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THE USE OF TIMBER INTO THE TRADITIONAL NEPALESE ARCHITECTURE

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Abstract

Following the occurrence of a major seismic event in Nepal on April 2015, several technical reports based on field surveys have documented recurring forms of damage in traditional buildings, discussing the possibility of recognizing seismic protection solutions. In the opinion of several authors, originally anti-seismic awareness was present in the builders, but was lost mainly in recent times due to the uncontrolled modernization of the main cities.

This viewpoint is here discussed with reference to the frequent presence of wooden elements among the ruins of masonry buildings and the peculiarity of some timber details. Based on the damage surveys which followed the earthquake and some drawings from Nepalese historical manuals, the use of timber appears to be systematic within the local building tradition, both for structural and aesthetic purposes.

In addition to the use in roof structures and floors, timber is present also in portico systems and articulated massive frames around openings, probably intended as seismic protection solutions. However, despite the level of seismic hazard in the area, it is surprising to note the total lack of simple measures such as chains, curbs and tie rods. One reason could be found in the poor quality of masonry which, as it is known, can make solutions of this kind totally ineffective.

The opinion of limited anti seismic awareness in builders is also supported by the lack of truss systems in roofs. The analysis of both recent pictures and historical drawings, indeed, reveals the systematic presence of thrust actions on the walls; this can be noticed not only in vernacular buildings, but also in the monumental religious ones.

Throughout the present work, an overview of the use of wood and relative criteria is given, highlighting the details of the traditional system with special reference to local characteristic roofing systems.

1 INTRODUCTION

Nepalese architecture, otherwise known as the Newari style, has been influenced over the centuries by three main factors: environment, materials and craft activities. This style is very different from those present in other Asian countries with similar cultures, traditions and religions. Surely, a distinguishing factor of this Newari style is in the use of the two main construction materials, wood and brick. The main material, which creates a connection between this architecture and the environment, is the clay soil of the Kathmandu Valley [1].
An opportunity for better knowledge of this building tradition has been given by the M7.8 and M7.3 earthquakes which occurred in 2015 on April 25th and May 12th, followed by a series of M5-M6 aftershocks. During the first event, the maximum peak ground acceleration recorded in Kathmandu was 0.17 g [2] . In relation to these events, thanks to the large availability of reports and photos documenting the earthquake damage, an analysis of the seismic response has been developed for some existing buildings, with the attention mainly focused on historical and rural masonry constructions located in Kathmandu and in the surrounding villages.
In the Kathmandu valley, the Newari traditional system is characterized by three floor masonry buildings with some timber detailing, apparently developed for the specific purpose of enhancing earthquake resistant resources [3]. However, even if the original design was inspired by seismic awareness, several modifications introduced overtime have negatively affected the building behavior during the last seismic event.
In general, traditional and vernacular buildings provided a rather poor performance compared to modern reinforced concrete structures [3]. Evidence of this was given through preliminary data available from the Global Shelter Cluster [4] showing that, with reference to the fourteen districts declared as "crisis-hit", about 70% of the traditional masonry constructions collapsed or exhibited severe damage, whereas 87% of reinforced concrete structures presented a damage level from zero to moderate [3].
Looking at such a large extent of damage affecting traditional buildings, it is of interest to discuss, in line with some comments by Langenbach [5], whether a "seismic culture" can be recognized in the local building tradition. Considering, indeed, that the local seismic activity is characterized by an average value of 80 to 100 years for the return period of major seismic events, the presence of earthquake resistant construction criteria might be expected. A discussion about this is presented in the following.

2 VERNACULAR BUILDINGS IN THE KATHMANDU VALLEY

2.1 The Newari house

While documentation about religious buildings is widely available, historical information concerning private dwellings is almost non-existent [6]. One of the earliest descriptions of Newari houses dates back to 200 years ago when Father Giuseppe, a Christian monk, visited Nepal: "*The houses are constructed of bricks, and are three or four stories high; their apartments are not lofty; they have doors and windows of wood, well worked and arranged with full regularity*." [6]. As reported by [7], the traditional building technology was originally developed for a two story building (the Bahal type). From the 17th century, an additional story was added and today 3-5 stories are normally built, without any modification of the construction details (foundations, materials, structural layout, etc.).

The main characteristic of these buildings lies in the symmetry inspiring the architectural design, which is clearly recognizable in the façade, organized with respect to the central axis of a main window or door. Other windows are paired around this central axis, and the central window of each floor is emphasized by its size and detailed carving.

Where the ground floor is not used as a shop-front or a workshop, this section of the façade remains rather simple, with a low narrow door and perhaps one or two small windows on either side. Any irregularity in the ground floor façade, due to a door or row of columns, usually is not repeated in the upper stories and are arranged independently in a symmetric configuration.

2.2 Architectural features

Traditional dwellings are similar in dimensions, but present differences in relation to the availability of materials and the owner's economic condition. The typical house (Fig.1) has a rectangular plant, generally 6 meters in depth, while the length is usually in the range between 4 and 8 meters, although different values can be found in some cases. The main feature is the vertical arrangement of the rooms at different stories, that is, generally, not related to the size of the base. The number of floors range from 2-4.

The traditional building technology was originally developed for a two storey building (*bahal* type). Later on (from the 17th century) additional storeys were added and today 3-5 stories are built, still adopting the same structural scheme. [7]. The most common storey arrangement is based on 3 levels: ground floor (known as *chhendi*), first floor (*mattan*), second floor located under the roof (*chota*). The third storey is an unusual addition in these traditional dwellings and, when it is present, is used as a large family living room [8]. A central spine wall (*Du Anga*) divides each floor in two main rooms, except for the last level, where an open space room is present. The internal spine masonry wall, characterizing the first two stories, is here replaced by a series of timber columns, which contribute to realize a unique architectural open space under the roof, to be used as a kitchen and dining room.

Figure 1: (left) Axonometric projection showing a typical Newari house [6, p. 37]; (right) detail of the façade (Authors for the purpose of the article, 2019).

2.3 Materials

In typical Newari houses, there is a mixture of both masonry and timber structural elements. Both construction materials present a wide variety of qualities, due to the great availability of clay and timber in Nepal. Typical images of these dwellings clearly show the extensive use of timber, which is locally available in the Kathmandu Valley, where the large woodlands covering the South areas of Nepal are present. Timber is mainly used for the roof structure, characterized by an unusual scheme, and it is present also around openings, where it plays the role of a reinforcing frame.

Two main kinds of bricks are used: one on the internal side of masonry, while the other is visible on the external side. Masonry panels are composed of three vertical layers (Fig.2): the external layer is made of *daci appa* bricks where the central core is filled with rubble stones, brick fragments and a mud mortar, on the internal side *ma apa* bricks are disposed. Connection and collaboration of the three masonry layers is not always guaranteed by brick interlocking; low quality mortar, moreover, does not help. The combination of poor quality mortar and lack of maintenance may cause a loss of thickness in the mortar joints, which is amplified by environmental agents; the containing action onto the inner core and, in general, the bearing capacity of the wall panel are thus further reduced. Another common phenomenon is the detachment of a brick layer, caused by both poor material properties and water penetration during monsoon rains. The lack of interlocking between bricks affects the global resistance of the wall and is a major cause of failure during seismic events (Fig. 2).

Figure 2: Masonry details: (left) a sketch of a hypothetical arrangement of layers in the wall thickness (Authors for the purpose of the article, 2019); (central) 2015 Earthquake effects on masonry walls [9 – Bagmati 2015]; (right) 2015 Earthquake effects Baktapur [10 – Baktapur 2015].

Due to the large availability of wood in Nepal, timber elements are widely used in Newari buildings. There are several tree species all around the Valley: *Gwaisasi (Schima Wallichi), Salla (Pinus Roxburghii), and Utis (Alnus Nepalensis)*. Among these species, only *Gwaisasi* can be used for construction purposes. However, for the production of structural elements, the most used tree is *Sal (Shorea robusta)*, which has a higher quality than *Gwaisasi*.

Sal and *Gwaisasi* are good hardwood species, suitable for construction because of good strength and resistance properties. These wood qualities do not require any particular treatment for protection against water coming from monsoons or insects, so that they can be used for beams, columns, horizontal bands and for frame openings [1]. *Sal* and other species of hardwood used for construction come from the southern Terai region, characterized by a subtropical climate suitable for the growth of such trees. Other woods that can be found in the Kathmandu Valley are too soft for building purposes and need to be treated for a sufficient durability. [1]

2.4 Timber details in the Newari house

One of the main features of the Newari house is the arrangement of openings. In most traditional dwellings, reproducing the classical disposal of windows, it is possible to notice the symmetrical organization of openings in the façades. Traditional houses have two complete timber frames around the openings, both in windows and in doors, tied together at the lintel and the sill level. Over the centuries, the opening design evolved in terms of proportion, but the use of the internal double frame remained the same. Older houses have lower and wider openings, starting at the slab level (Fig. 3).

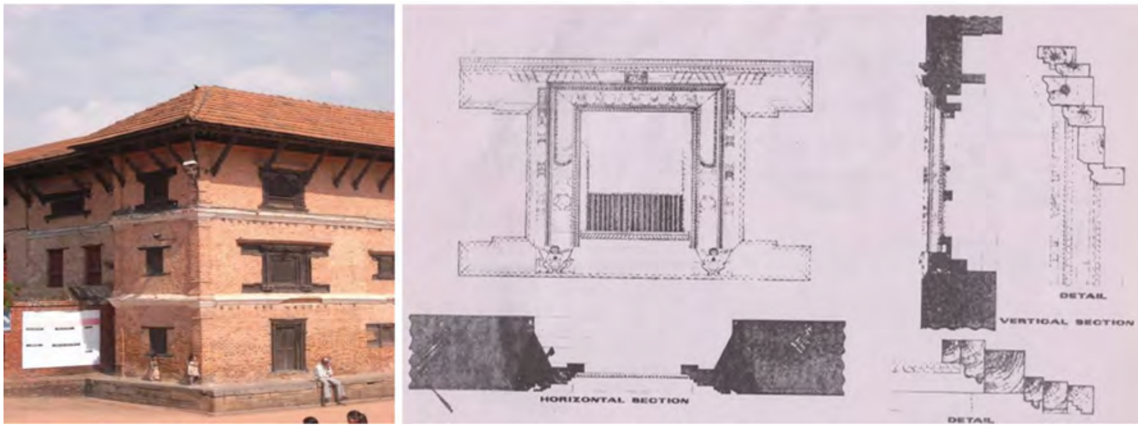

Figure 3: (left) a typical Newari house in Bhaktapur (S. Tonna, 2011) ; (right) a window detail of a historical Newari building [7, p. 262].

However, since the 19th century, openings have acquired a taller and tighter shape, showing a more vertical orientation. The new style of windows totally modified the external appearance of façades, replacing the presence of a bigger central window with a row of windows (Fig. 4) [6].

Figure 4: (left) a new Newari house in Bhaktapur (S. Tonna, 2011) ; (right) the two Newari types (the traditional and the new one) compared (S. Tonna, 2011).

3 THE DOUBTFUL PRESENCE OF SEISMIC DESIGN CRITERIA

From a structural point of view, the main construction details identified as being the main features providing earthquake resistant properties to the Newari houses, as reported by [11,12, 3] are:

1. symmetric plant configuration, which is rectangular for most of the traditional buildings (Fig. 1);

2. reduced length-to-depth ratio (in most cases, 1.5 or less);
3. symmetrical location of small openings (Fig. 1);
4. reduced inter-story height (less than 2.5 m) and limited number of stories (usually up to three);
5. presence of timber bands at floor levels (Fig. 5-right);
6. vertical posts at corners, acting as vertical tensile reinforcement;
7. timber corner stitches (Fig. 5-central);
8. timber pegs (*chokus*);
9. framing of openings using timber elements (Fig. 5-left);
10. use of timber wedges and effective carpentry joints (dovetailing, etc.).

All of the above listed timber elements clearly enhance the earthquake resistant properties of the Newari houses [8]. Carved timber elements, framing door and window openings, reduce vulnerability typically induced by openings; in some cases, they cover entirely the wall thickness, while in other cases they simply run over the edges. Moreover, through the use of timber wedges, carpentry joints provide energy dissipation.

Figure 5: (left) The framed window [9 – Kathmandu 2015]; (center) timber corner stitch element (S. Tonna, 2011 – Baktapur); (right) the timber bands at each floor [9– Kathmandu 2015].

In conclusion, the use of timber appears to be a relevant characteristic in the Newari building typology; it is even more pronounced, indeed, in the close Kashmir area, where the *Dhaj-ji-dewari* houses are built with unfired mud bricks.

Earthquake resistant properties are undoubtedly present in the Newari tradition, as some studies have proven [13], but it is difficult to establish whether they were inspired by clear and sound structural criteria for earthquake protection, or rather simply for aesthetic purposes.

Despite the level of local seismic hazard, the frequency of events, the number of victims, and the damage produced by each earthquake, what is striking is not so much the absence of a framed system, perhaps simply not belonging to the local tradition, but rather the total absence of simple traditional devices such as chains, curbs and tie rods. These elements are normally present, throughout the world in buildings located in areas exposed to seismic risk. One reason could be found in the poor quality of masonry which, as it is known, is the first requirement to make such solutions really effective.

Such considerations can be applied also to the curb running at the top of masonry walls, which should be intended to act in favor of the box-like behavior of the structure. Such ring beams, indeed, are usually discontinuous and possibly decay over the years. The floor joists are connected to the ring beams with a special system of "chokus" (timber wedges that allow for some displacements). Through time, wooden curbs have been replaced by reinforced concrete elements in several cases, also compromising any possible connection to the floor through the traditional system (*chokus*) and worsening the balance of the masses.

Finally, as discussed in the following, the lack of a truss system in the roof [7] is further in favor of the opinion that clear seismic design criteria were not developed inside this building tradition.

3.1 An unconventional roof system

A peculiarity of the Newari house is also given by the overhanging roof. The roof traditional construction is based on a timber structure, covered by a thick insulating mud layer and clay tiles. The main function of the cantilevering part of the roof is to protect facades from monsoon rains. The massive roof layer is not in favor of seismic response, due to the high inertia loads generated by the ground motion, which are transferred to the underlying structure [14].

Traditional roofing details, as given in Fig. 6 [7], are reproduced in Fig. 7.
From these, interesting considerations can be drawn in terms of the assemblage criterion in use for such roof systems and, consequently, a comment is possible on the load transfer mechanism and the impinging effect produced by this system onto the supporting walls.

The procedure for the roof assemblage clearly starts from installing the central column (element 1, in Fig. 8), normally resting on another column or a wall; at the same time, element 2 is also assembled, which allows for the correct vertical configuration of element 1. Subsequently, the ridge beam 3 and longitudinal beams 4 can be installed, which provide support to the roof covering surface, normally inclined at 30°. Additional supports are provided by the external wall and by elements 5 and 6, which make it possible to handle the pronounced protruding effect on the roof surface. It has to be underlined that in the typical configuration the horizontal element (5) is not in line with the slab, so that, in the absence of a tie-beam effect, no truss scheme can be recognized for this roof system. Element 5, typically working in tension, is clearly anchored at the wall internal side, thus producing a bending effect onto the wall.

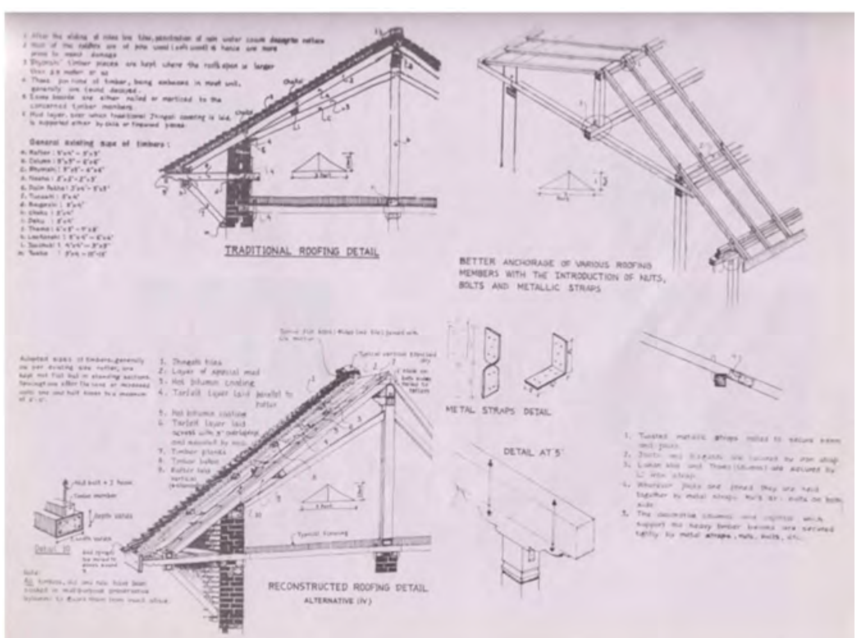

Figure 6: Roof detail of the typical Newari building [7, p. 193].

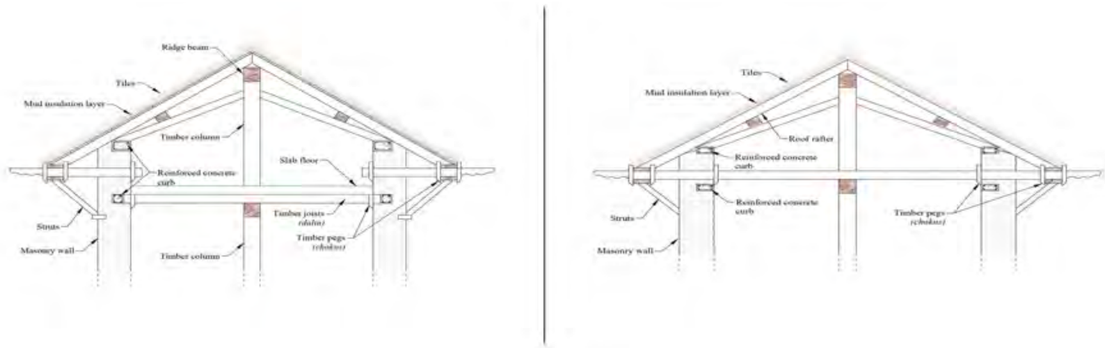

Figure 7: Graphic analysis of the typical Newari roof structures (Authors for the purpose of the article, 2019).

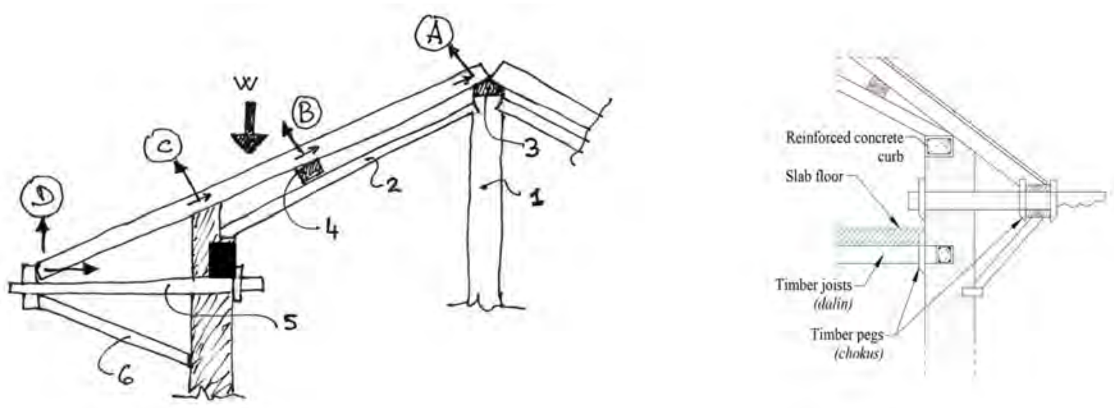

Figure 8: (right) The load transfer mechanism of the traditional roof system (C.Chesi for the purpose of the article, 2019); (left) typical Newari roof structure detail (Authors for the purpose of the article, 2019).

Looking at the real restraint condition at locations A, B, and C of Fig. 8, it has to be assumed that, while a reaction force normal to the roof surface is certainly provided, the presence of the orthogonal component parallel to the roof surface, relying mainly on friction, is doubtful. At location D, therefore, a horizontal reaction also has to be developed in addition to the vertical one in order to oppose the possible sliding of the roof surface. This results in an additional tension force transferred to the wall.

All of this refers to the permanent effect of gravity loads; in the presence of horizontal inertia forces produced by ground motion, the reaction developed by element 5 (or the symmetrical one, depending on the direction of motion) will increase; correspondingly, the bending effect in the wall will also increase.

Impinging effects produced by the roof system onto the supporting walls, indeed, are normally increased by seismic actions; it is believed, therefore, that local builders had not developed any advanced form of consciousness of the seismic problem, with the adoption of effective construction details to oppose seismic effects.

It is of interest to recall that a similar configuration for the roof system can normally be recognized in temples also, where the construction quality is higher than in common residential buildings. The lack of seismic resistant criteria has therefore to be confirmed.

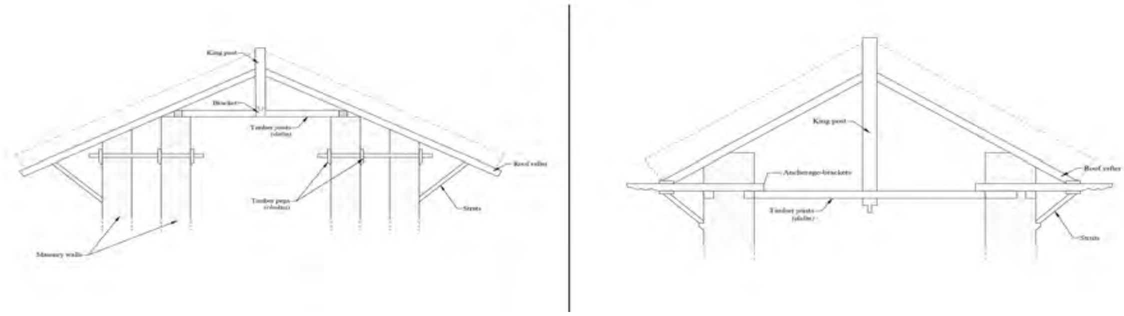

Figure 9: Graphic analysis of the typical Temple roof structures (Authors for the purpose of the article, 2019).

4 CONCLUSIONS

The seismic event, occurred in Nepal in 2015, generated a series of studies and reports devoted to characterize the resiliency of traditional building systems in that region. In particular, this research focuses on a specific Nepalese architecture, known as Newari style, that has been developed over the centuries targeting three main factors: environment, materials and craft activities. Indeed, the Newari building tradition, based on the mixed use of timber and masonry, is characterized by a variety of details, associated to both aesthetic purposes and enhanced resistance properties as well. In consideration of the frequent recurrence of high intensity earthquakes in the Nepal area, the question arises whether such structural details were consciously conceived in the past to provide resistance towards seismic actions.

Whereas a wide review of such details is done and a critical evaluation of them is attempted, some inconsistencies are revealed, leading to the conclusion that local builders did not develop coherent general criteria to oppose the destructive effects induced by earthquakes.

It may be assumed that there was an anti-seismic awareness, but that it was lost during the last century due to an uncontrolled building development. The aim of this research is to offer visibility to this construction type and to highlight both its criticalities and potentials, especially with the aim of recreating awareness and a new state of the art with the aim of encouraging a simple but effective method for the preservation and consolidation of the remaining examples.

However, as it is now generally acknowledged, simple interventions could be considered, in many cases, which might improve seismic capacity without affecting the global building layout; the original architecture would therefore be preserved.

The bearing capacity of masonry walls is often compromised by poor transversal connection, through the thickness, between the wall parallel layers; the insertion of diatones or, in general, elements providing connection between the wall external faces, could highly improve the performance of masonry panels.

A recurring form of damage produced by earthquakes is given by the pull out of beams from walls; technological solutions to improve this kind of connection are widely available, which also act in favor of the global box behavior of the building.

At a global structural level, a curb running at the top of perimeter walls if often lacking; the insertion of such an element, typically a wooden one, could improve the global seismic performance. The curb stiffness, as it is known, should be carefully chosen in relation to masonry mechanical properties.

Finally, thrust actions produced by the roof system onto the external walls could be easily balanced by the insertion of steel or wooden tie rods, creating connection between end walls; again, this would be in favor of the box behavior.

In any case, interventions should be based on a preliminary historical-critical analysis, in order to support any decision about upgrade interventions on a sound level of knowledge of the real building conditions.

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