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Exploring Traditional Nepalese Building Techniques and Timber's Role Structural Integrity

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***Abstract*— This paper aims to explore traditional Nepalese building construction techniques and the significant role of timber in enhancing the structural integrity and longevity of these buildings. With a long history of utilizing materials that are readily available locally, particularly wood, clay, stone, Nepal a country renowned for its rich architectural legacy has built buildings employing these resources. The study delves into the various traditional building techniques employed in Nepal, including the intricate craftsmanship and cultural significance associated with them. Additionally, it investigates the unique properties of timber that make it an ideal choice for construction in the Nepalese context.**

The finding talks about the construction of buildings various techniques which are employed to assemble structures. This includes information, on building materials, functional space allocation and the terminologies used in building construction. These terminologies hold value as they are derived from our tradition, in building construction technology. The findings of this research can serve as a valuable resource for architects, engineers, conservationists, and policymakers involved in the restoration and sustainable development of traditional Nepalese buildings.

***Keywords*— "Construction technology, longevity, Structural integrity, Traditional techniques, Building materials."**

Introduction

The traditional building construction techniques of Nepal have long been admired for their architectural beauty, cultural significance, and resilience in the face of natural hazards. Nepal, a country tucked away in the magnificent Himalayas, is renowned for its rich history of traditional architecture that showcases an amazing fusion of skill, cultural identity, and environmentally friendly building techniques. Nepal's traditional building methods have developed over ages, influenced by the region's physical, climatic, cultural, and historical factors. These techniques reflect a deep understanding of the local environment, seismic considerations, and the efficient utilization of available resources.

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As Nepal embraces modern construction practices and materials, it is crucial to recognize the value and wisdom embedded in the traditional building techniques and timber utilization. By studying and understanding these traditional practices, we can gain insights that inform sustainable, resilient, and culturally sensitive building practices, not only in Nepal but also in other parts of the world facing similar challenges.

Literature

A. Introduction to traditional Newari dwelling

The typical architecture of Newari dwellings is either built in rows leaning one against the other, facing the street, or in quadrangular shapes creating courtyards. Regardless of social class, dwellings are typically rectangular or quadrangular in shape.

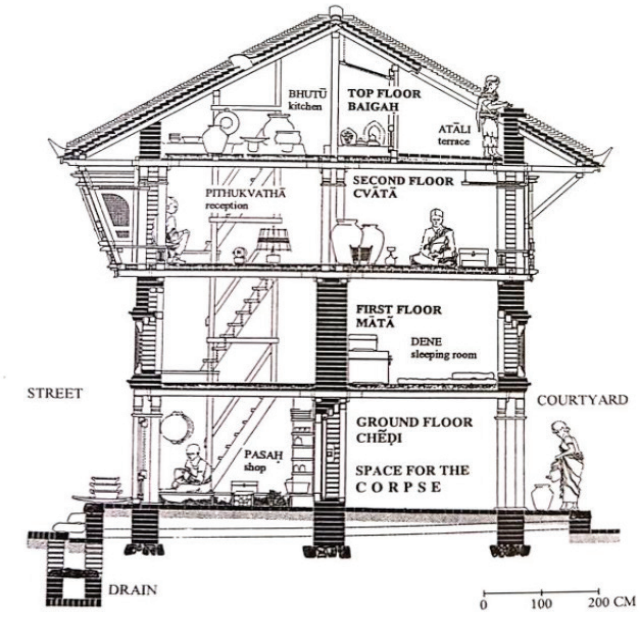

Fig I: Section of a traditional Newari Building (Gutschow, 1987)

The typical traditional Newari house has a rectangular floor plan and is built up to three stories. The plan typically has a depth of six meters and façades that range in width, but are typically four to eight meters with a height between 2.3 to 2.5 meters [1].

B. Floor plan and it's usage

Each floor has given floor specific name such as "Chheli" as the ground floor, "Matan" as the first floor, "Chota" as the second floor and "Baiga" as the attic. Depending on the socioeconomic position of the occupants, the floor appears to be used differently. It appears that all social strata use the matan and baiga floors in the same way. Most commonly the matan is used for bedroom, sitting room and the treasure room whereas the baiga is used as the kitchen and puja room. However, the usage of the two floors namely chheli and chota found to be varied depending on the occupation of the occupant. If the occupants belong to farming community, then chheli is generally used as storage of agriculture implements, if Silpakar (wood carver) then as workshop. Similarly, business community used it for shops and warehouses of their merchandise goods. The chota being the widest space it is generally used as family gathering, holding feast primarily across all social strata.

C. Building Materials

1) Brick: Two types of bricks were commonly observed in use: the standard sun-dried bricks, which had dimensions of 210 x 105 x 50 mm, and the specially burnt bricks known as "dachi-appā," which have the same dimensions but are shaped like trapezoidal cross section. On the outside course of the façade, the dachi-appa is especially utilized.

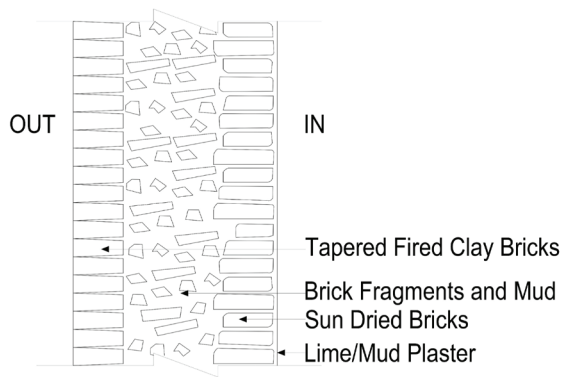

Fig II: Section of wall showing two types of brick

2) Roofing tile: The aypa roofing tile is a typical design that measures 190x90x18 mm and is constructed of clay cooked in a kiln. A mould is used to create a small longitudinal groove on one side of the tile, and once the tile is removed from the mould, a second groove is manually created on the other side using water. These grooves are meant to interlocking of the tiles in roofing [2].

3) Clay: The most common building material utilized from very far back in time is clay. Clay is typically used in traditional homes to unite brick or stone masons for the walls and roof. Various varieties of clay are utilized in building; among them is the grey/black clay that is frequently used to make bricks and tiles. White clay is generally used for internal and externall paintings. Yellow clay is used between the joints of trapezoidal-cut bricks to prevent water seepage inside the walls since it is believed to have water-resistant properties [2].

4) Wood: The primary timber components found in traditional homes include doors, windows, purlins, rafter, beams, columns, door leaves, stairways, joists, struts. Traditional houses utilize wooden pegs, nails, or wedges to link or unite various wooden structural components.

5) Stone: The ground floor columns of typical Newari houses are supported by columns made of base stone, called ilohan in the local language, and the foundations. Typically, natural or irregularly shaped stones are used for the foundation of homes, and they are mortared together with clay.

Casestudies

To learn about the traditional practices and methods of two distinct locations, I have selected two Newari traditional buildings for my studies: one in Dhulikhel and another in Lalitpur

A. Case Study of Laxmi Dhoju House-(Dhulikhel)

This house is located in Kwachha Marg, Wo- tole, Dhulikhel orientated to the North-East. The house owner's name is Laxmi Dhoju. It was constructed in 1985 B.S. It was later renovated and reconstructed in 2060 B.S. It is a four storied building with a total floor area of 70.04 square meters. It has a load bearing structure with bricks collected from Bhaktapur and local materials.

This house has red paint in the façade, made up of brick and mud plaster with beautifully carved wooden windows. The ground floor has cement plaster on its facade, where it used to be brick and mud plaster.

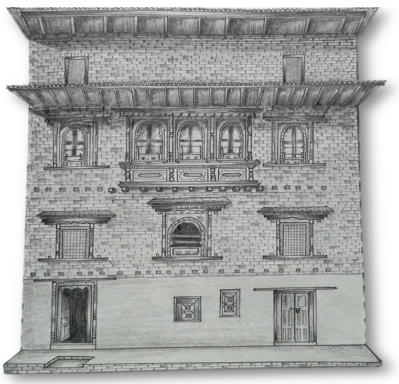

Fig III: Sketch of house

1) Floor plan and its usage: The main door leads to a lobby space with two toilets and another door leads straight to the

bedroom which is rented now. The ground floor used to be a storage space where it is all empty space now.

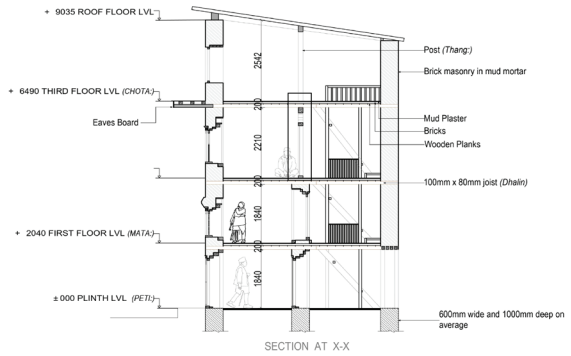

Fig IV: Ground Floor Plan

Walls on the ground floor typically have a minimum thickness of 50 cm, with the thickness decreasing as one moves up the levels. The building's substantial base and enormous wall construction were intended to make the home earthquake-resistant. A staircase often consists of one flight to one side of the layout, usually at the back bay, and it circles the house clockwise as it ascends to higher levels, treating the home as a hallowed shrine.

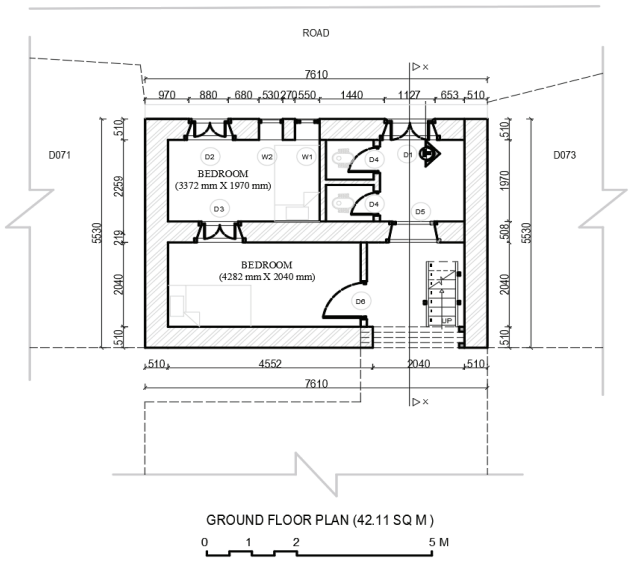

Fig V: Section of the Building

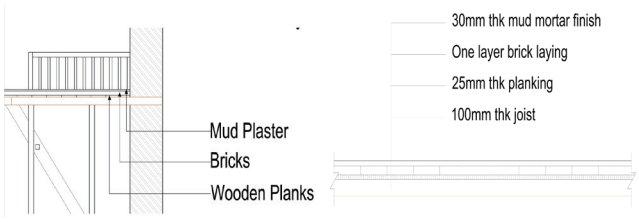

Fig VI: Section of Floor Detail and Floor Detail

2) Flooring: Simple rectangular battens, which serve as the foundation for laying boards, are used to construct floors. In this building flooring consist of wooden plank, brick soiling and on the top that mud plasters.

On the top of 100 mm joist, 25 mm plank are rested perpendicular to the Dahlin and on the top of 25mm plank, 55mm brick soling is done and on the top of the brick soling 20mm mud plaster is placed.

3) Door: Newari doors are renowned for their exquisite woodcarvings. Common motifs include geometric patterns, floral designs, mythical creatures, and religious symbols.

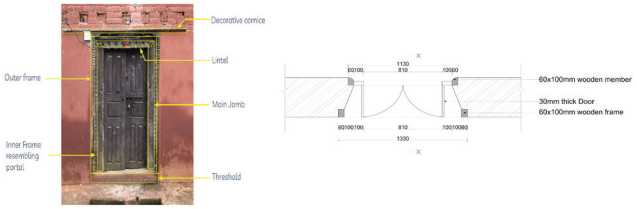

Figure VII: Entrance door and plan of door

As we can see the two inner jamb as the structural member of the door from inside the building which are tie together with crossties. The door leaf is supported by the main jamb. We can see the sliding door bolt which act as the chukul system in the door and it is supported by the two-bolt holder. The frame of the door is tie together with the help of the cross tie. Overall, Newari traditional door mechanisms are a testament to the rich cultural heritage and craftsmanship of the Newar community. They showcase a blend of practicality, artistry, and cultural symbolism that continues to fascinate observers and serve as a reminder of Nepal's diverse architectural traditions.

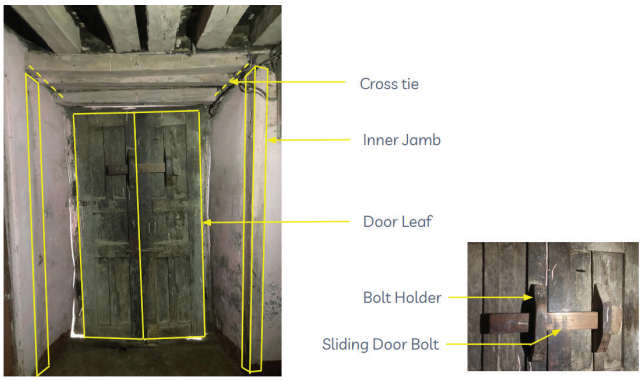

Figure VIII: Structural part of door

4) Window: The windows of traditional Newari buildings share similar characteristics with the doors, reflecting the Newar community's artistry and cultural heritage. The bottom part of the window is the sill, while the top part is the lintel. Both the sill and lintel may have decorative carvings and serve as essential structural elements that provide support to the window frame.

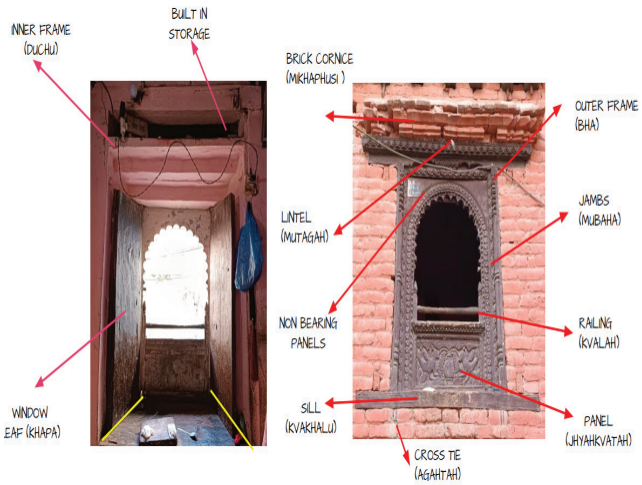

Figure IX: Structural member of the window

Construction technology of the window is similar to the door, window will also have the two-member inner member and the outer member and this member are tie together with the help of cross tie and chuku. These two cross ties are provided at the top of the frame and bottom of the frame and it hold two members strongly so that at the time of the earthquake there won't be any kind of damage to the structure.

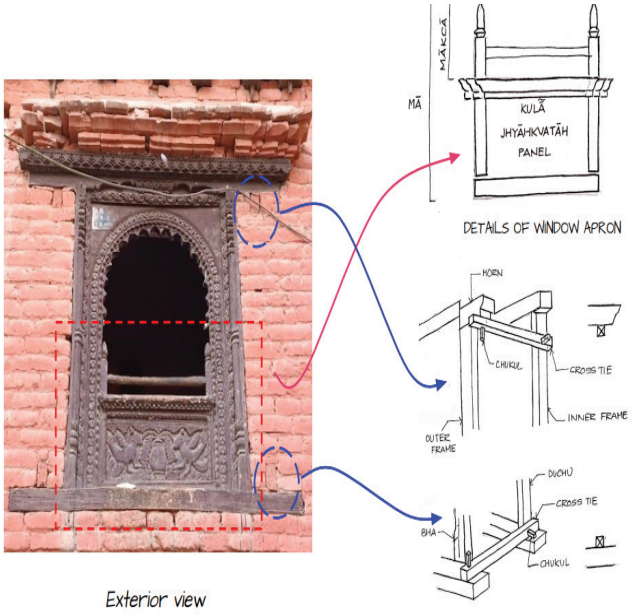

Fig VII: Structural Detail of the Window

5) Sa- jhya detail: Sa jhya is one of the mostly used window in the Newari art of wood carving to the vibrant cultural and artistic boundaries in Nepalese architecture. Centrally placed Sa-Jhya. The window frame is divided into three vertical sections, and each section contains a unique lattice design made from wooden strips. These lattice patterns often incorporate geometric shapes, floral motifs, and cultural symbols, showcasing the exceptional craftsmanship of Newari artisans.

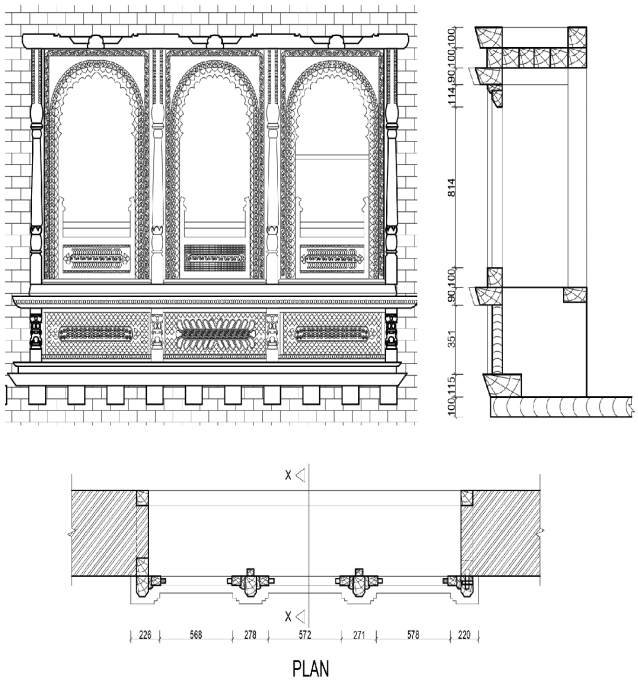

Fig VIII: Details of Sa-Jhya

6) Tiki jhya and window detail: This product is a wonderful Ankhi Jhyal also known as Tiki Jhya locally (grilled window) found in traditional houses of the Newar community; hand-carved by one of our skilled woodcarvers of Bhaktapur. This window has been made completely by interlocking carved pieces of wood at different angles. Three different kinds of slender batten are swan from a plank, carved into decorative geometric design and then fitted into another, either at right angle (macika), 45 degree (icika) or 50-60 degree (rusipu) [3]. This window is usually located on the second floor because it allows light and air to enter the room but restricts the passersby to have a peek inside. Glass had not been used until recently, so the wood carving which is covered in a patterned wooden lattice, and often of unbelievable intricacy.

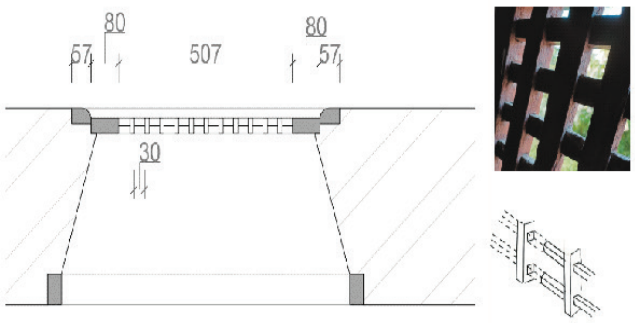

Fig IX: Batten joints for lattice work in tiki jhya

window will also have the two-member inner member and the outer member and this member are tie together with the help of cross tie and chuku. These two cross ties are provided at the top of the frame and bottom of the frame and it hold two members strongly.

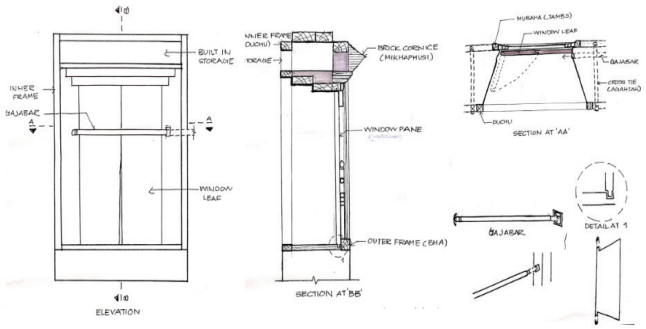

Fig X: Structural Details of Window

7) Joist (Dhalin): There is no beam in floors around the perimeter of the house area which is a necessary component as without the beam the load directly goes to the wall and it causes joist and wall damage. The second floor has a beam but not on the periphery but only in the internal wall. The top floor has 3 beams lining up parallelly to each other. The cross-section size of Dhalin (joist) is gradually being changed and also the spacing of joist has been changed from compact to expanded form in different floors.

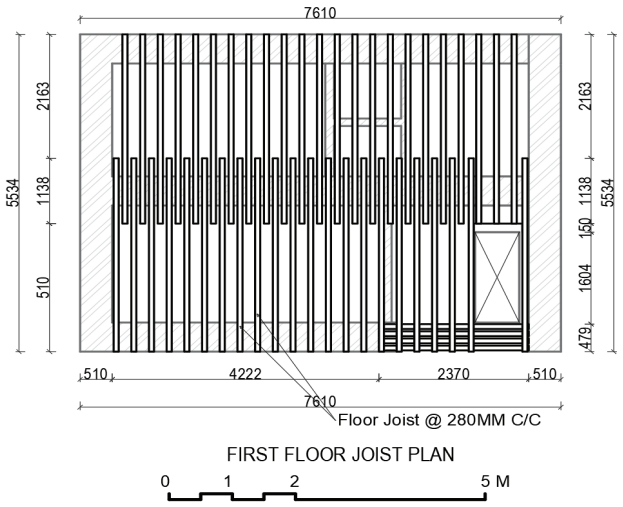

Fig XI: Joist Plan

The cross-section size of the joist is 100X80 mm and in this joist arrangement we did not see the placement of the chuku which ties joist and the beam firmly. There is middle wall which acted as the beam and joist were rested on the wall directly.

8) Staircase: The most popular type of stairway is those with seven to nine steps that are steep and narrow. The lowest floor discovered in this building is 2.04 meters high, while the highest is 2.5. Most often, the staircase in a building is located close to the front door, facing either north, east, or west (mu: lakha). Due to religious considerations and beliefs, no staircase (swona) is directed in the direction of south. The staircase is located on either side of the façade wall, or external wall, which is called the central wall (dhatu aanga) of the building.

Fig XII: Staircase

Furthermore, a staircase is always placed and positioned parallel to a joist (dhalin). The other main dhalin (joist), which serves as the resting spots for the staircase (swona), is parallel to a shorter dhalin that is positioned perpendicular to it. It is referred to as a half joist (betwadhalin), which is about equivalent to the principal dhalin (joist) size. A void (space) is created by the placement of this half-joist, or betwadhalin.

9) Roof: The traditional tiled roof is made with combination of timber and thick layer of clay. The entire roof is supported by number of loads bearing wooden columns and the the ridge beam rest on the center pillar known as “Dhuri than”. Two principal rafters are tied up in the central pillar. The rafter leans against the lateral wall on the wall plates. Loads coming from the rafter is point load whereas this wall plates distribute the point load equally to the wall. Purlins rest on the principal rafter whereas the secondary rafter rest on the purlins.

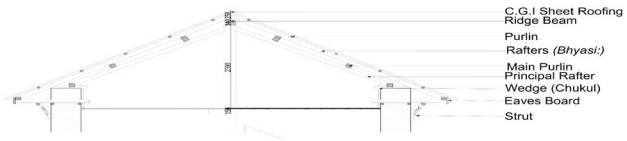

Fig XIII: Roof Detail

D. Case study of Shrada Shrestha house- (Lalitpur)

The building was constructed two or three years following the devastating 1934 earthquake (1990 B.S.), according to the owner's grandmother which indicates that the structure is roughly 76 years old. The house, originally used by a single family, has been acquired by multiple family members over time. The upper part has been damaged, the front face is in ruins, and the skirt and upper roof have been damaged by rain. Restoration measures have been taken for private use [4].

1) Floor plan and its usage: There are two rooms in the ground floor, one given on rent and other used for storage. Toilet on the North West corner lacks ventilation and the space under the staircase has been used.

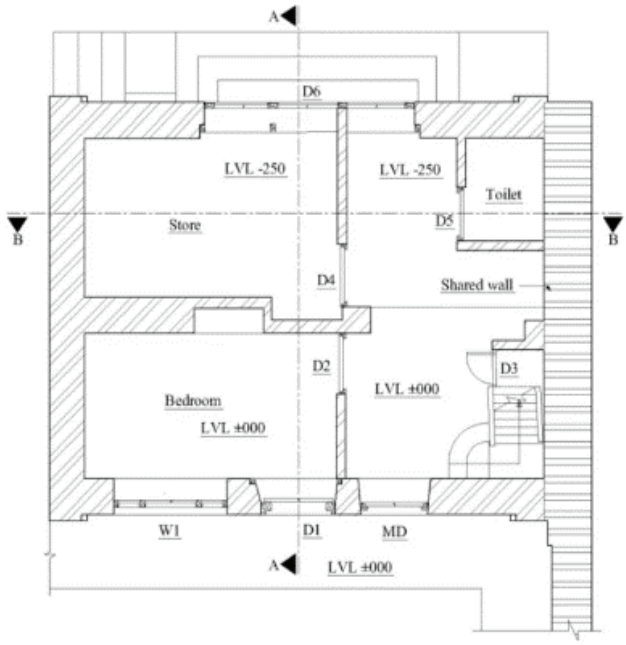

Fig XIV: Ground Floor Plan (Amit Pokhrel, 2012)

The first floor seems to be quite intact in terms of traditional Rana building characters like vertically extended windows, less decorative wooden post, and wooden planking with mud flooring above. The second floor also seems to have gone through modifications like use of new modern glass windows on opposite walls facing east west. It has been used as living room and top floor has been used as the kitchen.

2) Flooring: The floor is another important part of the Newar dwelling. The floor are mainly two types: one is internal floor and other is external floor. Among the internal floor, the common floor is Dhalin+ kolapu+cha+ siyucha and Dhalin + kolapu + cha + chikanapa.

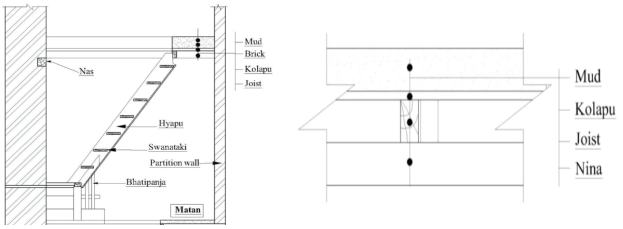

Figure XV: Floor detail (Amit pokhrel,2012)

The above-mentioned flooring can be seen in the first floor and the third floor. while a layer of brick soling with thick floor has been observed on second floor. This kausi is constructed as similar to internal floor: the major difference is only in the placement of kausi paancha in place of normal cha.

3) Opening and member ties: Traditional Newar dwellings feature double frame openings, Lukha and Jhya, with external and inner posts made of timber members called tan. These posts are joined by chuku or sa joints. The system of joining Jhya and lukha is similar to older ones, using various types of joints like Thapu, Chuku, Kopu, Chuku Sa: dog matting, dove tail, and bearing joints. New doors and windows are assembled using holdfast and nails.

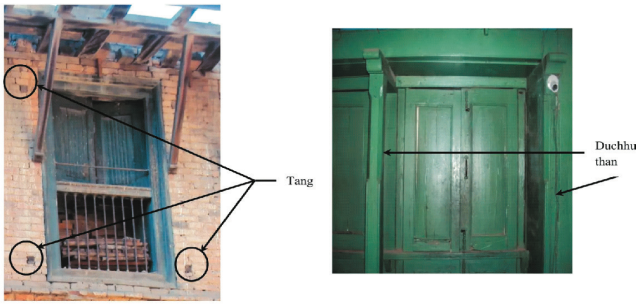

Figure XVI: Tang and Duchhu than on window

Like the door, the window is built using a similar method; it has an inner and an outer component that are connected by cross ties and chuku. Two members are securely held together by these two cross ties, which are provided at the top and bottom of the frame, so that the structure won't be harmed during an earthquake, as shown.

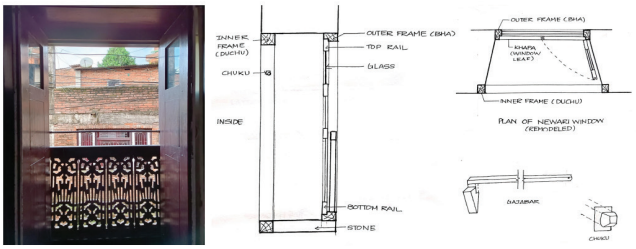

Fig XVII: Window Details

4) Dhalin (joist): Dhalin (joist) is the horizontal structural member which holds the different weight of ba: (floor). Dhalin are placed closer in the Newar style dwelling. On the case of this building, dhalins are being closely placed together on the ground floor and second floor. While on the first floor they are being placed at certain gap compared to the lower floor.

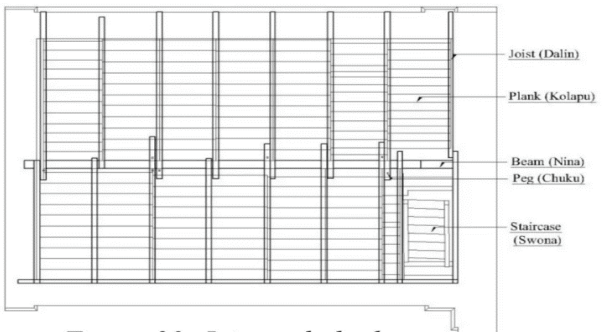

Fig XVIII: Joist Plan

The cross-section size of Dhalin (joist) is gradually being changed and also the spacing of dhalin (joist) has been changed from compact to expanded form in different floors.

5) Nila (Beam): Nila is the primary beam which carries the whole load of the dwelling. The nila (beam) has been placed in mattan (first floor), chota (second flor) and upper floor replacing dathu aanga (central wall). This is rest on the than (post) which may be single or double according to the building volume.

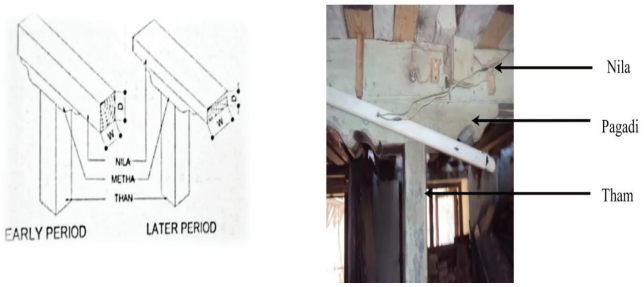

Fig XIX:Orderly placement of vertical member supporting floor

6) Rafter (Musin): Musin (rafter) is a structural member which holds the weight of kolapu (wooden peices- planking), cha and polan apa (roofing tile). This is an inclined member called rafter, is rest on the thayma, a ridge beam. The size and spacing of musin (rafter) are different in different dwellings. The musin (rafter) had been provided earlier on this building but most of them were already removed during our study period.

7) Staircase (Swona): Most frequently used are steep and narrow flights of steps with seven to nine steps. The height of the storey rarely exceeds 2.10 m to 2.20 m. In this building, the minimum height of the floor found is 1.70 m and the maximum is 2.

Fig XX: Staircase of First and Second Floor

Mostly the staircase in the building is placed nearby the main door orienting either north or east or west direction (mu: lakha). no staircase (swona) is oriented to south direction because of the religious aspects and belief. The staircase is either rest towards central wall (dhatu aanga) of the either side of facade wall i.e., external wall (pithu aanga). and also, staircase is always placed and positioned parallel to the dhalin (joist). A dhalin is shorten and placed perpendicular to the other main dhalin (joist) which is the resting points of staircase (swona). This is known as half joist (betwadhalin) more or less similarly to primary dhalin (joist) size.

Comparative Chart

Table 1

Comparative Chart

Elements	Literature	Case-1	Case-II	Inferences
Foundation	0.60 wide & 1m deep, 0.45m above G. L	-	2m deep & 0.7 m wide	0.60 wide & 1m deep, 0.45m above G. L
Wall Thickness	200mm to 600mm	510mm	520mm	200mm to 600mm
Plan of Building	Symmetrical plan, L/B< 3	L-7.6m & B- 5.5m	L- 7m & B- 6.5m	Symmetrical plan, L/B< 3
Band	Use of collar band or single band	No use of band	No use of band	Band helps to distribute load evenly
Floor height	2.3 to 3.5m	2 to 2.5m	1.7 to 2m	2.3 to 3.5m
Staircase	Seven to nine steps, north or east orient	Seven steps, orient to north	Seven steps, orient to north	Seven to nine steps, north or east orient
Flooring	Dhalin+ kolapu+cha+ siyucha. Dhalin + kolapu + cha + chikanapa.	Dhalin + kolapu + cha + chikanapa.	Dhalin+ kolapu+cha.	Dhalin+ kolapu+cha+ siyucha. Dhalin + kolapu + cha + chikanapa.
Door	The access doors do not exceed 70x160 cm. Double frame system	85x180cm. Double frame system.	75x152 cm. Double frame system.	The access doors do not exceed 70-90x200cm. Double frame system.

Analysis and Findings

A. Repair and Construction Techniques

1) Brickworks (Foundation and wall): The Jaga is a robust underground structure made of masonry stone blocks in trenches, typically 0.60m wide and 1m deep, that transfers the superstructure's load to the ground and is typically extended by 0.45m to protect the brick walls from rainwater [5].

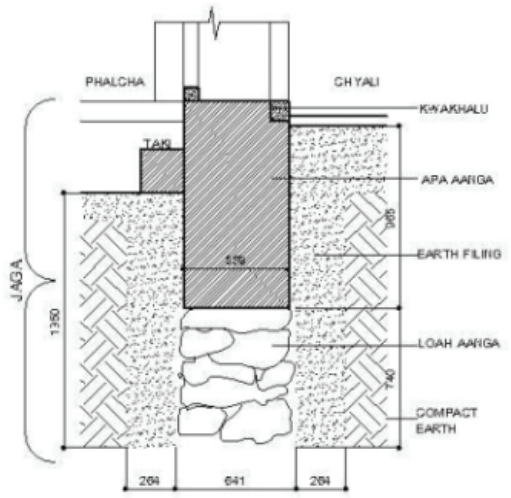

Fig XXI:Section of Foundation

The bricks used for the various types of construction are: Kachi Appa, which is merely a sun-dried brick and not very durable; Appa, which is a fired brick of crude quality; Chikan Appa, which is the slip glazed facing brick, that is shaped and fired with care and accuracy. To prevent the clay mortar from being easily washed away by rain, the brick joints are kept to a minimum thickness.

Traditional homes have walls made of three layers: outer layer with dachi apa bricks, middle layer filled with brick bats, rubble, and mud, and interior layer with ma apa bricks with mud mortar and normal joints. Where there are major problems in the masonry wall then connecting butterflies must be inserted to connect the three layers of the wall, they must be made of stainless steel or other metal which will not corrode.

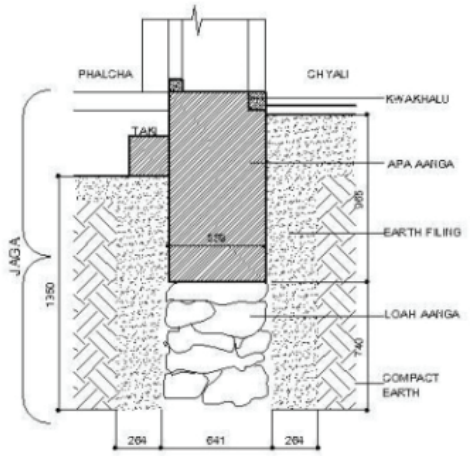

Fig XXII: Improvement of wall bonding (Heritage Preseration Manual)

2) French Drain: Installing a French drain outside the wall is one way to partially address moisture issues in walls. After excavating a trench, it is backfilled with sand and gritty debris. Any standing water is emptied away to a French drain pipe or a soak pit.

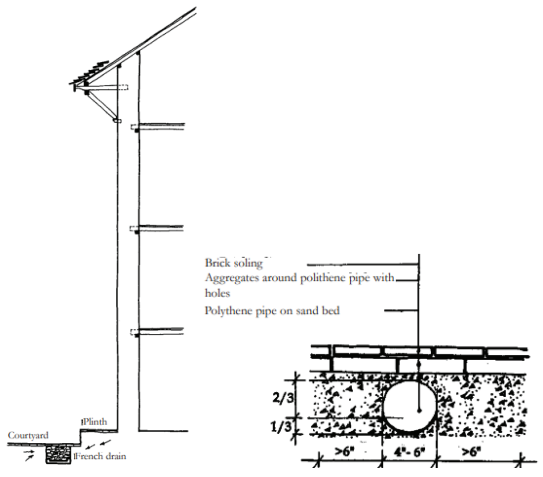

Fig XXIII: French Drain (Heritage Preseration Manual)

3) Cruciform joint for the post: The majority of timber posts have rotted at the bottom from moisture. Conventional joinery should be used in the suggested repair. The cruciform tenon of this traditional joint, which local craftsmen employ to join a new bottom to a post, fits into a cruciform mortise that is cut at an angle to the sides of the timber.

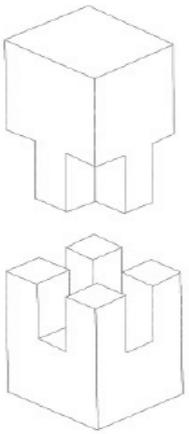

Fig XXIV: Cruciform Joint

4) Beam: To level the beams again, there is no way to prevent their settling. Reinforcing the current state is therefore the most efficient way to stop additional damage. One new steel I-beam can be inserted between two beams if there are enough spaces but if there isn't enough space between the inner and outer beam then we can add steel I-beam just beside the inner beam as shown in the figure to reinforce the old beams.

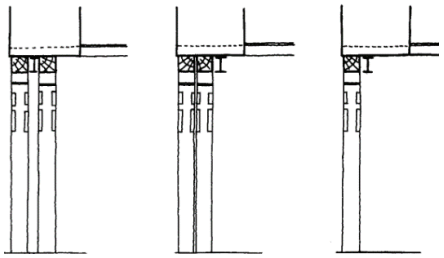

Fig XXV: Reinforcement of old beams

5) Rafter: The diagram illustrates the correct lap joinery, with the upper rafter being lapped above the lower rafter for load bearing. Metal plates are added for reinforcement. The sketch shows rafter joinery with metal plates above the wall plate, allowing both rafters to rest on the wall plate.

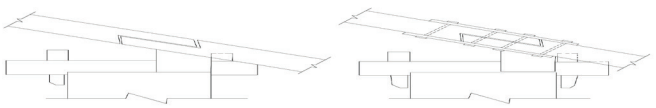

Fig XXVI: Repaor of rafter with lap joint

6) Door: Door has two frames: an inner frame and an outer frame. At the bottom of the door frame is another frame that is also known as the threshold. When installing the door, the threshold is placed over bricks to ensure that it won't collapse during an earthquake. Additionally, to make the door stronger, the two frames are connected by crossties at the bottom and top of the frame, as shown in the figure.

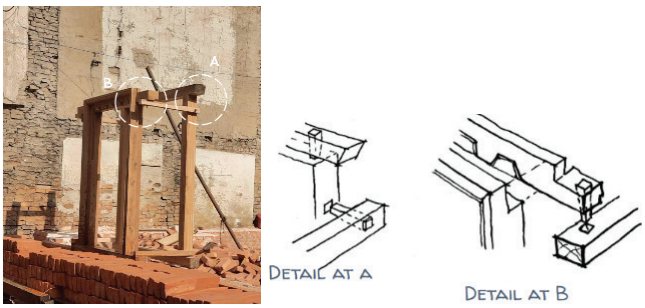

Fig XXVII: Structured Detail of Door

E. Features to reduce impact of the earthquakes

1) Plan Configuration: symmetrical plan configuration, which is rectangular for most of the traditional buildings that gives perfect symmetry in terms of distribution of mass and rigidity. In the case of street facing residential houses, although the centre of mass and rigidity are coincident, the general overall proportion is a 2: 3 rectangles.

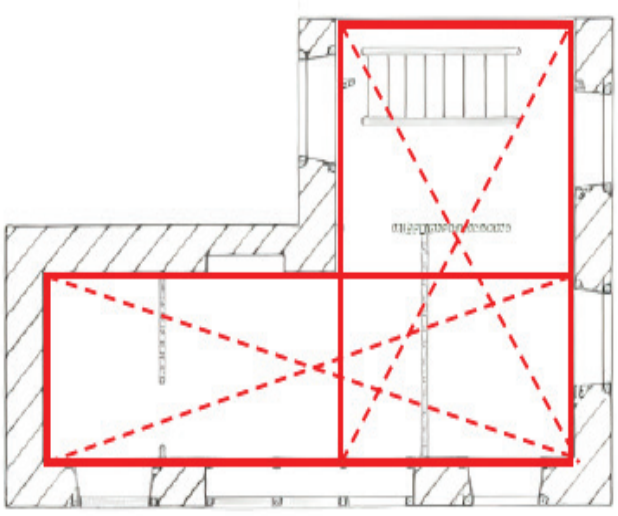

Fig XXVIII: Plan Configuration

2) Triple wall of Residence: The residential building structure features a central spine wall parallel to exterior long walls, with non-load-bearing side walls. The layout of floor joists and wall tie/plate distributes stresses throughout the building. Later constructions use a double timber post and lintel system with light timber partition cross walls, increasing shear capacity. Long walls take shear during earthquakes.

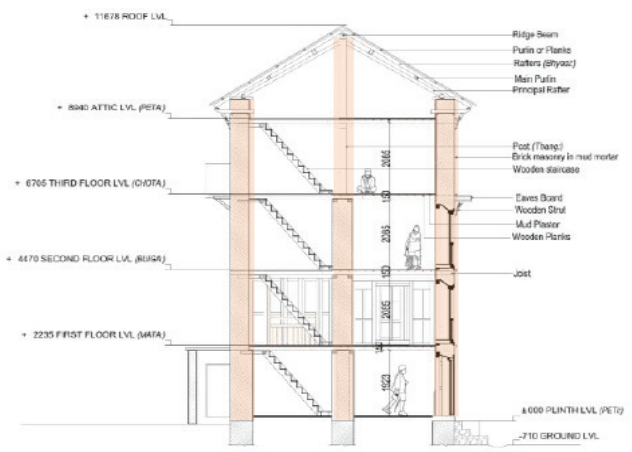

Fig XXIV: Section of House showing triple wall

3) Double framing of opening: Use of double wood frames going all round the opening on both sides of the thick wall and use of cross ties.

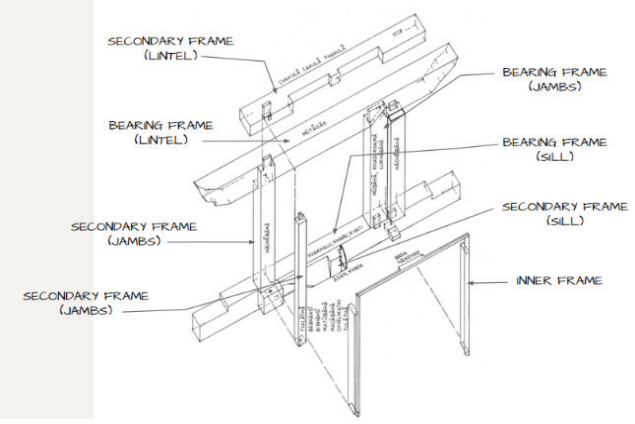

Fig XXV: Double Frame Window

4) Wall plate: Wall plates are safer from water damage than other timber elements. If a roof is opened during repair, replace the wall plate with a new one, as partial repairs are difficult. Add a metal plate in the corner to protect against horizontal thrust loads from rafters, even when reusing old wall plates.

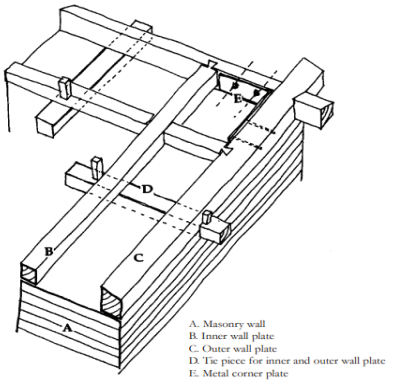

Fig XXVI: Wall Plates (Heritage Preservation Manul)

5) Band: Use of band helps to distribute the load evenly throughout the building and prevent from spreading of wall due to lateral load and minimize tilting or settlement.

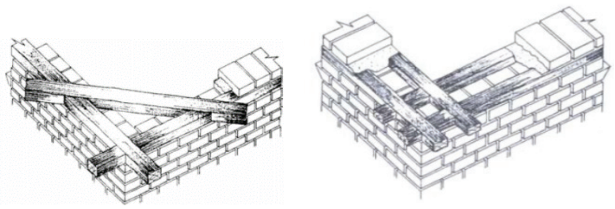

Figure XXXV: Single and collar band (NBC 202 1994).

F. According to the construction techniques

TABLE 2
CONSTRUCTION TECHNIQUES FOR VARIOUS ELEMENTS

Construction Elements	Expected output
Plinth construction	Building in sloping sites having plinths found to have less damage occurrence due to stone braces help anchor the building to the foundation and improve lateral stability, reducing swaying during an earthquake.
Wide base of the building	The design principal distribution building load over a larger foundation area, reducing soil stress and minimizing earthquake settlement or tilt risk.
Building shape	Virtually all building should be rectangular assuring L/B < 3 provision of Nepal Building Code.
Openings	Small opening with double frame system should be provided. BxH: 1.35x0.64 m size of door in average.

G. According to the seismic Design Criteria

- Reduced length-to-depth ratio (in most cases, 1.5 or less);
- Symmetrical location of small openings.
- Reduced inter-story height (less than 2.5 m) and limited number of stories (usually up to three).
- Presence of timber bands at floor levels.
- Vertical posts at corners, acting as vertical tensile reinforcement.
- Timber corner stitches.
- Timber pegs (chokus) need to provide which stitches various connections.
- Framing of openings using timber elements.
- Use of timber wedges and effective carpentry joints (dovetailing, etc.).

Conclusion

This research work was carried out to find out the Newari traditional building construction techniques and the timber's role in the structural integrity. This research made the case studies of two different traditional building of two different place to compare the construction technique, material that were used to construct the building. The Newars have created logical and scientifically sound technological advancements. Construction materials such as joists, nila beams, posts, musi, rafter, wooden pieces, walls, thayma, and ridge beams can be replaced if they become damaged or degraded. This is an example of how building technologies are flexible in structure. There won't be any difficulty in replacing the structural components.

Traditional buildings are well-assembled and harmonized with materials, fixed using chukus and joints, and tightening materials like tei kachi (rope of bamboo). Moreover, the adaptability of traditional Nepalese building techniques to seismic challenges underscores their resilience in the face of natural disasters. The use of timber, with its flexibility and strength, plays a crucial role in absorbing and dissipating seismic forces, safeguarding the lives and livelihoods of communities.

As contemporary architecture continues to evolve, there is much to be learned from the time-tested practices of Nepalese builders. The exploration of these techniques provides valuable insights into sustainable construction methods, fostering a deeper appreciation for the intrinsic connection between culture, environment, and structural integrity. We can contribute to contemporary construction methods that emphasize sustainability and utility by taking cues from traditional building knowledge from Nepal, guaranteeing a robust and culturally rich architectural heritage for future generations.

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