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Ecologic-mud-bricks: Ladakhi vernacular resilient architectural strength for hostile environment

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ABSTRACT

Ladakh is a cold arid climate in the great Himalaya with several glaciers at an altitude from 3000 to 8000 metres amsl. Due to its high altitude, region is always freezing cold and dry for most of the year. Over the centuries, Ladakh's inhabitants have successfully countered the extreme winter climate by using thick mud brick as resilient building material for thermally comfortable and sustainable housing by trapping the sun's heat during the day and release it evenly through the night. It was recorded that in the region where temperature dips as low as -40 degree during whole winter season and all the houses were constructed with mud bricks locally known as Pag-bu, paku etc. It is a simple low cost construction technology with significant practical and environmental advantages over other construction materials, suited for use in cold arid Ladakh. Still, resource poor farmers still continuing to use mud-brick based constructions for the shelters. Mud bricks are prepared and sun-dried using farmers' own soil after filtering out small gravels with the use of hired labour and his family members and save transportation. Due to climate change and post flood context, although few progressive farmers have initiated and changed the construction pattern and adopting cement-based bricks to strengthen house building and protection necessary for survival. Efforts by several organizations are being made to promote and develop new solar technologies to capture and store the sun's energy by enabling their inhabitants to survive in this hostile environment.

1. Introduction

Ladakh, or "Little Tibet", is a wildly beautiful desert region high in the Western Himalayas, at altitudes ranging from 10,000 to 14,000 feet (from 3,000 to 4,300 m). It is a place of limited resources with an extreme climate. The Himalayan Mountain range has significant bearing on the climate of India, as its towering height created a vast rain-shadow zone in the north. The cold dry tracts of the zone referred to as cold arid region, spread over in the northern states of India. The cold dry tracts of this zone referred as the cold arid region are spread over in the northern union territory of Ladakh (Leh and Kargil districts), Himachal Pradesh (Lahaul-Spiti, Kinnaur and parts of Chamba district), Uttarakhand (parts of Uttarkashi, Chamoli and Pithoragarh districts). Ladakh lies between 32° 15' - 36° N and 75° 15' - 80° 15' E, and is a high altitude cold arid region of India. Due to harsh winter, and heavy snowfall, Ladakh remains cut off for almost seven months i.e. from October – May from rest of the world by surface transportation. Ladakh has a very low population density per square kilometre. It has been described as a "constellation of villages" within the "crossroads of Asia" (Pelliciardi 2010). Despite extreme topography, and a highly variable cold desert climate, agriculturalists have strategically managed the environment for perhaps 8,800 years (Miehe *et al* 2009), but the risks are changing as a result of recent and rapid climatic and socio-

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economic shifts. It is possible to adapt to risk, if it the context is understood and the risks are well communicated (Sherratt, 2014). Currently, there are extremely wide variety of alternative construction materials and techniques which are used around the world. Soil is one of the natural building materials, and its mud can be formed for shelters and can match with all environments. Many are examples of countries those used earth as a building material in ancient time. India also shows very old earthen buildings, like the Shey Palace in Ladakh, which was built with adobe in the 17th century. And, the Tabo monastery in Spiti Vally, Himachal Pradesh was built with rammed earth in 996 AD (Molla, 2012). In a highland region like Ladakh where harsh winters remain for seven months and becomes difficult to survive under dipped temperatures. The constructive system called ''adobe'' based on using mud bricks to make earth buildings in use since the ancient era (Quintilio, 2010) is also under use at cold arid region. Adobe or mud brick building technique is an ancient technique dating back at least to 8300 BC (in Jericho). The oldest continually inhabited structures in the world are adobe. Some built in North America around 900 years ago are still in use (Kusuma, 2004). Efforts were made to carry out the survey to understand and study the climatic resilient building material 'mud-brick' locally known as PAG-BU and PAKU. This investigation deals with the mud-brick based life in hostile environment at cold region of Ladakh.

2. Methodology

Survey was carried out by Regional Research Station, ICAR-Central Arid Zone Research Institute, Leh-Ladakh under National Mission on Sustaining Himalayan Ecosystem for Task Force-5 on Network programme on Convergence of Traditional Knowledge Systems to understand its utilization pattern, strength and resilience to high altitude Ladakh region where the temperature range varies from $\pm$ 35 degree Celsius with the annual precipitation of 100 mm. For, three villages (Upper Tukcha, Thiksey, and Chushot) were identified with varied soil types to find out the strength test. These villages Forits sustainable development in the Indian Himalayan Regionin upper plain (Upper Tukcha) and river-bank based villages such as Thiksey, and Chushot where farmers in addition to their agricultural-cum-livestock rearing livelihood, they are in business to excavate their agricultural land and utilize the clayey material in shaping the climatic resilient mud bricks. For the purpose, survey was carried in above villages and privatized brick-making agency for the facts and figures. The progressive and old farmers were identified from these villages for exploring the local knowledge on mudbrick. For testing the tensile and compressed strength, method proposed by McIntosh (2014) was utilized taking soil samples from excavated soils for mud brick work.

3. Results and discussion

Indigenous and local knowledgeand practices (ILKP) help local communities' adaptations to the changing climate risks of any of the vulnerable regions. Ladakh being at high altitude, suffers from an extremely harsh climate during winter (-30^{0}C) and remains cut off for almost seven months i.e. from October-May from rest of the world by surface transportation and access to the groceries and other required materials become very difficult. If these are available cost so high that resource poor families think to assure nutrient security such as vegetables, fruits, local leafy vegetables, dried leafy materials etc. In Ladakh, local communities have evolved themselves andadapted to natural and varied harsh climatic variability and other changes for centuriesby innovating and institutionalizing ILKP in managing local natural resources andinfrastructure development. These practices are enriched, sustained and improved over time bysucceeding generations. Hence these are time-tested and specific to local needsand priorities. These enhance resilience, reduce disastrous risksto ecosystem and livelihood resources and create adaptation solutions to deal withclimate change vulnerability and impacts. They can enable local communities and theirinstitutions to prepare adaptation strategies, develop and implement plans and actions. Many of these practices if integrated with scientific knowledge, tools and practices support significant adaptation strategies, modifying or transforming existingnorms and behaviourswhile dealing with both climatic and non-climatic shocks anddisturbances. Intheir present form, however, and without external support ILKP will not be able to deal with the extreme events that climate change is likely to bring aboutthough IKLP may help provide initial understanding of potential adaptive practices.

Use of local material for low environmental impact and high safety; local skills to reduce dependence on external aid; improved building material such as stabilized compressed earth blocks to ensure safety from future floods; simple and low cost technologies to reduce earth quake risks in this high seismic risk region; traditional house design to preserve cultural heritage; permanent structures with scope for expansion, participation of families in design and reconstruction of their houses.

Mud is the traditional material for construction in Ladakh, cost effective, but heavy floods can collapse because of low compressive strength. All the mudbricks are prepared from the place where farmers have identified for agricultural lands. In both the cases like Upper Tukcha and Chuchot villages were identified for the study. The details of soils are as given below:

Table 1. Soil properties of identified village soils

Pedon Locations	Horizon	Land use	Parent material	Depth of soil	pH	EC dSm-1	OC (%)	N Kg/ha	P Kg/ha	K Kg/ha
River side agricultural land at Chushot-Gongma	Ap	Cultivated to wheat, barley & vegetables	Alluvium	15cm	7.79	0.76	0.10	56.12	27.96	209.55
	Bw1			2 feet	8.06	0.51	0.25	53.63	12.81	37.96
Farmer's agricultural land at Upper Tukcha	Ap	Cultivated for crop and vegetables	Alluvium	15cm	8.05	0.34	0.38	184.59	51.09	74.84
	Bw1			1 feet	8.18	0.15	0.31	63.61	12.50	42.88
	Bw2			2 feet	8.34	0.14	0.26	119.73	20.62	26.78
	2C			3 feet	8.35	0.08	0.20	111.00	14.37	0.47

The data in Table-1 revealed that the soils of these two villages at cold desert high altitude region are suitable for agricultural uses, coming under sandy loam and calcareous with alkaline in nature indicating advance stage of weathering. The soils of Chushot where most of the mudbrick makers utilize silty clay loam soil. The silt and clay contents of Chushot range from 20-30 and 15-20 per cent, respectively. The pH ranges from 7.79 to 8.35 varied attitudinally showing alkalinity of soil. More than 90% soils in this region are low in available phosphorus but high in potassium with availability of the potassium depending upon the other parameters of the soil. The soils are low in nutrient contents beside phosphorus which is showing medium nature of the identified sites. The soils varied in depths and some parts of Chushot village was recorded fertile and these fertile lands were explored for making mudbricks to a depth of 2 metres along the Indus river. Calcareous soils here were utilized for making mudbricks that has significant compressive strength as compared to Tukcha soils.

Mud bricks (Pag-bu) are prepared from the fields having more than 60 per cent clay content from the cultivated soil, dug 2 to 2.6 feet as shown in the picture and separated from the stones and are added with water for preparing mud and shaped as mud-brick sizing from 10x6x6 cu inch. In the early period, bricks were sized as 14x6x6 cu inch but in the modernization of changing of housing construction and demand, size has been reduced to 10x6x6 cu inch. For preparing the same, 2-3 labourers are required with the contract of Rs. 2 per brick preparation for mud brick and totally 400-600 bricks are prepared per day. They are dried for 2-3 days when there is sunny, otherwise, it takes 6-7 days when the sky is cloudy. As shown in fig.-2, it shows that bricks are kept upright for proper drying from all sides. The total life of the bricks is 30-40 years. To revive the excavated soil area i.e. cultivated area, they again start growing alfalfa fodder to make the soil fertile for 2-3 years and then grow staple crops. Stabilized compressed earth bricks (SCEB) locally known as *PUGBU*, offers a cost effective, and environmentally sound masonry system. Mud bricks consist of clay, water, and binding material such as rice husks or straw. The advantages of mud brick include its low-cost and great thermal behaviour.

1

2

3



4 5 6

Figure 1: Mudbrick groundwork at Chushot, Leh
(1-Soil identified for mudbrick making; 2-frame used for making mudbrick; 3- the cart utilise to transport the mud; 4,5-labourer using frmae and making mudbrick and 6- immediately after soil excavation, the field is available to utilize by sowing alfalfa for few years to build up the productivity)

Limitations

The two main reasons for the damage to the houses are:

The pressure exerted by the water, mud and rocks and use of mud is the only option for making mud-bricks (pag-bu) and walling. Mud losesitsstrength to bind and eventually dissolves once it comes in contact with water. In case of heavy floods took place in 2010, mud bricks collapsed at high degree because of low compressive strength of mud.

Passive energy

To make the buildings suited to the local climate, they are well-insulated with mud and straw, and the most important room always faces south for sunshine. The modern architecture recognizes this technique of passive solar energy. People here also have a sense of aesthetics and beauty-every house has its own character (Kaur, 2015).

On interviews with local mud-brick makers in Chushot, Thiksey and Upper Tukcha, Leh revealed that mud bricks are best one which provide moderate to high thermal mass if the walls are thick enough. Most of Ladakhi buildings are at least one metre deep below ground on north side where earth's temperature at that depth is relatively warm in winter and cool in summer. Mudbrick preparation include low embodied energy through using local and natural resources with minimal use of manufactured products, High thermal mass and good sound absorption characteristics along with the ability to breathe through the walls. Some modern mud brick homes use mud brick for external walls and light partition walls internally; it is more effective for thermal and acoustic performance to use mud brick for the partition walls and lightweight, well-insulated external walls. These bricks can also be made from a wide range of soils that can be manufactured on site like Chushot mud-bricks involves more clay as compared to Upper Tukcha or other than river-bank villages. In case of fire and vermin resistance, since soil does not burn, and do not readily provide habitat for vermin, mud brick walls generally have excellent fire and vermin resistance.

Mr. Rinchen Tundup also told the age his building more than 60 years. His is third generation in the same building. So Choshot side buildings are more durable as they involve clay in it. Also, he added that this building has faced extreme weather situation. Chushot soils are very resistant to weathering, as a general rule mud brick needs protection from driving rain and should not be exposed to continuous high moisture. He also explained that the house-construction throughout regionis similar and most of the houses have same facilities with minimum two stories having big rooms with few small and shallow roof of poplar tree trunk.

Other ways: Combined with modifications to the traditional construction, such as the use of cavity walls and insulation, these measures will help to achieve more comfortable living conditions in one of the most extreme inhabited places on Earth.

Table 2. Mud-bricks at different villages of Leh

Particulars	**Rinchen Tundup**	**Mohd. Hussain**	**Angchuk Rigzin**	**Cement**
Village	Chuchot Gongma	Chuchot Gongma	Upper Tukcha	Shey
GPS	N 3502.446 E 07739024 H-10715 ft	N 3402.053 E 07739467 H-10743 ft	-	-
Age	67 yrs	75 yrs	50 yrs	-
Types of Pagbu	Mud bricks	Mud bricks	Mud bricks	Cement

Pagbu size (inches)	12x6x6 Bigger size of 14x7x7 in Shakti n Matho	14x7x7 before 45 yrs; Sizes varied from 14 to 18 inch in length	12x6x6	12x6x6
Pagbu size depends on	House and hotel	House	For home	Commercial purpose only
Material required	Cropped soil	Cropped soil	Cropped soil	Cement+sand+bajri
Quantity	For one house , atleast 10000 bricks are made	Cement 1: Sand 5: Bajri 4	As per requirement	
Quality and period of bricks	Fields are not properly puddled so quality of bricks are not good, previously 45 yrs before, mud was properly puddled by legs and mixed for better bricks. Leh palace bricks are 200 yrs old.	Curing 11 days	-	-
Number of bricks per month	10-15 thousands	-	-	13000-14000
No. of brick per cement bag	-	-	-	40-50 no of bricks
No. of agencies involved in cement bricks	Every households in Chushot, shey, Thiksey, Ranbirpur	Every households in Chushot, shey, Thiksey, Ranbirpur	Every households in Chushot, shey, Thiksey, Ranbirpur	30-40
Years of bricks existence	Since inception	Since inception	Since inception	Last 4-5 years, cement bricks started in Leh
Pagbu tools	Commonly used tools are Reda (cart to carry mud), Belchha, grinder to sharpen the belchha, Tasla, Pakshang-iron	Pankha, tasla, panja, measuring tool, belchha, panji/ iron pakshing	-	-
No. of house 40 yrs and now a days	-	9 before 40 yrs 52 this period	-	-
Pakshang types (brick frame)	Wooden and iron types with 12x6x6 and 14x6x6 sizes	Wooden and iron types with 12x6x6 and 14x6x6 sizes	Wooden and iron types with 12x6x6 and 14x6x6 sizes	iron types with 12x6x6
How many times fields is utilized for pagbu	Once but Twice hardly depending upon on the requirement and cost	Once	Once	-
Income from PAGBU for labourers per day& month	Rs. 2.40 to 5 per brick and Rs. 30-40 thousands per montyh	Rs. 2.40 to 5 per brick	Rs. 5 per brick	Rs. 5/- or per day labour rate of Rs. 450/ Rs. 500 if hired for personal purpose, the Rs. 7-8 per brick
Truck loads	700-1000	700-1000	700-1000	700 no. of bricks
Loading charges	Charges of making brick includes loading	Rs. 27/- without loading Rs. 28/- with loading		
Capacity to make pagbu in a day	300-400	300-400	300	500-600

No. of bricks per months	10000-15000	10000-15000	Required quantity	13000 to 14000
Brick-heave called	Choltha	Choltha	Choltha	Choltha
No. of labourers required	2 (Nepali husband+ wife)	2 (Nepali husband+ wife)	2 (Nepali husband+ wife)	4 male labourers
Income from PAGBOO for labourers per month (Rs)	30000-40000	30000-40000	28000-30000	15000 per labourers
Market price (Rs.)	Rs. 10-12 per brick	Rs. 8-12per brick	-	Rs 24-26 per brick
Which labourers	Nepali labourers are involved mostly	Nepali/Doda/ Bihari	Nepali/ Bihari	Doda/ Bihari
Name of labourers and involvement type	Mr. Manoj Bahadur, 32 with wife (only husband-wife)	-	Mr. Naresh, 32 with wife (only husband-wife)	Doda and Bihari labourers
How many years before labourers started preparing bricks	17-18 yrs	17-18 yrs	As per requirement	Since 2012-13
Types of soils under use	Clayey	Clayey	Sandy loam	Cement
Longevity of bricks (yrs)	More than 70 years	200 yrs	50 yrs	-
Yield of the plot before	Depends on soil type but 4 times of seed rate	Normal 5 times of seed rate	Kitchen garden	-
Yield of the plot after	improves after 2-3 years	Yield is reduced by 50 per cent and improves after 4-6 years	-	-
Puddling	Puddling is being followed since 40 years			Mechanized and manual
Months for preparation	May to Sept			
Purpose of brick preparation	For home before now commercialized	For home only	Personal	Commercial
Depth of soil for digging	2-3 fts	8inch to 1 ft before 20 years Now 2 to 2.6 ft	4-5 fts	-
Fertility improvement processes	Immediately after mud brick preparation, wheat crop is sown but previously alfalfa used to be grown Composting with sand	After brick making, wheat is sown if stones are there, fields are left for some years to gain litters. Compost, sheep for improving	Vegetable growing	-
Number of bricks from 500 sq metre (One Kanal)	One kanal produces about 30-40 thousand bricks	One kanal produces about 40000 bricks	-	-
Rate of preparing 1000 bricks	2006-07: 1000 bricks-1800/- 2013-18: 2500/- @ Rs. 8-12 per brick		-	-

	When fields are located in remote areas, rates are low if approachable, bricks are costly			
Types of soil in area	Nagal-Chushot East more Dambu Shaksha: Chushot west Less Dambu Paisa: South Chushot Less Dambu	Sabjang- clayey Nagal-Fine	Sandy loam	-
Strength of bricks	Clay silt: Chushot Halka: Thiksey	Hard	Hard	Standard
Foundation of house	Bricks based	Stones and bricks	Stones	-
Vegetation around	*Staphenomaria* *Cardaria* *Alfalfa* *Phragmites* *Convolvulus* *Peganumharmala*	-	-	-
Cement	-	-	-	Cement: bajri: Sand 1: 4:5 suitable for 40-50 bricks being made at 30-40 places
Compressive strength (MPa)*	1.8	1.7	1.3	15-25

(* McIntosh, 2014)

Strength of mud-bricks

Compressive and tensile strengths are the two properties, required by Earth and these determine the pressure (McIntosh, 2014). A good mud brick has a compressive strength of 1.6 to 1.9 MPa (Megapascal) when compared to clay fire-brick which has around 14. While concrete brick has compressive strength of 15 to 25 MPa. A mud-brick at 1.4 MPa is 14 times stronger than gravity, a clay-fired brick at 14 MPa is 140 times stronger than gravity or 140 atmospheric pressures. Tensile strength is found in all material with varied degrees. Here, concrete has low tensile strength and mud bricks can handle 14 atmospheres, but like concrete they have poor tensile strength. The tensile strength of a material is its ability to resist snapping and cracking. Mud bricks of Upper Tukcha and Chushot villages were tested for their strength. Both the bricks were dropped from waist height and it was found that Chushot mud brick is stronger than the Upper Tukcha villages of Leh district as both the soil materials are with different texture i.e. Chushot soil was dug deeper to 1.8-meter depth where silt and clay varied at different depths in a soil profile. Records reveal the sand silt and clay contents varied attitudinally i.e. 52.40, 35.08 and 12.53 per cent atv 10000-11000 feet elevation, while 63.21, 11.41 and 25.38 between 11000-12000 feet elevation, respectively (Charan et al, 2013). It indicated that Upper Tukcha had less clay per cent as compared to Chushot village. A test was carried out to measure the strength of mudbricks of both villages using technique suggested by McIntosh, 2013 (Fig. 2). Test revealed that the mud brick of Upper Tukcha broken into 2-3 larger pieces (with 1.3 MPa) while Chushot mudbrick didn't break besides few scrapings from corner and recorded as fantastic (1.8 MPa). In many of the cases in the light of modernization, many houses and guest houses have initiated utilizing concrete bricks in their bathrooms and kitchen where seepage is expected more.

Figure 2. Comparative strength of mud brick of two spots (Chushot and Upper Tukcha)

4. Conclusion

The study revealed the soils of identified villages, known to prepare mudbricks had varied silt and clay contents and their strength due to varied elevations. The soils used for mudbricks were again cultivated for growing alfalfa fodder crop to rebuild the productiveness of the dug soils to a depth of 2 metres. In mudbrick, if clay is mixed with straw works like steel in concrete. In case of Ladakh region where temperature dips near to lower level of -30 degree, should have straw-based mudbricks for enhancing insulation. So, there is a need to add straw while making mud-bricks to give more tensile strength as well as insulation value during harsh winter. In addition, the outer wall thickness should be around 28 inches to strengthen the weight and safety from the rainfall.

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