027, # 3,195,445) technology is offered free to the deprived of the world, and licensed for commercial use (S. Holgate, 2003). It comes from the concerned heart of someone who did not want to be bound to any one system of construction and looked for only one answer in human shelter, to simplify.

Superadobe is a kind of ecological and sustainable building, which can be coiled into vaults and domes, the way a potter coils a pot, with barbed wire reinforcement, to build structures that pass international earthquake codes (L. Elizabeth *et al*., 2005; C. Adams *et al*., 2005, J. Z. Teslik *et al*., 2013; N. M. Vodicková *et al*., 2013). Structural design uses modern engineering concepts like base-isolation and post-tensioning to be stabilized, waterproofed, and finished as permanent houses where the barbed wire adds the tensile element to the traditional earthen structures, creating earthquake resistance despite the earth's low shear strength. The aerodynamic forms resist hurricanes and sandbags add flood resistance with easy construction, while the earth itself provides insulation and fire-proofing. The system is

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applicable to build silos, clinics, schools, landscaping elements, or infrastructure like dams, cisterns, roads, bridges, and for stabilizing shorelines and watercourses. The whole family can build together and there is no heavy lifting or backaches, no expensive equipment.

Sustainable Solution to Human Shelter, based on Timeless Materials (earth, water, air and fire) and Timeless Principles (arches, vaults and domes). The structural principles of the timeless forms of arches, domes, vaults are built with the materials of earth, sandbags and barbed wire using the engineering of single and double curvature compression shell structures, to reach the ultimate in strength and aesthetics. Because of self-supporting arched roof structure, it can be one single space, or form more spaces through merging multiple arch systems as in Fig. 1 (P. Sharma, 2015; N. Khalili, 2014). This allows for flexibility and variability of the space. Because of its materials are native and recyclable as well as its structure needs no construction equipment, and its prototype has good ventilation, lighting and insulation.

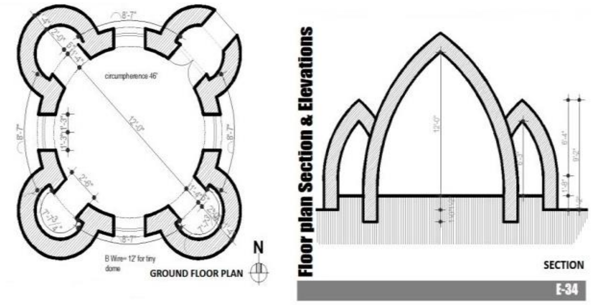


Figure 1: The plan of Superadobe Source: redrawn by the author according to HBRI

II. Literature Survey

The technique's current pioneer is Nader Khalili who originally developed the superadobe system in 1984 in response to a NASA call for housing designs for future human settlements on the Moon and Mars. His proposal was to use moon dust to fill the plastic Superadobe tubes in layer. The Super Adobe Method is now use in Canada, Mexico, Brazil, Chile, Iran, India, Siberia, Thailand, as well as in the U.S. The adobe is stretched from history into the new century. It is like an umbilical (birth) cord connecting the traditional with the future adobe world.

Rumi conceived that elements such as water, air and fire in the land have a great power, which can cycle inside and outside of the life (Z. Z. Qi Lub *et al.*, 2015 and X. Jiangc *et al*., 2015). If these elements can be well balanced, the environment and all life in the world would have good status (S. Holgate, 2003). Rumi had said "The earth will become the gold of the wise". Affected by Rumi, Khalili realized the value of the earth and formed his design concept using clay to build (Fig. 2) and fire to burn (Ceramic House) (P. Sharma, 2015).

Figure 2: The outside view of Superadobe Source: www.calearth.org

Nader Khalili began to research how to use natural resources as much as possible and to study the possibility of no use of high technology to build house in modern world. The Superadobe system could satisfy above request and it has good seismic performance. It is a good option for the poor and is also suitable for the moon. In 1986, Khalili founded a research organization called Cal-Earth which began practice in the California Hysperia area of the Mojave Desert. His main studies are about earth art and the technical problems of clay construction (P. Sharma, 2015). The scope of his research includes building a house on the moon with technical innovations for NASA (National Aeronautics and Space Administration) as well as building housing for homeless people in the United States. The building philosophy seeks harmony between art and nature. The sandbag engineer prototype won the Aga khan Award in 2004. Cal-Earth has posted their concepts and methods on the Internet. The works and practices of Cal-earth have been studied by other research institutions as a model.

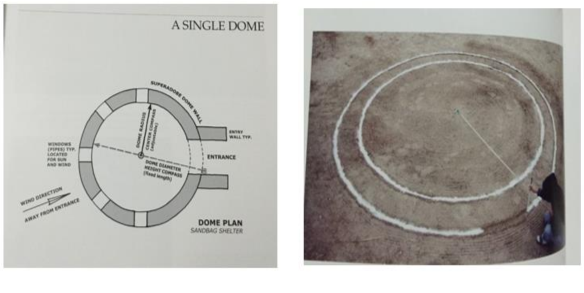
To build a sandbag shelter, the principle of construction with long or short sandbags is similar to the way a child puts his donut-like toy rings on top of each other (H. Kaki *et al.,* 2004; D. Kiffmeyer *et al.,* 2004). This geometry is one most appropriate for superadobe construction since the earth filled coils can lay flat on top of each other, and step them gradually inwards. This is called “corbelling”. Equal steps will give us a conical shape, but to create a more spacious interior an egg-shaped volume has been used. The resulting beehive shaped structures employs corbelled arches, corbelled domes, and vaults to create single and double-curved shells that are strong and aesthetically pleasing (The Green Building Program 2006). It has received growing interest for the past few years in the natural building and sustainability movements. In the last century earth bag buildings have undergone extensive research and are slowly gaining worldwide recognition as an optimum solution to the global epidemic of housing shortages.

III. Methodology

Building with earthbags (sometimes called sandbags) is both old and new. Sandbags have long been used, particularly by the military, for creating strong, protective barriers, or for flood control (Kennedy *et al.,* 2007; Joseph *et al.,* 2007). Earthbag building fills a unique niche in the quest for sustainable architecture. The bags can be filled with local, natural materials, which lower the embodied energy commonly associated with the manufacture and transportation of building materials. Many different materials including un-stabilized sand, earth, gravel, crushed volcanic rock, rice hulls, etccan be used to construct Superadobe. Normally earth or sand, cement or lime, and Superadobe polypropylene tubing; bags can be polypropylene, or burlap. What is important is that they are UV resistant or else quickly covered in plaster (Green Home Building and Sustainable Architecture, 2007-08-18).If the fill material is weak the bags have to be really strong and UV resistant, or else plastered right away.

The material can be either wet or dry, but the structure is more stable when the tube's contents have been moistened. Other materials needed include water, shovels, tampers, wheel barrow, mechanical pumps, scissors, compass, large plugs or pipes (for windows), and small buckets or coffee cans for filling the sacks. However, for the quicker way electric or pneumatic tampers can make the tamping easier, electric or gas powered bucket chain that can reach 7 meters or higher would eliminate the need of manual filling of sacks or tubing using coffee cans or small pails.

Mud, water, air and fire are the main materials of the Superadobe System. The building process is easy, time efficient and built a single dome following ten steps (Figs. 3-8) (N. Khalili, 2014). Firstly, collect some tools such as scissors, a rod, a shovel, a roll of woven sacks, short tubes, kegs or coffee tank, Materials-sand bags, Small buckets, gloves, tamper a roll of metal wire with barbed and a pair of pliers. Then dig mud from the base of the ground and mix some cement and water together, add cement or lime or an asphalt emulsion for reinforcement. Add enough water and squeeze it into a ball until it does not stick to your hand. The location of the entrance should be chosen to avoid the rain and the winds. The dome layout should be based on landscape and climate.



(a) (b)

Figure 3: Step-1: (a) Dome plan (b) Dome Layout in construction phase

The foundation for the structure is formed by digging a 30 cm deep circular trench with 2 to 4m diameter.

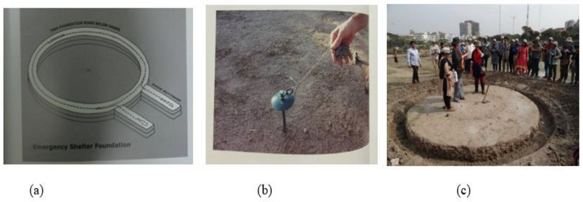


Figure 4: Step-2: (a) Theoretical dome layered foundation (b) Centre scale on site (c) Foundation on the constructed site

Then, lay a bag along with the ditch. Fold the tail section to make it closed, and then it will be like a short rising column. Pour the soil into the bag and constantly shake it into the bottom. A good method inclining the bag to your feet in the helping of the gravity could be used to prevent the bags twisted, and withdraw your foot after the bag is well-filled (Freedom Communications, Inc. 22 Jan. 2007). Then its position is corrected by a compass. It is required to make sure that the tail section of the bag is well folded to close.

Figure 5: Step-3, 4, 5, 6: (a) Theoretical Base Plan. (b) Base making phase on the site adding sands (c) Base making progressive phase adding barbed wire with tamping earth bags.

A tamping is used to make the sandbag compacted. To make it smooth, fixed and uniform sealing good until they become strong enough. In order to make them stable, barbed wire is tied between the different layers of sandbags. First wire is 4 meters long, the next need more 65cm longer to make sure overlapping part when fracture occurred. Two or three layers of the filled polypropylene sand tubes (superadobe tubing) are set below the ground level in the foundation trench (L. Elizabeth *et al.*, 2000; C. Adams *et al.*, 2000). When build it in certain height using two compass to ensure the shape of the roof. The one is central compass formed with a wire rope or other chain unable to stretch and the ground center. The other is a height compass that can be increased according to the layer. And the sandbag should be rearranged if it's not matches compass trajectory.

A chain is anchored to the ground in the center of the circle and used like a compass to trace the shape of the base. Another chain is fastened just outside the dome wall: this is the fixed or height compass and gives you the interior measurement for every single layer of superadobe bags as they corbel ever higher. The height compass is exactly the diameter of the dome. The center chain/compass is used to ensure the accuracy of each new superadobe layer as it is laid and tamped. The compasses must be made of non-stretchy material to ensure an accurate geometry.

On top of each layer of tamped, filled tubes, a tensile loop of barbed wire is placed to help stabilize the location of each consecutive layer: it plays a crucial role in the tensile strength of the dome - it is the 'mortar'. Window voids can be placed in several ways: either by rolling the filled tube back on itself around a circular plug (forming an arched header) or by waiting for the earth mixture to set and sawing out a pointed arch void. A round skylight can even be the top of the dome.

It is recommended not to exceed the 4m diameter design in size, but many larger structures have been created by grouping several "beehives" together to form a sort of connected village of domes. Naturally, this lends itself to residential applications, some rooms being for sleeping and some for living.

Figure 6: Step-7: (a) Repeat the process and completed dome

The next step is making the door and windows. Cutting parts of the sand bags to form openings. Excision and then tamping to make ensure that cutting soil not to stick in original sandbags. The door could be pushed when at least 5 layer sandbags is masonry (Husain *et al.*, 2007, Yasha *et al.*, 2007). Insert the pipe into the sandbag as a window. Arched windows-make a form with loosely-filled bags or other materials, build the dome around the form and remove the form when the dome is completed. Make an 'eyebrow' over larger window openings. Pipe windows build the dome over the pipes for ventilation and light.

In order to prevent the rain inflow to inner, the pipe should be inclined to external. Keep the bag indentation in the top and form an adobe. Add the arched doorway to support and protect the entrance. The door way could be arched or sloped, higher or lower.

(a) (b)

Figure 7: Step 8: (a) Doorway of dome on site (b) Inside of dome on site

The buttress walls are built for the entry and connect to the dome at every row with barbed wire.

(a) (b)

Figure 8: Step 9, 10: (a) Barbed wire in every rows of buttress walls used multipurpose (Kitchen, Toilet, Storage) (b) Buttress walls with ventilation and light with hollow plastics.

Eventual step is to use learning arches to complete a small entry vault to protect the doorway. Alternatively, use very short lintels for a 'mineshaft" entry after the upper dome is completed.

Once the corbelled dome is complete, the work needs to protect. And cover waterproof material to let it to be moisture proof and anticorrosive. it can be covered in several different kinds of exterior treatments, usually plaster. Khalili developed a system that used 85% earth and 15% cement plaster and which is then covered by "reptile", a veneer of grapefruit sized balls of cement and earth (N. Khalili, 2014).Reptile is easy to install and because the balls create easy paths for stress, it doesn't crack with time. There are many different possibilities. Some Superadobe buildings have even been covered by living grass, a kind of green roof but covering the entire structure. Any exterior treatment and building details would need to be adapted to a region's specific climatic needs.

(a) (b)

Figure 9: (a) Exterior Outlook without ornaments. (b) Exterior Outlook with ornaments.


(a) (b)

Figure 10: (a) Dome with natural light. (b) Ventilation of Drawing room.

IV. Some features of the Eco-Dome

- Built from local earth-filled Superadobe coils (earth stabilized with cement or lime) *(Sinclair et al., 2006 Cameron et al., 2006 , Kate Stohr et al., 2006)*
- Tree free.
- Maximum use of space through alternative options. The main dome and four niches, depending on local code approval, can function as:
  - Main living room, entrance hall, kitchen, bathroom, bedroom (called "bed-womb" because of its small, organic form!)
  - Living room, entrance hall, and three bedrooms.
  - Living room, entrance hall, two bedrooms, and a bathroom.
- Self-contained single unit (potential for a guesthouse or studio apartment) or double unit (larger family residence).
- Can be repeated and joined together to form larger homes and courtyard houses.
- Can be built by a team of 3-5 persons.
- Designed with the sun, shade and wind for passive cooling and heating.
- Wind-scoop can be combined with a rated furnace unit, depending on local code approval. Solar energy and radiant heating may be incorporated.
- Interior furniture can be built-in with same material.

V. Advantages of Superadobe Domes

- Natural, reversible and recyclable building materials are used causing no harm to health and environment.
- Good thermal mass material: perfect heat storage capacity, regulation of temperature and humidity resulting comfortable interior microclimate.
- Good acoustic parameters.
- Statically strong, durable and resistant even to extreme weather conditions and natural catastrophes like flood, windstorm, fire, hurricane and earthquake.
- Wide range of use.
- Harmonic and diverse – traditional or modern forms and styles.
- Economic and environment friendly, easy and quick building with locally available materials, small waste production, minimal need for industrial background and use of machines, low shipping costs, low energy input and environmental pollution.
- Low housekeeping costs.
- Anyone can learn this building technology, the whole community from young to old.
- With building vaults and domes one can omit and minimize the use of wood, iron or reinforced concrete bond, beam system and roofs.
- Ideal for humanitarian purpose, strengthen communities and equal opportunities.

VI. Disadvantages of Superadobe Domes

- It does take a lot of people to build a house by hands only.
- It gets difficult after several hours of lifting the heavy bags.
- It takes strength to lift and carry each bucket.
- No mention of them in building codes.

VII. Analysis

In order to discuss the system’s energy sufficient characters, it can be analysed from aspects of ventilation, lighting and insulation. The prototype be chosen is a single adobe. First of all, the dome roof has better ventilation effect than the flat one when they share the same inner wall length (Fig. 17) (Hunter *et al.,* 2004; Kaki *et al.*, 2004; D. Kiffmeyer *et al.*, 2004) when the model has been overlap together, the height from roof windows to the floor certifies that dome roof has accelerated the air fluent better because it forms a Stack effect.

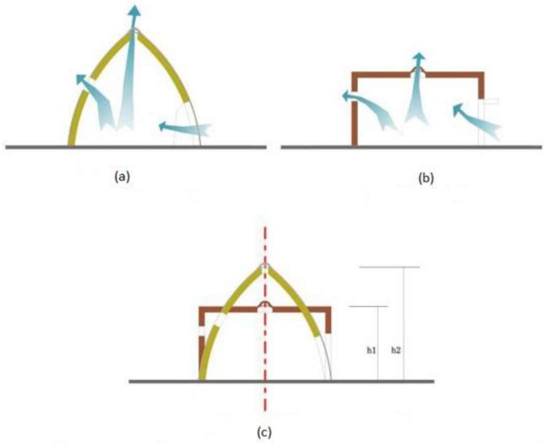


Figure 11: (a) Dome roof ventilation (b) Flat roof ventilation (c) The different height from roof windows to floor with the same inner wall length

Designing comfortable homes without extensive energy use or associated cost for people in freezing temperatures is essential to the earthbag village.

Every material in a building has an insulation value that can be described as an R-value. Most builders think of R-value as a description of the ability of a structure or material to resist heat loss. This steady state value does not change regardless of the outside temperature variations that occur naturally on a daily and annual basis(One Community, Earthbag village Heating and Cooling). So why does an earthbag structure (or any massive earthen building for that matter) with an R-value less than 0.25 per inch (2.5 cm) feel cool in the summer and warm in the winter? Because this R-value can also be expressed as the coefficient of heat transfer, or conductivity, or U-value, which is inversely proportional, that is U=1/R. From this simple formula we can see that material with a high R-value will yield a low U-value. U-value (units of thermal radiation) measures a material's ability to store and transfer heat, rather than resist its loss. Earthen walls function as an absorbent mass that is able to store warmth and re-radiate it back into the living space as the mass cools. This temperature fluctuation is known as the "thermal flywheel effect." The effect of the flywheel is a 12-hour delay in energy transfer from exterior to interior. This means that at the hottest time of the day the inside of an earthbag structure is at its coolest, while at the coolest time of the day the interior is at its warmest.This thermal performance is regulated by many factors including the placement and condition of windows and doors, climatic zone, wall colour, wall orientation, and particularly wall thickness. This twelve-hour delay is only possible in walls greater than 12 inches (30 cm) thick.

Thermal lag is a time unit assigned to a material that indicates the amount of time it takes to heat up or cool down. Thermal mass is the material heated or cooled.

The time that passes from heating one side to the other side heating up too is the "thermal lag" expressed by:

$$thermal\ lag = 1.38 * (thickness, m) * \sqrt{((Cp * \boldsymbol{\rho})/\boldsymbol{k})} \qquad (1)$$

Heating a material (and its effectiveness as thermal mass) depends on how much heat it can absorb (Specific Heat: C_p), the rate at which the heat can penetrate (thermal conductivity: k), the density of the material in question (density: ρ), and the thickness of the material.

This means that when domes experience cyclical temperatures (day and night, seasonal) the temperature inside the domes lags behind.

The issue with earthbags is that they provide fantastic thermal mass (Figure 12) but truly are not a great insulator. The R-value of compacted earth is roughly R-1 per foot, so a standard earthbag wall might yield no better than R-2 (about the equivalent of a dual-pane glass window). Their insulating properties can be improved by adding materials that create air pockets inside them like volcanic rock, rice hulls, perlite, or vermiculite. This, however, has positive and negative elements.

Table 1: Comparison of Material R-Values.

Material	R-value/inch	R-value/15″
Rice hulls	R-3	R-45
Perlite	R-2.7	R-40
Vermiculite	R-2.13	R-32 to 36
Extruded polystyrene	R-3.6 to R-4.7	R-54 to R-70
Molded low-density polystyrene	R-3.85	R-58

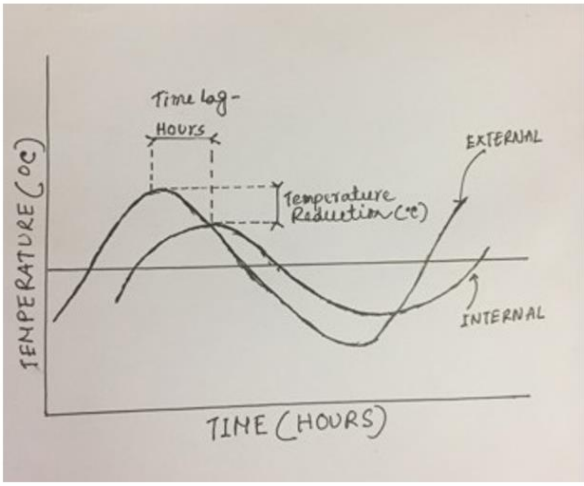


Figure 12: Thermal Lag Calculation

Simple thermal dynamics state that heat travels from warm spaces to cooler spaces and air pockets inhibit this heat transfer. If the goal is keeping heat in, inhibiting the transfer of heat through walls can be very good. The more you add air pockets or insulate the walls, the less heat will move through those walls (Kellogg *et al.*, 2005; Stuart *et al.*, 2005; J. Quigg *et al.*, 2005). The downside of this is in the summer when heat being absorbed by the walls would have a cooling affect that would be lessened by this reduction of heat transfer.

Suggestions and options on what is the best approach vary and can be affected dramatically based on the building environment. For areas that are consistently cold, with a quality internal heating system, a person would do well with a solid earth-filled earthbag wall that has an external insulating layer (S. Holgate, 2003). This would provide thermal mass on the inside and a barrier to that thermal mass losing its heat to the outside. In areas that are consistently hot, however, this external insulation approach could create environments that warm up and are difficult to cool again, so building deeper in the ground and eliminating insulation is a better approach.

VIII. Conclusion

On the basis of the interpretation of the materials, the construction method and the achievements of the Cal-earth, the system can be analysed from four aspects.

First of all, it is material choice (T Katauskas 2007).The materials of Superadobe are almost all natural, such as mud, water, air and fire that can be easily gained. They are from nature and return to nature after construction when they must be abandoned. It can be circled in the ecosphere. That is sustainable. Besides, the thermal inertia of the earth makes the inner house to have good insulation as well as the material using make it have good air-tightness.

Next, its construction method is taking care of. No large construction equipment be needed in building and it can be finished just by several men in a short time. No noise, non-pollution and little impact on the surrounding environment. On the other side, The Superadobe system provides a possibility for those who need temporary housing in case of emergency because it can be easily assembled and disassembled. Moreover, Go to its appearance, Superadobe follows the Islamic traditional building method, which was using dome. In addition, its construction method is also drawing lessons from the Persian Sassanid Dynasty (AD226-651) when the brick corbel method was popular. The difference is he uses sandbags to corbel and each cross section is a circle. The advantages of the dome space they choose have been talked about in the front text from the angle of technology. Another explanation of the dome used by Khalili is that building just as smooth as human's body without edges and corner just like the nature itself. Its smooth surface gives a special view outside and a safe space to play for children inside.

Finally, the scope of application of Superadobe system should be discussed. For signal building, its flexibility of space organization provides choice for different number of population. One family and more together (parent living with their children who are married) are both possible. It can expand space according to different situation. For building group, another question is if it suit to all cities or countries? First of all, the main materials of Superadobe system are clay. Not enough clay could be built in the density cities. For another the system itself can not satisfy the high-rise building requirement. However, it is suitable for the low-density rural area because of low cost, environment friendly and time efficiently. Meanwhile, due to water permeability of the soil, Superadobe is more adapt to dry areas than wet regions, especially for desert districts.

Superadobe system is an economical, ecological and energy efficient system. The scope of its application is dry and low density rural areas. Superadobe connects the nature and tradition. It is inexpensive technology. Natural, reversible, recyclable building materials are used which are not harmful to our health and the environment. It has low energy input and causes very less environmental pollution. Small waste production is there. It is environmentally friendly. It is statically strong, durable, and resistant even to extreme weather conditions and natural catastrophes like flood, windstorm, hurricane, fire, and earthquake. It reduces global warming and Speedy in construction which could be very effective for climate resilient energy efficient structure as such in Bangladesh.

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