The Comparative Study on Vernacular Dwellings in Bhutan

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***Abstract*—** Bhutan is a small developing nation sandwiched between China to the north and India in the south. Traditional construction techniques range from rammed earth to bulky stone masonry which is in some degree similar to the neighbouring countries such as Tibet, Nepal and northern India. However, Bhutanese vernacular structures are unique and it significantly contributes to the already rich cultural heritage. Epitome of traditional construction in Bhutan can be dated back to the 17th century during which many of the dzongs (Bhutanese administrative buildings) and Lhakhang (temples) were constructed. The traditional construction typology of Bhutan can be classified under rammed earth, stone rubble masonry, adobe block, ekra (wattle and daub), timber houses and bamboo houses. Many of these structures were constructed without pre-prepared drawings. The construction would proceed on site under the vision of a head carpenter/mason. The paper presents the different types of un-engineered houses/dwellings in Bhutan, its construction methods and their structural integrity and configuration.

***Keywords*—** vernacular structure, rammed earth, wattle and daub, adobe block, jamthog, dzongkhag.

INTRODUCTION

The Kingdom of Bhutan is located in the eastern Himalayas, landlocked between China and India. The 38,686 square kilometers of mountainous country spans at an elevation ranging from about 160 meters in the southern region to more than 7500 meters in the northern region. The general climatic conditions are subtropical in the south, temperate in the central region and alpine in the north.

The total population of the country was 757,042 and over the past several years, urbanization and infrastructure development has increased at an alarming pace (Department of Human Settlement, n.d.). The first recorded buildings in the history of Bhutan were the temples built around the 6th and the 7th centuries. The main building materials were stones, compressed earth (mud), woods and bamboos. Wooden shingles were commonly used for roofing as there were no other alternate materials (Traditional Architecture Guidelines, n.d.). Initially, buildings in the inner Himalayan valleys of Bhutan were constructed from rammed earth in the western region and quarried stone in the central and eastern regions.

Villages in the inner Himalayan valleys, which are the focus of this study, were developed at the base of mountain slopes overlooking fields and a fast-flowing river.

Villages typically consisted of a number of dispersed farm houses often loosely grouped around a Lhakhang (temple) or it is located in close proximity to a Dzong (fortress) built at a strategic point of the valley.

2. THE VERNACULAR STRUCTURES IN BHUTAN

The traditional construction typology of Bhutan can be classified under rammed earth, stone rubble masonry, adobe block, ekra (wattle and daub), timber houses and bamboo houses.

However, as per the interview with the local craftsmen there were historic records of some composite vernacular structures like wattle and daub over rammed earth ground floor and timber compartment over stone masonry ground floor. Some of these construction topologies in Bhutan are discussed below:

2.1 Rammed Earth Houses

Rammed earth construction of Bhutan is distinctive with its own architectural components and features. The construction practice is grounded based upon the past knowledge of the craftsmen and their thumb rules. The rammed earth construction is predominant in western Bhutan(Jentsch et al., 2017). However, similar houses can be seen in central Bhutan as well. It consists essentially of foundation, rammed earth walls, timber floors and roofs. Most of the dwelling units have attic covered by half gable roof known as Jamthog over main gable roo f(Traditional Architecture Guidelines, n.d.). This is essentially used for various basic purpose like drying space.

Figure 2:Bhutanese rammed earth house (Department for Conservation of Heritage Sites,2015)

2.1. 1 Foundation

Foundation comprises of strip of stones layered typically as shown in figure 2. Most often thin paste of mud mortar are placed at the intersection between foundation and super structure(earthquake resistant Construction Training Mannual, 2013). It will create a levelled surface for rammed earth above. Traditional wooden formwork is arranged over the top of stone foundation to begin with wall erection.

Figure 3: Foundation section (left) and work execution(right) for rammed earth houses.

The dimension of the footing obtained from mason's interview which were verified after multiple field visits is tabulated below.

No of floors	Depth of foundation	Width of foundation	Plinth height
1-2	1.2m	0.9m	0.6m-0.9m
3	1.8m	1.05m	0.6m-0.9m
4	1.8m	1.2m	0.6m-0.9m

Table 1: Foundation Dimensions

2.1.2 Rammed earth wall

Good quality soil (Clay: 18 – 22% by weight, Silt: 40 – 45 % by weight and Sand: 30 – 40% by weight) (earthquake resistant Construction Training Mannual, 2013) sourced locally is mixed with desired quantity of water and is rammed to form wall. The texture of the mud used is generally light brown, with some red and dark earth mixes. In some cases, the use of a significant amount of sand is visible at the lower band of the blocks (Ministry of Works and Human Settlement, 2013). The wall directly rests on top of strip foundation. Each layer is thoroughly rammed before subsequent layers are placed. Although in some buildings it was not possible to see the various layers of compaction, since the walls are totally plastered by mud mortar. The visible mud layers are generally irregular, with varying thicknesses between 50 mm and 140 mm, having an average of 100 mm. Each block has around 5 and 9 compaction layers, with an average of 6 layers. The thickness of the walls of the rammed earth houses varies between 580 mm and 770 mm, with an average of 630 mm. Although most walls have the same thickness from the base to the top, there are exceptions, with a difference of 100 mm between the base and top of the wall (Chettri, 2018). There is overlap at the corners in the connection between transverse walls. Typically, such houses rise up to three storeys of maximum.

Figure 4: Shuttering for wall erection (left) and rammed earth wall compaction process(right)

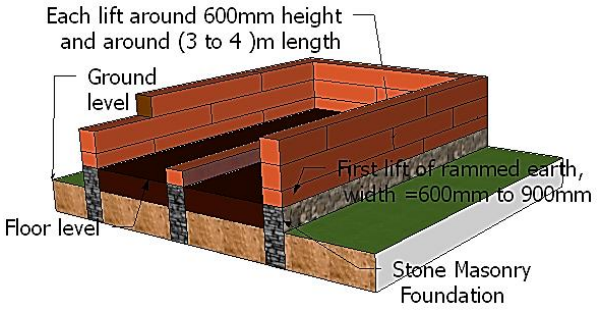

Figure 4: Construction configuration of rammed earth Walls and Foundation.

2.1.3 Flooring

The floors of traditional Bhutanese rammed earth houses are constructed of wooden structures. It consists of wooden joist usually measuring (80 × 100 mm),

(130 × 150 mm), (160 × 140) mm or (120 × 220) mm, spaced between 300 mm to 1000 mm. The spacing of the joist is decided by the carpenter based on his convenience and his past experiences. In some cases, is also decided by the house owner to increase joist number based on his wealth.

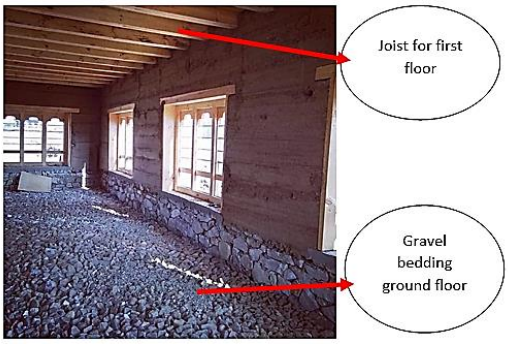

Figure 5: Gravel bedding for first floor and joist for second floor visible

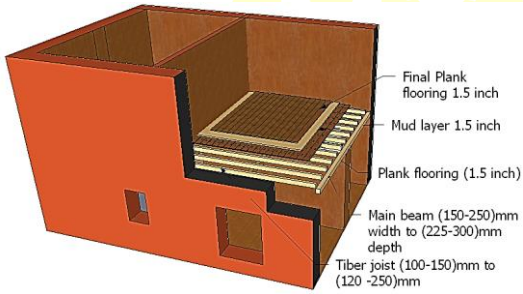

Figure 6: Floor joist and flooring configuration

On some floors there is a second alignment of transverse main beams to the first, usually of cross-section of (150 × 300) mm and (200 × 240) mm. Sometime bearers are provided over the shear wall to bear the joist. Location of the bearers are decided based on the dimension of the floor and distance between two consecutive shear walls. If the distance between the shear walls is more, bearers are placed in between so that the length of joist is reduced. Above these joists, there is a layer of wooden planks of varying length and width of usually 30mm to 40mm depth. The different types of the wood are being used but in Bhutanese traditional building, wood that are available in the locality are preferred for the flooring(Promotion of Timber as a Construction Material, 2017).The most commonly used wood for flooring of Bhutanese traditional building are chir pine and blue pine. Over these planks 30mm to 50 mm thick mud layers are placed and finally this earth layer is followed by second layer of wooden planks of usually 30mm to 50mm thick and 20 mm to 1000 mm in width. In the case of roof attic floor, the layer of compressed earth is thicker and may reach up to 200 mm but without the top layer of wooden planks.

2.1.4 Floor Joist

Joist is the horizontal structural member used in framing to span between the mud shear wall or two bearers that subsequently transfer loads to the vertical members(Langenbach, 2010). Floor Joists are most important part of the supportive structure of the floor. They hold up the weight of the floor and transfer the load either to bearer beam or shear wall on which it rests. It is the part of subfloor which must be designed to provide support to the flooring and make the building itself more rigid and stable to withstand years of heavy use.

2.1.5 Roofing

A Bhutanese roof is distinctive and is characterized by large overhangs and is simply supported on the wall. Traditional roofing materials were mostly the wooden shingles and slates in the eastern, central and western part of Bhutan until the early 1960s(Om, Gyeltshen, & Lama, 2015). Most of the wooden shingles were replaced, more or less recently, by CGI sheets (Corrugated Galvanized Iron). The roofs were usually placed on wooden pillars that rested on walls built above the attic (cholo), or on the structure of the attic floor. The trusses (dingri) of the roof and the abutments on which they are supported are not positioned directly on the main walls, but discharged on additional walls (cholo) built above the attic level and on wooden structures made of blocks of wood and boards(Chettri, 2018). Two most prominent roof types found in Bhutanese Traditional residential buildings are gable roof and hip roof(Traditional Architecture Guidelines, n.d.). Gable roof is the standard traditional roof found in Bhutan. And the hipped roof is a new form of roofing gaining popularity in Bhutan with the advent of new materials like corrugated sheet and roofing tiles(Ministry of Works and Human Settlement, 2013).

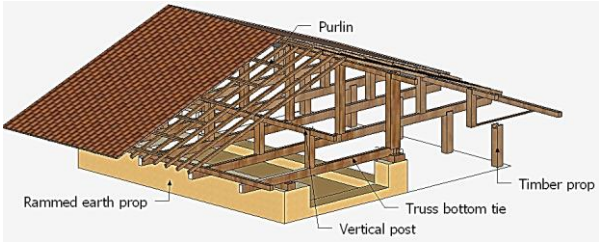

Figure 7: Layout of Traditional Roof truss and its elements

2.2 Stone Rubble Masonry

Most of the houses in eastern and central Bhutan comprises of stone masonry. A typical masonry wall consists of piers between openings and a portion below the openings known as sill and above the openings is

called spandrel. However, stone masonry houses can be also found in southern Bhutan as well, especially in Tsirang and Samtse. Overall geometry and configuration of stone masonry is same as rammed earth houses. These houses have some basic difference to stone masonry houses of eastern Bhutan. The stone used in eastern Bhutan are rounded or cubical where as those in southern Bhutan are much flatter. Most of the stone masonry houses in central and eastern Bhutan are not plastered compared to the mud plastered dwellings of the south. Additionally, timber is used much more lavishly and elaborately in the other regions than the south. People in the southern Bhutan usually prefer one-meter width of cantilevered balcony. It helps them to monitor their crop from wild pest as well as protect from harsh climate. Figure 8 and 9 shows pictorial representation of the foregoing description.

Figure 8: Various Type of stone masonry structure in eastern Bhutan (MOWHS)

Figure 9: stone masonry house (right) in southern Bhutan, left thatch roof covering

2.2.1 Foundation

The basic integration and layout of foundation resemblance that of rammed earth houses. However, there are some dimensional differences. The minimum depth of the foundation should be one metre. The minimum width of the foundation should be 2 times the wall thickness for two storied and 1.5 times the wall thickness for one storey. The thickness of footing should not be less than 450mm for one storey and 600mm for two storied. It is preferable to have larger stones for foundation (earthquake resistant Construction Training Mannual, 2013).

2.2.2 Stone masonry walls, Floor, Joist and Roof

Stones with mud mortar available in the locality are used for the wall construction. Houses investigated in central and eastern Bhutan were mostly found to have cubical stones whereas few people have also used flatter like in south. The thickness of the wall is around (0.4-0.6) m. These walls are mostly not plastered or finished with lime washing. Comparatively flatter stones are laid over the walls found in southern Bhutan especially in Tsirang, Dagana and Samtse. Its thickness is around (0.6-0.8) m and are finished with thick mud plaster (40-50) mm. The layout of the joist and roof remain same as in rammed earth house. Detail layout of floor joist is shown is figure 10 and 11. The roof covering used in eastern Bhutan are mostly shingles whereas vernacular stone masonry in south comprises of thatched/ straw as roof covering.

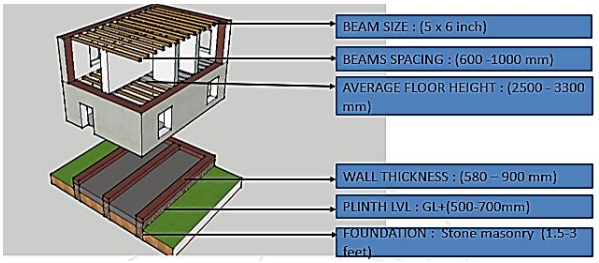

Figure 10: Overall configuration of stone masonry houses

Figure 11: Timber joist over stone masonry wall

2.3 Adobe Block (Mud Bricks)

Masonry with adobe are crude air-dried, unbaked, bricks, possibly reinforced with straw, also called mud bricks (Damme & Houben, 2018). It is a very simple and also a very ancient technique practiced by Bhutanese. Adobes are generally made by filling a wooden mould with moist earth and demoulding the crude brick as soon as the mould is full.

Figure 12: Mud brick house in Wangdue Dzongkhag (District)

Figure 13: Bhutanese mud bricks (Bhutan Green Building Design Guidelines)

Adobes are moulded in the soft or plastic state, with earth(Ministry of Works and Human Settlement, 2013).Soil suitable for manufacturing adobes can be found in central and western Bhutan. The particle size distribution has an upper cut off around a few millimetre (this can be obtained by sieving) and their clay content is generally between 10%to 30%.

2.3.1 Foundation and Super structure.

It has similar foundation system as discussed in case of rammed earth houses. Mud bricks (15 to 20) cm width and (30-40) cm length are laid over this stone foundation. The rest of the components of super structures are laid in same manner as houses discussed for rammed earth.

2.4 Wattle and Daub (Ekra)

As per the survey carried out in southern Bhutan especially in Dagana, Tsirang and Sarpang several villagers had wattle and daub houses. The remains of such houses were observed in Sarpang during the site visits as shown in figure 14. It provides great freedom of shapes, in particular for curved walls which are structurally more stable than rectilinear walls with right angle joints(Damme & Houben, 2018)

2.4.1 Foundation and super structures

Excavation of around 0.6m to 1m is done which is filled with stone soling. The top surface of the soling is smoothened with mud layer over which timber member are placed around the periphery. Similarly, vertical timber member (3 x 4) inch or (2 x 3) inch framing system is formed. Bamboo lattices are woven along these frames. In some of the cases these lattices are left un plastered. The mud mixed with straw is pressed against the woven lattice of bamboo strips. Wattle and daub technique is mostly adopted in a single storey and low-cost houses. Wattle and daub composite compartment first floor were also significantly constructed over rammed earth walls in the past as shown in figure 15(Vasconcelos, n.d.).

Figure 14: Wattle and daub house (left) and old remains of wattle and daub house (right)

Figure 15: composite wattle and daub over rammed earth ground floor (João M. Guedes et all).

2.5 Timber and Bamboo Houses

In northern places like Gasa, Bumthang and Phobghikha house made up of timber are preferred owing to its climatic benefits. The outer cover of tress (bakal) are sawn out and used as shown in figure 19.

Composite structures such as the one shown in figure 17 are variations that are being adopted(Sethna, 2008).The residential house in southern Bhutan comprises of finished timber planks used as infill material for timber post and framing system as shown in figure 16.

In the places like Tsirang, Sarpang and Dagana bamboo houses were predominantly constructed in the past although the practice has declined nowadays.

Figure 16: Wooden (bakal) house (left) in Thimphu

dzongkhag and well finished timber vernacular house in Tsirang dzongkhag.

Figure 17: Composite timber first floor supported by brick masonry(left) and rammed earth (right) in ground floor

Figure 18: Bamboo house in the Tsirang dzongkhag (district) Bhutan.

CONCLUSION

The work presented in this paper is the compilation of field visit across different parts of Bhutan and the result of interview with the local carpenters. It has been observed that people in different regions of Bhutan has come up with houses that are compatible with local climate, material and with the environment. Across the country, dwellings differ from basic geometry to some little differences in structural features. Most houses remain almost same in the east, west and central Bhutan. However, vernacular structures existing in south differs from others which are mainly to suit the extreme heat in the summer. These vernacular structures are still constructed in many parts of rural Bhutan although it has declined in urban areas. As per questionnaires with house owner in urban areas it has been noted that social status and their standard have been the determining factors over choosing reinforced cement concrete houses over the vernacular structures. However, there are necessities to carry out further research on thermal building performance, lighting efficiency, vulnerability to disaster and seismic performance of all the vernacular structures discussed above. Whilst basic architectural design elements have been retained in the newly built vernacular structures in Bhutan, the construction methods have however changed over recent decades.

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