सुरक्षित घर

Sarakshit ghar

A safe home

Documenting the changes in earthquake-resistant construction elements in the housing of the Kathmandu Valley in the period of 1769 - 2023

Janek Bosman | March 2023 | Lalitpur, Nepal

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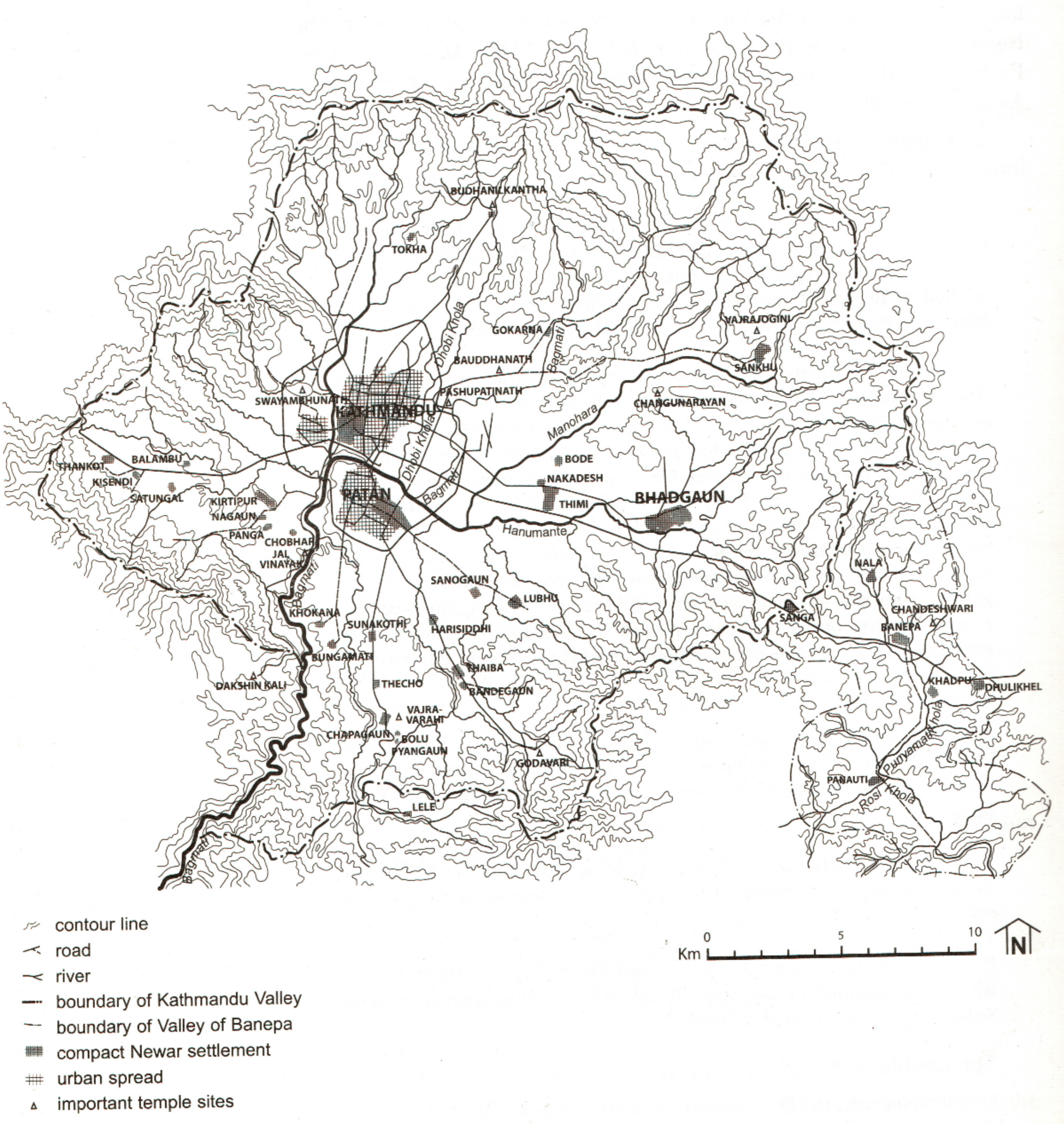
Picture on previous page: Kathmandu skyline as seen from Chakupat, Lalitpur towards the north-west

(Author's own photograph, 2023)

Map of the Kathmandu Valley (Korn, 1976)



The main body of work contains **9470 words** (excluding the bibliography, prologue and appendices)

Prologue

I have written this thesis while working and living in Lalitpur. For two months I stayed in the historic part of the Lalitpur: Patan. Most of the pictures are taken by myself on explorations throughout the Kathmandu Valley. The ones for the Newar-style housing typology have been from the guesthouse that I have stayed in: the Hira Guesthouse is the oldest guesthouse in Patan (according to the owner, Manju), and its located inside a 300-year old Newari type building.

Staying in Nepal for three months total has given me the opportunity to speak a lot of people that are knowledgeable about Nepal, its architecture and the earthquakes, especially the 2015 one. It truly became a daily topic in conversations and altered the way I look at the city. I want to thank all the people I have met and helped me along with my research, but most of all:

To all the lovely people of Patan, the colourful women I passed by on the streets, the salesmen who told me about the city (and their 'very cheap' goods), the devoted temple-goers in the mornings, the dancers and musicians in the evenings, the highly pet-able street dogs and all the others who make this living museum an everyday joy to be in.

May you stay safe in the earthquakes to come.

Chapter 01: Sarakshit Ghar (A Safe Home)

1.1 Introduction

Nicknamed "the roof of the world", Nepal is often seen as an attractive picture for tourists around the globe. However, the same Himalayan mountains that form a blissful *shangri-la* for mountaineers, create a great source of tremor for the Nepali people. As the Indian tectonic plate converges beneath the Eurasian one, pressure builds up, resulting in a major earthquake[1] every 70 to 80 years, and hundreds of light to strong ones (M_w = 4,0-6,9) every year (Chaulagain et al., 2018)

The most recent major earthquake (7.8 M_w) struck Nepal in April 2015; one that still echoes in the forefront of people's minds. Ever since, many researchers have been trying to find answers for the massive amount of buildings destroyed in that earthquake. The shock and the following aftershocks impacted over eight million people, claiming 9000 lives and over half a million homes (Chaulagain et al., 2018).The answer is not easily found in blaming poorly constructed concrete homes that arose in the 1990's, but lies more deeply than that: dwellings from multiple periods were destroyed in the tremor. Weak, age-old brick walls of Newari architecture collapsed too, while other Newari houses left almost unscathed (Tonna et al., 2019). At the same time, both traditional and contemporary houses survived, as long as they incorporated earthquake-resilient elements (Adhikary, 2016).

The recent 2015 earthquake showed how Nepal was not prepared enough. According to Hülssiep e.a. (2020), the level of public awareness of the response to highly destructive earthquakes like the one in 2015 is low, given the high frequency and susceptibility of them in Nepal. "A lack of structural integrity, roof collapses, foundation issues, poor building quality, or other issues affecting loadbearing walls" have caused many dwellings to collapse (Vegas et al., 2020).

The current housing stock in the Kathmandu Valley exists of residences from multiple time periods, architectural styles and constructional qualities. The traditional and iconic Newari architecture is found in all of the three royal cities: Kathmandu, Lalitpur and Bhaktapur, as well as many smaller villages in the valley. Old dwellings in the historic city centres that have been destroyed or passed down to younger generations are often replaced by modern concrete structures (Karki et al., 2022). Outside the 'old towns', in neighbourhoods like Sanepa, Chakupat and Kupondole, a mix of concrete and concrete-frame-masonry houses is found, that often contains neoclassical decorative elements.

Research findings show that the post-earthquake reconstruction of residences have so far produced inconvenient and unfit houses (Karki et al., 2022).Vernacular design is replaced by cheap and readily available materials, often not constructed with earthquake resistant features (Dixit et al., 2004). The introduction of corrugated sheets has been helpful is quick reconstruction, but damaging to Nepal's architectural traditions and knowledge-transfer (Feenstra, 2023).

Roughly 90% of the houses in Nepal are non-engineered (Gautam et al., 2016). An interesting fact is, however: only earthquakes of magnitudes higher than 6,5 are known to damage buildings in Nepal (Chaulagain et al., 2018). The fact that Nepal has a self-building culture increases the tendency of owners to follow trends more than vernacular building traditions (Karki et al., 2022). Because of multiple reasons, documented in this thesis, many traditional earthquake-protecting elements in architecture have been lost over the years. Documenting the seismic protectional qualities of the vernacular might increase awareness of reigniting these traditions in current housing.

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[1] Earthquakes of a scale of 7,0-7,9 on the Richter Magtitude Scale are considered 'major'. M_w (*moment magnitude scale)* is the commonly used physical quantity for earthquake magnitudes.

1.2 - Research question

To gain a better understanding of the seismic protection traditions in Nepal, this research aims to look at the good and the bad of the current housing, that exists of a colourful mix of housing of different time periods, of different traditions and trends. The present paper aims to document the changes in constructional qualities. Therefore, the main research question is as follows:

What changes can be documented in the use of earthquake-resilient elements of vernacular houses in the Kathmandu Valley cities from 1833 until 2015?

It is important to elaborate on the definition of 'vernacular' in this question. According to AlSayyad (2006), for some structure to be recognized as "vernacular", it is generally assumed to have the following qualities:

- native or unique to a specific place;
- using local materials and without the need for imported products; however, this point may prove difficult in the current highly globalized world;
- it might be built by the inhabitants themselves.

AlSayyad argues how the definition of vernacular has to change epistemologically. The modern is also vernacular, as the vernacular has never been a constant in history. In a way, the vernacular is always the most updated, new, modern version of the previous architecture, changing with the new traditions in construction, new materials and new ways of living (AlSayyad, 2006). For the present paper, this broadly determined meaning of vernacular is used, meaning: the modern concrete house is as much a current vernacular as the thatch-roofed shack used to be centuries ago, while nonetheless agreeing that older vernacular traditions play a great role in the development of sustainable future built environments (Asquith & Vellinga, 2006).

1.3 – Methodology

This history thesis describes the overall development of earthquake-resistant architectural features in residential architecture of the last two centuries. In four chapters, excluding the introduction and conclusion, the changes are described chronologically. Chapter 02 covers the historic background information needed to understand Nepali architecture. The origins of the Kathmandu Valley are essential for reading the architectural developments through the right lens. Chapters 03-05 each follow a similar structure: descriptions of the residential architecture from that certain period, followed by an analysis of the earthquake-prepared elements of this architecture. In chapter 03, the Newar architecture of the Malla Period is described through the use of existing literature, drawings and photography of current remaining structures from this period. Chapter 04 covers the residential architecture that is heavily influenced by the neoclassicist Rana Period. Finally, chapter 05 dives into the new, modern concrete houses that have been predominant since the 1980's. In Chapter 06, conclusions are drawn, showcasing the change in earthquake-preparedness of housing throughout recent history.

To gather information, a mix of sources is used. Firstly, a great amount of literature is used that is written in different times. These sources provide a convincing background for the analyses conducted further on in the research. Secondly, two unstructured interviews are held with professionals to answer questions not found in literature. Thirdly, photographs of existing houses are used to analyse their earthquake-preparedness.

1.4 – Relevance

The present paper addresses a critical gap in the knowledge on the development and loss of earthquake resilient construction methods in the housing stock of the Kathmandu Valley. A great amount of literature can be found about the architecture of the Kathmandu Valley, regarding the materials used, construction techniques and the benefits of the vernacular (Korn, 1976; Thapa e.a., 2008; Yeomans, 1996; Bonapace and Sestini, 2003). Documentation of the destructions have been done after each massive earthquake, with the best-documented one being 2015 (Goda e.a., 2015; Chaulagain e.a., 2018; Limbu e.a., 2019; Liu e.a., 2021). Plenty has been written about the earthquake resilience of cultural and religiously important buildings (Joshi and Kaushik, 2017; Ranjitkar, 2006; Adhikary, 2016), while seismic vulnerability is proven to be much higher in residences due to inferiorities regarding workmanship, construction technology and maintenance (Parajuli e.a., 2020).

The most compelling stories have been written about the iconic architectures of the Newars. Though making up for the great majority of the housing stock, the modern residences of the 20th century, especially the neoclassical palace-like structures, are largely undocumented and undervalued in academic writing.

Some research is focused on housing recovery after earthquakes, less so on improving the existing building stock. Karki e.a. (2022) urge the need for a bird's eye view on the quality of architecture, and not see the earthquakes as singular events that are unconnected to for example persistent social inequalities and unfinished construction proposals. One could also argue that aesthetic trends have become more important than sustainable building techniques, knowing "most of the participants [wished] the post-earthquake housing to be *rāmro* (nice or beautiful)" (Karki. e.a., 2022). Though pleasant housing is important, the same mistakes should not be repeated when it comes to earthquake safety, for it is buildings that most often kill people, not the earthquakes themselves. Increasing awareness of indigenous earthquake-protection methods in architecture is essential in mitigating future losses.

The most important reason for choosing this particular topic for the present thesis is: to gives space for new perspectives in the discourse about earthquake-resilient materials and construction in the residential architecture of the Kathmandu. The current thinking is: concrete is strong and safe, traditional buildings are weak and dangerous. It is the hypothesis of this thesis that this thinking is not true, and that the safety of a building has to do with construction techniques and maintenance, not with materials.

Chapter 2: Nepal and its 'Sequestered Mountain Valley'

2.1 - The crossroads of the Kathmandu Valley

Once a shimmering lake at the foothills of the mighty Himalayas, now a bustling centre of life, culture and history. The Kathmandu Valley, also known as the Nepal Valley or sometimes just 'Nepal' in rural communities (Gellner, 1986), has been the dominating power of the central part of the Himalaya for over two thousand years. The bowl-shaped valley contains some of the oldest human settlements in the Himalayas (Thapa e.a., 2008). Its strategic location proved essential to the former dynasties and kings: the most accessible mountain passes to Tibet are found just north of Kathmandu; while essential trade routes with India flow down south (Korn, 1976; Weiler, 2009).

Nepal is a small landlocked country in Central Asia, bordering India to the South and China to the North, therefore being jokingly referred to as "a turnip between two giant rocks". The country is roughly divided into three belts: the lowlands of the Terai (about 17%), the greenlands in the middle generally referred to as 'the Hills' (about 18%) and the snow-capped peaks: the Mountains (about 65%) (Gautam e.a., 2016). The largest part of the Himalayan mountain range is to be found in Nepal, with outshoots in India, Pakistan, Tibet and Bangladesh.

Centralised in the middle belt, the Hills of Nepal, the Kathmandu Valley consists of a relatively flat floor of thirty by thirty-four kilometres (Haack and Rafter, 2006) at an altitude of about 1350 meters (Korn, 1976). Several smaller streams converge into the Bagmati river, a gentle but polluted stream that eventually joins the river Ganges in India, the most sacred river to Hindus. Though holy, the river has lost most of its beneficial purposes to the city, like bathing and agriculture due to seepage of waste water and septic tanks (Thapa e.a., 2008). The Kathmandu Valley is a meeting point for cultures; a buffer zone between predominantly Buddhist Tibet and Hindu India. It shelters several important pilgrimage sites for Hindus and Buddhists, such as Pashupatinath Temple and the Bouddhanath Stupa (Figure 1). However, when asking a Nepali whether they're Buddhist or Hindu, most respond with: "Why, we don't distinguish, we worship all shrines" Even though one of the two religions is imposed to you at birth, in Nepali life they seamlessly melt into one another (Fleming and Fleming, 1978; Gellner, 1986). One of the origins of the name *Nepāl* is from the meaning "sequestered mountain valley", poetically describing the city as the sheltered pause point it was for travellers and tradespeople crossing the Himalaya (Weiler, 2009).

The Kathmandu Valley houses three 'royal' cities: Kathmandu (Kantipur), Lalitpur (Patan) and Bhaktapur (Bhadgaon), with the former being its contemporary name, and the latter its historical. The names for the cities are used interchangeably in literature and daily life. Each of the cities were separate kingdoms from 1482 to 1769, after which Prithvi Narayan Shah united the valley (Gellner, 1986).

The valley contains the highest population density of Nepal (Gillekens, 2017), that has only skyrocketed due to recent urbanization. Whereas the 1991 census counted 675 thousand people in the Kathmandu district, the 2021 census counted just over 2 million people (Niroula, 1998; NPHC, 2021). A quarter of the Nepali live below the poverty line, and Nepal is therefore the third poorest country in Asia (Vegas e.a., 2020). Per the UN's development status, Nepal is set to 'graduate' from a 'Least Developed Country' to a 'Developed Country' in November 2026. The date was originally set in 2022, but due to the COVID-pandemic and the 2015 earthquake, it was postponed (Pandey e.a., 2022). It is of great importance to look at this 'graduation' with a critical eye. The UN bases a development status largely on GDP, which is a Western classification of wealth. When measuring a community-based society like Nepal through the lens of money, Nepal will turn out to be very poor, even though people have enough food, water, housing, education and liberties (Feenstra, 2023).

Figure 1: *Urban growth around the Boudhanath Stupa area in Kathmandu. (a) is taken in 1967, (b) in 2001 (Haack and Rafter, 2006).*

2.2 - A brief history of Nepal

Over the course of 2000 years the consecutive royal dynasties of the Licchavis, Mallas, Shahs and lastly the Ranas have ruled over the Kathmandu Valley (Bhattarai-Upadhyay and Sengupta, 2016a). The sequence of regimes started off in the fourth century with the Licchavis, a Hindu-Indian dynasty (Gillekens, 2017). The Mallas, originally from the far west of Nepal, ruled over the Kathmandu Valley from 1257 to 1768 AD. Within the Malla dynasty, King Jayasthiti Malla (1380 – 1395) was the most renowned among his counterparts, introducing the Hindu based caste society and stratifying the land in categories of productivity (Thapa e.a., 2008). The caste system seeped through to the organisation of residential architecture, with the lower caste people living on the fringes of the cities, while the upper castes enjoyed the rich centres (Gillekens, 2017). These houses were still all in Newari style, which will be further described in chapter 3.

The country Nepal was in this time still merely a concept. It was not Nepal until Prithvi Narayan Shah unified the country under the Gorkha banner in 1768; conquering the three cities in the valley and declaring Kathmandu the capital of the kingdom of Nepal (Thapa e.a., 2008). During the Shah dynasty, houses generally kept the same characteristics as the Malla period, only slightly growing in size. Due to influence from Mughal architecture in present-day India, stucco on façades was introduced in Nepal for the first time (Ranjitkar, 2006).

Merely 78 years later, the Shah regime was overruled by Jung Bahadur Kunwar of the Rana dynasty in 1846. The Shahs were still monarchs, but merely as figureheads. It was in the Rana period that architecture really started to get influenced by the outside world, with trends in Newari architecture moving to larger, lighter windows (Ranjitkar, 2006). The Ranas built European-inspired luxurious palaces on the city periphery, strongly influenced by British and their colonial architecture in India. They lived extravagant lifestyles while ruling with an iron fist and ironically closing borders for foreigners (Thapa e.a., 2008; Weiler, 2009). With their 'pseudo renaissance columns', French windows, baroque ornamentations and neatly made stucco facades, the palaces stood in direct opposition with the existing heritage (Shrestha, 1981; Bhattarai-Upadhyay and Sengupta, 2016a). These new elements imported from European modernity soon became the identity of Nepali architecture moving forward.

The Rana regime was toppled by democratic movements in 1950, inspired by the newly-achieved independence of India (1948). It was then that big developments were made that propelled Nepal into the modern day; new highways, an international airport and urban development programs (Thapa e.a., 2008). Borders were suddenly opened, confronting the Nepali with the outside world, which soon reflected in the urban landscape. Materials like porous concrete, cement and corrugated iron sheets were introduced (Weiler, 2009). The most recent history (1950-2020) has been turbulent, and for certain slowing down the development of Nepal[2] .

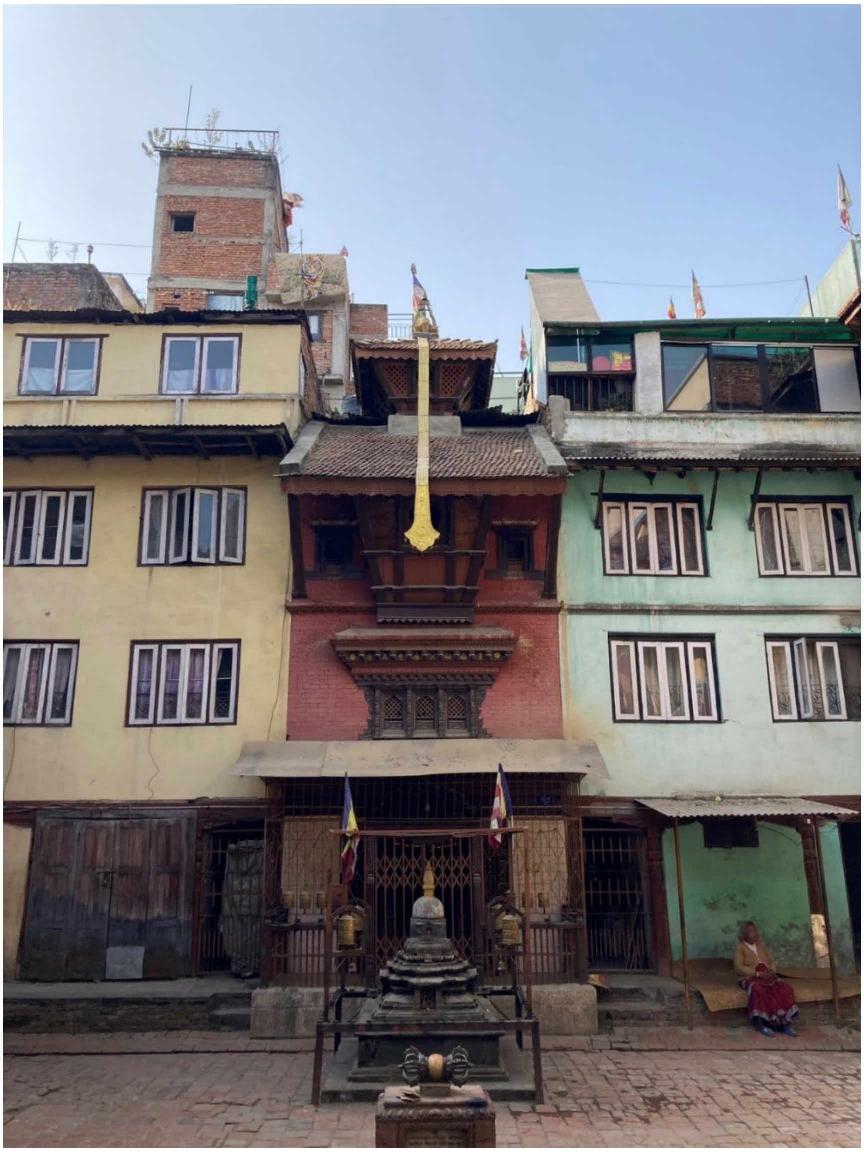


Figure 2: *A well-preserved Malla-era Newari house snugly remaining amongst newer, stuccoed residences. The older Newari houses are recognized by their small and arguably purely ornamental windows (Author's photograph, 2023).*

[2] The most recent history (since 1950) has been a fast-paced toppling of power, including the abolishing of democracy, a 'partyless' system, the reinstitution of democracy, a civil war and a massacre of the royal family. It is by far beyond the scope of this thesis to explain these events in detail.

2.3 - The Newars

Over 60 indigenous ethnicities are present in Nepal (Niroula, 1998). The predominant and clearly defined indigenous people in the valley are the Newars. They make up more than half of the population in the valley (Weiler, 2009). Korn (1976) beautifully summarizes their role as follows:

> *“The Kathmandu Valley, as a centre of attraction, forms a good sample of ‘tribal areas’ mixed with immigrants. The Newars are dominant not only in number, but also in their high cultural development. With their types of settlement in established towns and villages, their architecture and artistry, together with their business sense, they have usually outshone other ethnic groups in the Valley” (Korn, 1976).*

The Newars engage in their own specific traditions, art styles, cuisine, craftwork and architecture, as well as speaking Newari next to Nepali (Weiler, 2009). Their red-bricked buildings are easily recognizable in all of the valley. Much of the Newari architecture and culture came to flourish during the Malla dynasty (12th to 18th century), due to rivalry between the three still-separate kingdoms in the Kathmandu Valley (Gellner, 1986; Gillekens, 2017).

2.4 - Architecture of the Kathmandu Valley

Its clay-bound soil makes for a natural unifier in the Kathmandu Valley architecture. Bricks are by far the most visibly used of materials among Newari architecture. Intricately carved stone is more common in *sikharas,* a specific type of temple, and less so in houses (Bonapace and Sestini, 2003). In housing however, concrete seems to have won over the masses when it comes to building new (9,9% of the housing in Nepal (Gautam e.a., 2016)). Traditional architecture has slowly been replaced by ‘incongruous tall buildings with little emphasis on artistic taste’ (Shrestha, 2009). Nepal has a rich tradition of vernacular architecture, by using locally available materials like stone, wood, bamboo, burnt bricks (clay), rammed earth, adobe cob and wattle and daub. But in the last 30 years the vernacular has lost its widespread continuation due to government policies, for example those limiting wood harvest (Adhikary, 2016). Moreover, especially in rural areas a certain barter-system was quite common: for example, a number of families would come together and trade materials to build houses. Only when the first house was finished, they would move on to the next one. Money was no necessity for building while nowadays it is, resulting in half-constructed concrete remnants popping up in the valley (Feenstra, 2023).

Most houses in Nepal (44,2%) are still constructed with sun-dried/fired bricks or stone with mud mortar, supported by a building frame of wood (Goda e.a., 2015; Bonapace and Sestini, 2003). These building are generally able to sway a bit due to flexible floors and roofs. The masonry walls are thick, but often weak due to poor mortar (Korn, 1979). In the Kathmandu Valley, the concrete (9,9%) and cement-bounded brick/stone (17,6%) houses are quite popular (CBS, 2012).

In the vernacular architecture of the Kathmandu valley ‘the human scale is always present’. Houses are closely-packed and divided only by narrow streets, most unfit for car traffic (Weiler, 2009). Palaces, homes, temples and stupas are snugly placed in succession, showcasing the chaotic beauty of organic city growth (Figure 3). Symmetry is found in single buildings, but not in the city planning (Korn, 1976).

According to the ERRRP Project (2011), five types of houses are found in the valley:

1. **Mud-bound:** Adobe buildings (sun-dried bricks with mud-mortar); Stone-masonry in mud-mortar; fired bricks in mud-mortar.
2. **Cement-bound**: Fired bricks in cement-mortar; stone-masonry in cement-mortar.
3. **Non-engineered RC:** Framework of reinforced-concrete columns and beams, filled in with brick-masonry with cement-mortar. Not structurally designed or supervised by engineers.

4. **Engineered RC:** Framework of reinforced-concrete columns and beams, filled in with cast-in-situ RC infill-walls, floors and roofs. Lateral forces are resisted by moment-resistant connections in the corners.
5. **Others**: wooden and mixed material buildings.

The most important takeaway from this is that the prevalent building type in most urban areas falls under category 3 (ERRRP, 2011). The reinforced concrete (RC) housing arose in the late 1970s. These structures are "non-engineered (ie., not structurally designed) and thus lack sufficient seismic resistance" (Goda e.a., 2015).

Next to this distinction based on construction methods, a distinction can also be made on the basis of time periods and aesthetics; the Newari houses of the Malla period, the neoclassical houses of the Rana period; and the modern concrete homes. These three historic periods will be elaborated in full detail, in chronological order, in the following chapters.

Figure 3: The human scale of Patan. From left to right: a shop and Newar house, a Hindu Ganesh pagoda temple, in the middle a white-plastered Buddhist stupa, on the right a phalcha, a historic resting-place for travellers passing through the city (Author's own photograph, 2023)

2.5 – Occupational castes and architecture

Although caste discrimination is criminalized since 1963, the caste system is still present and has a ‘hegemonic hold on the Nepali society’ (Subedi, 2021, p.96). The caste system is a very complex social stratification based on hereditary aspects; a Nepali is born into a caste and traditionally that caste determines your occupation and socio-economic chances (Subedi, 2021). It is, however, beyond the scope of this work to go into the socio-economic interrelations of family, caste and occupation further in depth.

Since the caste and family system is so interwoven with profession, the Newari have to this day kept the traditions of craftspeople alive. (Gillekens, 2017; Gellner 1986). For example, the Awal, Maharajan, Silapakar, Shakya and Prayapati families were historically renowned for their manufacturing of clay, wood and stone elements (Bonapace and Sestini, 2003). The in 2015 collapsed Harishankara temple on Patan’s Durbar Square, Durbar meaning ‘royal’, stood proudly again in 2019, rebuilt by a team of carpenters, carvers, masons and blacksmiths, and supervised by architectural historians. Although 90% of the used materials were salvaged from the remains of the former one, many of the ornaments needed reparations (Nepali Times, 2022). Customs dictate that broken statues cannot be worshipped, so new brass, stone and wood sculptures stay in constant demand.

The traditional bond between caste and profession has loosened its reins over the years and although this is progressive in many ways, it has also resulted in a loss of generationally transferred construction knowledge (Dixit et al., 2004). The logic behind the use of a particular element of construction has been lost to some degree. For example, the embedded timber ringbeam, or *nash,* started appearing on only two sides instead of four. The concept of a rectangular ringbeam was therefore misinterpreted, leading to a significant loss in earthquake-resistance (Dixit et al., 2004)..

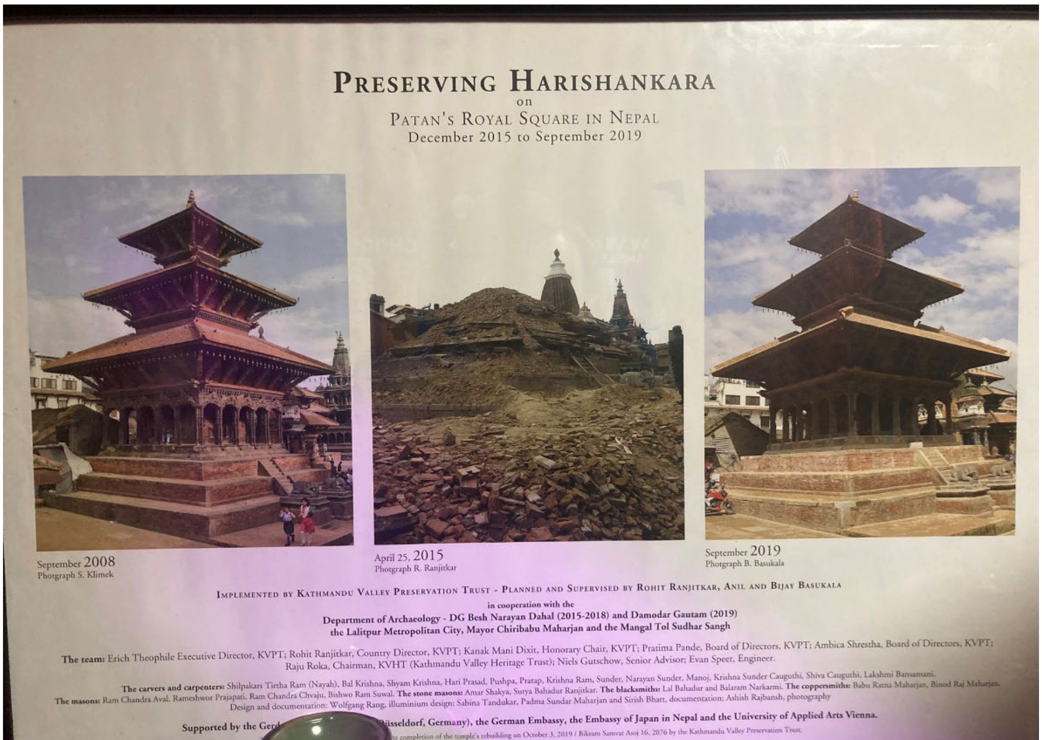


Figure 4 *The old Harishankara temple (left), built in 1706 and its 2015-earthquake collapse (middle) and reconstruction (right) (Nepali Times, 2022; Author’s own photograph, 2023).*

2.6 – The principles of earthquake-resistance construction

Vernacular housing is presently believed to make up 90 percent of the world's total housing stock (Oliver, 2006). However, "more often than not, vernacular houses are regarded as obstacles on the road to progress" (Asquith & Vellinga, 2006). So when the 2015 earthquake left its devastating scar in Nepal, questions arose as to how to rebuild. This subchapter provides the basic information needed to understand earthquake resilient constructions.

The following essential seismic design criteria are mentioned in this thesis:

§1) *Good quality of materials and craftsmanship*

According to Ortega e.a. (2017), poor quality of building materials, workmanship and maintenance result in seismic deficiencies in vernacular architecture. Lack of proper adhesion between bricks or stones, the presence of voids and brittleness make for easy collapses during tremors (Ortega e.a., 2017).

§2) *Proper structural integrity and connections between elements*

When the so-called ""box-behaviour" of a building is lost, the chance for major damages is much higher. Ringbeams, that form a square-shaped moment-resistant connection above and on top of walls, are essential in resisting inertial and lateral forces (Tonna e.a.,2019). The stiffness of the construction as whole is ensured by using these ringbeams, or similar methods of creating 'box-behaviour' (Ortega e.a., 2017). When two houses are placed right next to each other, either strengthening measures should be conducted to connect them firmly, or enough space should be left in between for movement (Lui, 2021).

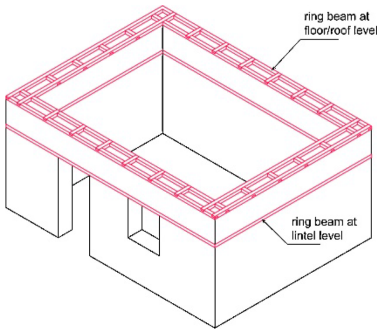


Figure 5: Timber ring-beam structure on roof and lintel levels (Joshi and Kaushik, 2017)

§3) *Implementation of earthquake-reinforcing elements*

The presence of certain elements, such as timber bands or ring beams embedded in the masonry, cornerstones, vertical wooden posts at corners, timber corner stitches, timber pegs, timber window- and doorframes significantly improve the flexibility of a building, allow for slight movement during earthquakes (Tonna e.a., 2019).

§4) *Reduction of building size and level height*

By building compact, earthquake damage can be minimized. Large spans increase the chance of ruptures and collapse of the structure (Feenstra, 2023). Low inter-story heights and a limited number of stories also help the construction to stay compact (Tonna e.a., 2019).

It must be recognized that seismic engineering is a whole field of study on its own, with many complexities that are not addressed in this thesis. Within the scope of this work, the most basic of engineering solutions will be mentioned: material usage and craftsmanship (§1), proper connections (§2), earthquake-reinforcing elements (§3) and compact building morphology (§4).

Chapter 3: the Newar architecture of the Malla Period (1769 - 1846)

3.1 - Courtyards of stone, brick and wood

Plenty has been written about the Newari housing typology; books about its intricate ornamentations, material usage and historic value in Nepali architecture. The style originally arose thanks to the technological and organizational skills of the Newars (Bonapace and Sestini, 2003). Many of the elements of Newari architecture stayed the same over the centuries due to an elaborate system of rules that determined the size, building materials and house location in relation to the street, based on caste and family groups. Houses of the elites were placed on streets closer to the palace. Lower caste houses were restricted to thatch roofs instead of tile roofs (Bhattarai-Upadhyay and Sengupta, 2016b.) With the 'typical' Newar housing described in this work, existing literature and still-standing buildings will be used.

The typical Newar dwelling is a three to four storied building, either facing an inner courtyard or a street (Figure 9) (Bhattarai-Upadhyay and Sengupta, 2016b; Korn, 1976). Although the length of houses differs, a depth of roughly 6 metres is the norm. The houses are organized around one courtyard or *chowk*, with at least one house providing a low-height passage towards the street (Figure 6) (Korn, 1976). The passages are not low just because people used to be smaller, but from the belief that a house is a palace and that everyone, unregards of class, needs to bow respectfully to enter. Courtyards are interlinked through a vast network of passages, streets and interconnected spaces, organizing households based on caste and occupation (Bhattarai-Upadhyay and Sengupta, 2016b).

A spine wall, locally called *dyā*, splits the 6-meter width on the first couple of floors in two rooms (Figure 7 & 12) (Maharjan, n.d.). The height of floors rarely exceeds two meters (Weiler, 2009). On the third floor, usually housing the living room, the spine wall is replaced by columns (Korn, 1976). The ground floor is more commonly used for storage and a storefront towards the street, whereas the top floors are for living, cooking and sleeping. Washing is mostly done outside the house in *dhunge dhara*, or public fountains.

Figure 6: Dachi- appā bricks (Author's own photograph, 2023)

The foundation of the Newari housing exists of a few layers of natural stones and clay mortar (Korn, 1976). The walls are on the outwards built up with fired bricks or sometimes special *dachi- appā* bricks: rectangular towards the front, but with tapered sides in the back to show a minimum amount of mortar on the façade (Figure 11) (Maharjan, n.d.; Pande, 2018; Weiler, 2009). The inner walls would exist of sun-dried bricks, or *ma- appā* bricks, while the cavity in between is filled with sun-dried bricks, bat bricks (bricks cut halfway the length) or just rubble bricks, which gives the walls its impressive >50 cm thickness (Tonno e.a., 2019). These massive walls were needed to make the houses earthquake-resistant (Maharjan, n.d.). The floors, doors, windows and roof structures are done in *sal* or *sisau* wood, often richly carved. These hardwood species do not require treatment to be weather- and insectproof (Tonno e.a., 2019). The windows are small to keep the winter cold out. (Bhattarai-Upadhyay and Sengupta, 2016a). The roofs are usually gable roofs cladded with tiles (figure 8). The overhang is generally 1 meter to protect the walls from the sunlight and powerful monsoon rains (Korn, 1976). Embedded in the load-bearing masonry, many horizontal timber beams are found. This is called the *taq* system, and it allows the walls to slightly deform during earthquakes without significant damage (Joshi & Kaushik, 2017).

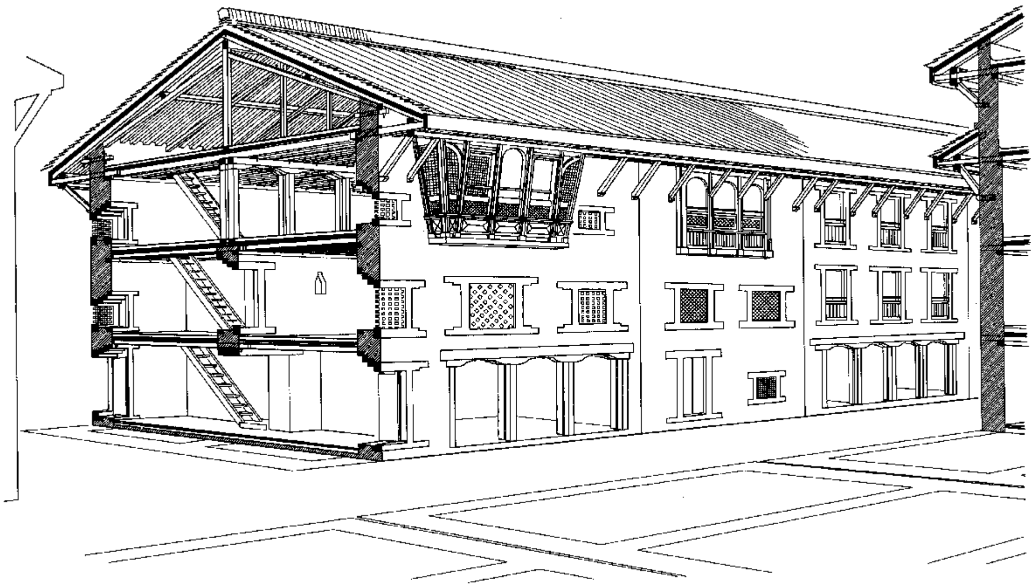


Figure 7: Drawing of a typical Newari house (Korn, 1976).

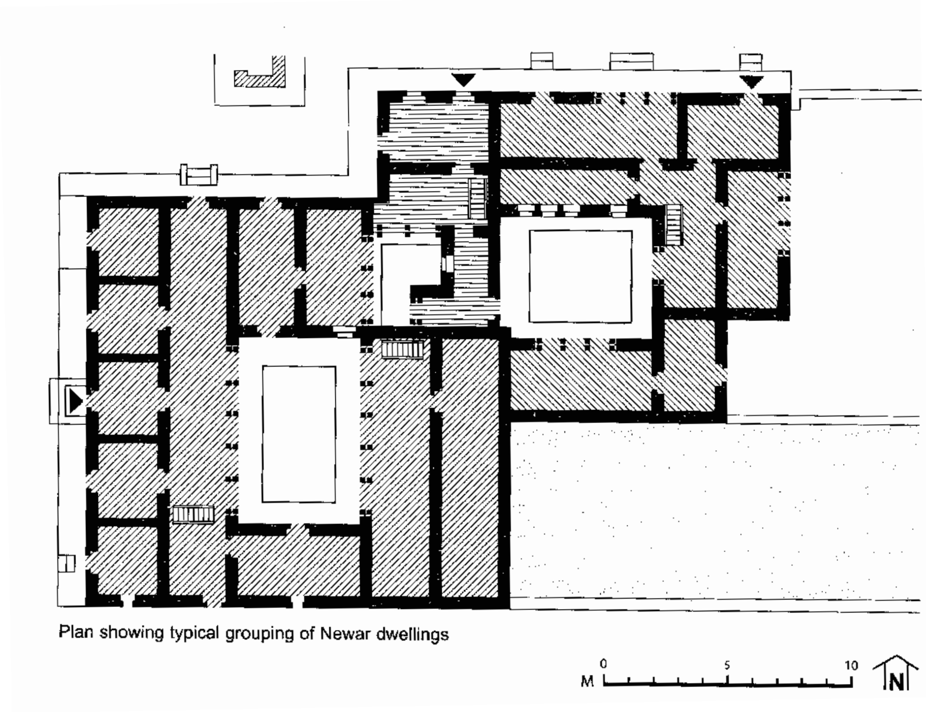


Figure 8: Floor plan of a group of Newari houses (Korn, 1976). The maximum 6-meter depth can be seen, as well as the dyā that splits the houses into two narrow room.

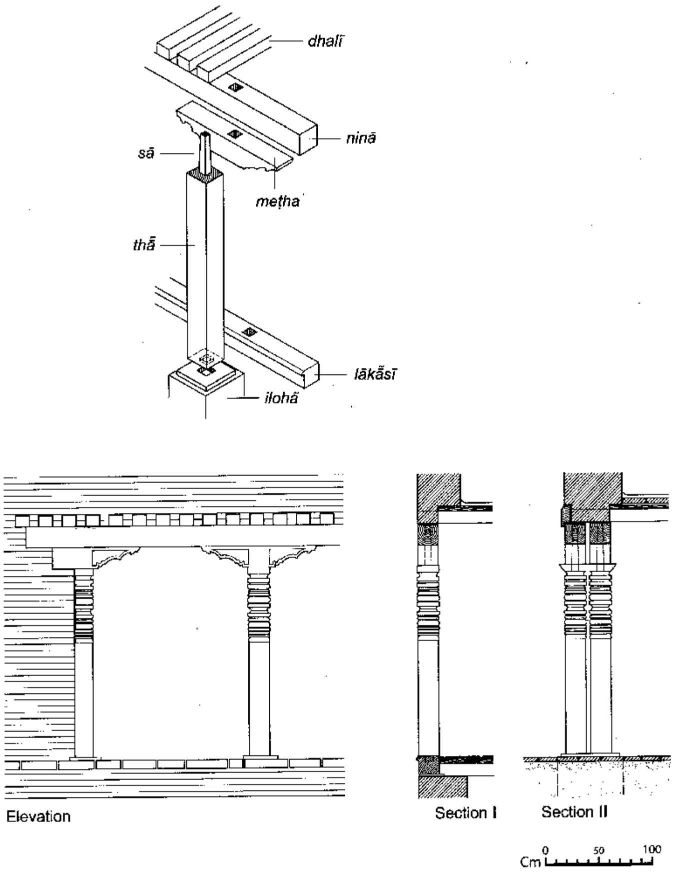
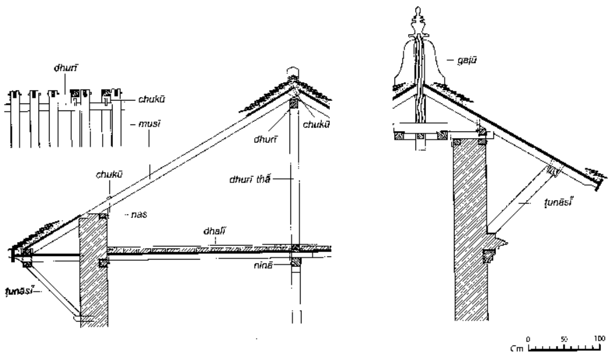
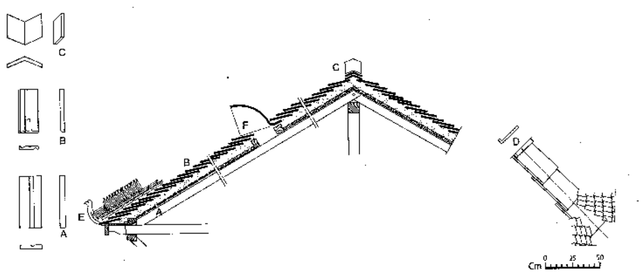


Figure 9: A typical wooden column in Newari architecture: made without any steel bolts or nails. Due to using wooden connections, slight deformity and flexibility is possible (Korn, 1976).



9.7 Sections Showing Typical Roof Details



9.8 Roof Tiles

Figure 10: A roof detail of a Newari house: lightweight timber construction, ceramic shingles and a 1,0m overhang to protect the walls against sunlight and rain (Korn, 1976).

3.2 - Earthquake preparedness

It is the combination of thick masonry walls with wooden floors, roofs and frames that make Newari houses rigid. The wood allows for slight movements during tremors, and the thick masonry walls give the building its weight (Bonapace and Sestini, 2003). Still, despite their strong appearance and quality of fired bricks, many Newar buildings are surprisingly weak. Korn (1976) accounted that to the following reasons:

- The use of mud mortar;
- Poor bonding between the inner and outer brickwork of the walls;
- Difference in brick sizes;
- Lack of proper adhesion between walls at the corners (§1).

Even so, from a structural point of view, the following features provide the Newari architecture with earthquake resistant properties: rectangular and symmetrical housing shapes, with a reduced length-to-depth ratio, small openings, reduced story heights and a limited amount of stories (§4); and the presence of timber bands inside the masonry, vertical timber posts on corners, door frames and windows, timber corner stitches inside the masonry and finally timber pegs (§2 and §3) (Tonno e.a., 2019).

As seen in figure 9, the wooden columns are often made without the need for nails or steel bracings. The wood-on-wood connections allow for slight flexibility, and it makes them easy to replace once needed (§2).

As a case study, the Hira Guesthouse in Patan is used (Figure 11-14). Timber can be seen in many places, including the window- and door openings, inside the masonry and as a floor structure. Horizontal timber beams provide flexibility in the masonry walls. The low ceiling height (<2,0 meter) allow for a compact building shape. The building makes use of timber and bricks in the wall, stone in the foundation, lime plaster on the interior- and exterior walls. This hybrid makes sure every material is used there where its qualities are needed the most.

3.3 - Earthquake of 1833

On the 26th of August, 1833, a major earthquake ($7.5 < M_W < 7.9$) struck Nepal and the northern part of India. Due to strong foreshocks, many people saw the big tremor coming and found safety in open spaces (Chaulagain e.a., 2018). 'Only' 414 fatalities were reported, and 4000 buildings damaged in the Kathmandu Valley (BCDP, 1994). Oldfield described in his *Sketches of Nipal* (1880) that the south-side of Patan's Durbar Square was completely destroyed, as well as temples on the Western side having fell into ruin. Other than that, for reasons unknown, he does not mention the earthquake once in his book.

Only general facts about the earthquake's magnitude are known. There is no photographic documentation, so how the tremor changed the urban fabric and architecture of the Kathmandu Valley, is largely unassessed (Shakya e.a, 2012).

Figure 11: The approx. 300 year old Hira Guesthouse is a textbook example of a Newar house; embedded in a courtyard, originally 3-4 stories high, but topped up with another floor later on. The facades are made of fired bricks with mud mortar, of which the ground floor is plastered with lime. The 300-year age is a nuanced story though; parts could have been changed and reconstructed, which is not documented (Ranjitkar, 2023) (Author's own photograph, 2023)

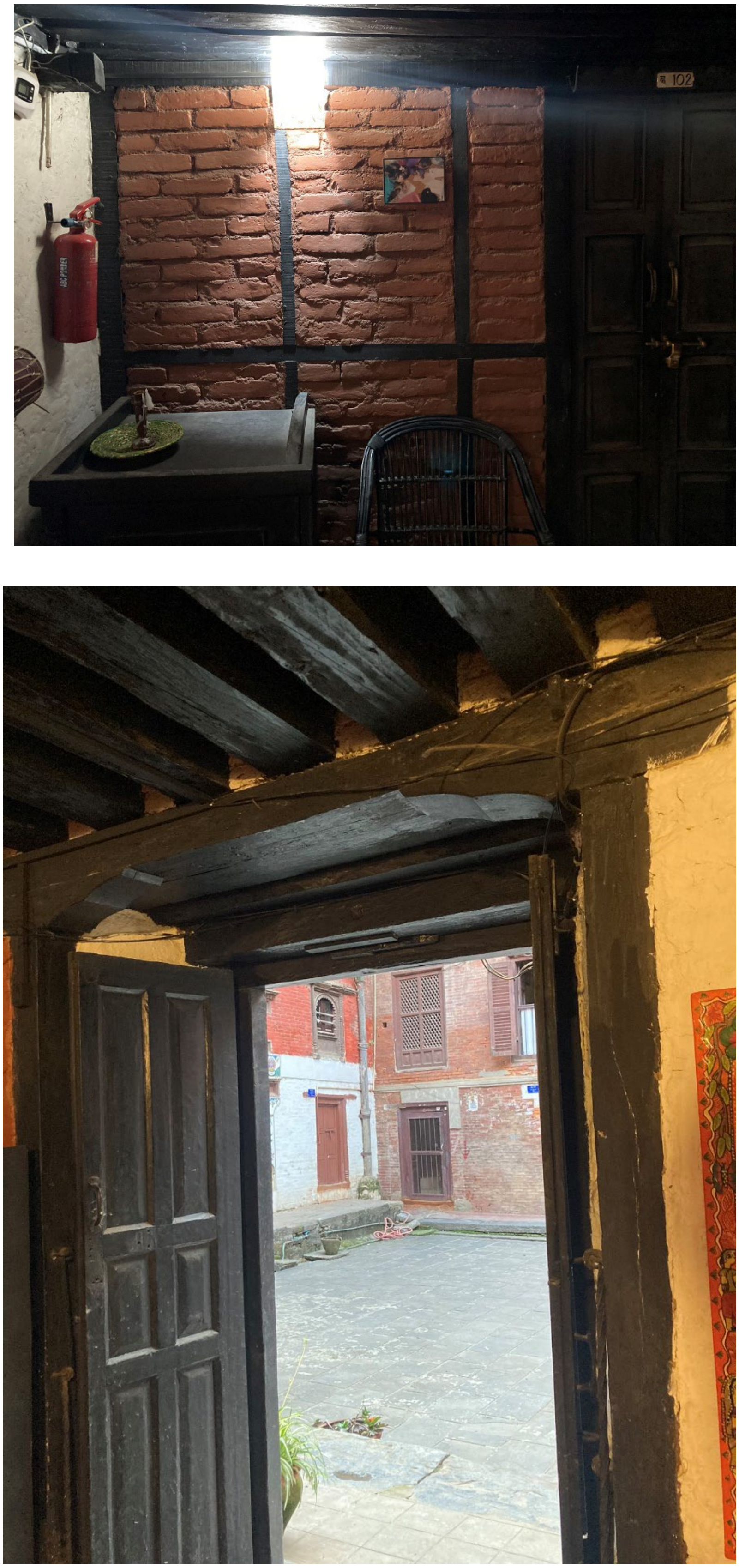


Figure 12: Details of the interior of the Malla-era Newar house: Hira Guesthouse. Vertical timber posts in corners, strong window frames, horizontal timber beams embedded in the masonry, thick walls, wooden floors and low ceiling heights. It is no wonder this building has survived three major earthquakes already. (Author's own photograph, 2023).

Figure 14: The inside of a typical Newar house, now transformed to a guesthouse living space. On the right, the dyā can be seen (white plastered wall). This 'spine' divides the 6-meter width in two spaces, therefore creating long and narrow rooms (Author's own photograph).

Figure 13: Construction of a wall of the Ikhachhe Bahi temple in Patan, as a part of the reconstruction of the temple. The wall thickness is achieved by multiple layers of brick, of which the outer layers exist of slightly tapered bricks (Author's own photograph, 2023).

Chapter 4: the neoclassicist architecture of the Rana Period (1846 – 1951)

4.1 - White-plastered wealth

As the Rana rulers travelled to Europe from 1846 on, they brought home neoclassicist, French renaissance and baroque influences (Bhattarai-Upadhay and Sengupta, 2016a). The royals started erecting white-washed neoclassical palaces in Nepal and by doing so, influenced the trends in residential architecture. The *Rana-style housing* can be devaluated as bad imitations, or enjoyed as a unique blend between European and Newar architecture (Weiler, 2009). Instead of Greek symbolisms, Hindu and Buddhist symbols can also often be found in the ornamentations (Ranjitkar, 2023).

Compared to the Newar housing typology, only little has been written about the constructional qualities of the Rana-style house. Mechanical properties are barely reported (Parajuli e.a., 2020). In India, the neoclassicist palaces were often constructed by European engineers, but foreigners were largely disallowed in Nepal at the time (Weiler, 2009). The palaces were built by British architects and craftspeople from Calcutta, but regular home-owners could not hire them (Ranjitkar, 2023).

A couple of facts are known, however. First of all, the monuments were built up with brick masonry in mud mortar, although some academic sources claim it to be surkhi-lime mortar (Parajuli e.a., 2020). This is a common misconception however. The surkhi-lime mortar was used for bridges and tunnels, not in residences (Ranjitkar, 2023). In Surkhi-lime mortar, sand is replaced by burnt-brick powder and it is therefore a cheaper option (Iqbal, 2022). The white façades were plastered with lime-mortar; a technique that started being widely used around the middle of the 19th century (Bonapace and Sestini, 2003).

Fig. 113-116
Patan, Ananda Niketan (1892).

Fig. 114
Mascarons and a *svastika* frieze adorn the wall in the *piano nobile*.

Fig. 115
Details of the façade: Classical urns replace the gables above the outer windows.

Figure 15: The Ananda Niketan-building (currently the Office of the Dean of the Pulchowk University), a neo-classicist palace from the Rana era (Weiler, 2009).

Secondly, all the palaces have sloped roofs covered with either galvanized iron-sheets or clay tiles (Khadka, 2018). It is unclear whether this is similar in the Rana-style houses of early 20th century.

Thirdly, and most interestingly, the neoclassicist houses' modernity was confined to its façade (Weiler, 2009). The surface was ornately decorated and white-plastered for the Newari noblemen of Kathmandu, but built by Terai craftsmen that became skilful in neoclassical façades due to Indian influence (Bonapace and Sestini, 2003). Contrary to the façades, the rest of the house was arranged just as it had been for generations: according to the traditional interrelations and order between castes and families (Weiler, 2009). The insides remained simple and largely unchanged from the late-Malla Newar housing (Ranjitkar, 2023). In the 1850's, the painter Henry Ambrose Oldfield visited Nepal, resulting in the published *Sketches of Nipal* (1880) after his death. He wrote:

> "Their exteriors are in the pseudo-classic, or carpenter's Gothic style of architecture, profusely covered with paint and plaster, instead of with rich carvings and fancifully cut wooden reliefs. In their interiors the private apartments retain the low ceilings and doorways, step-ladders, and trap-doors, which are characteristic of most native houses" (Oldfield, 1880, p.106-107).

Moreover, the Rana houses also sometimes contained 'large public reception rooms built in the English fashion', including all the furniture and decoration one would except in a British Victorian home (Oldfield, 1880, p.107). The use of 'European elements' was a mere show-off of wealth and status (Weiler, 2009). Though these facts provide us with a lot of information about the life in Rana-houses, not much is written about their earthquake resilient elements. Because the changes were mostly just in the facades, it can be presumed that the interiors contained many of the typical Newar-elements as described in chapter 3.

Figure 16: The Gaddi Baithak (1908) palace on Kathmandu Durbar (Royal) Square in the front. In the back the Kumari Ghar is visible, a typical Newari house of worship (Author's own photograph, 2023).

Figure 17: The Amatya House: a Rana-style housing complex in the center of Lalitpur. It contains stores on the ground floor, and residences on the upper floors. It was erected in 1945 and has therefore survived the 1988 and 2015 earthquakes (Weiler, 2009) (Author's own photograph, 2023).

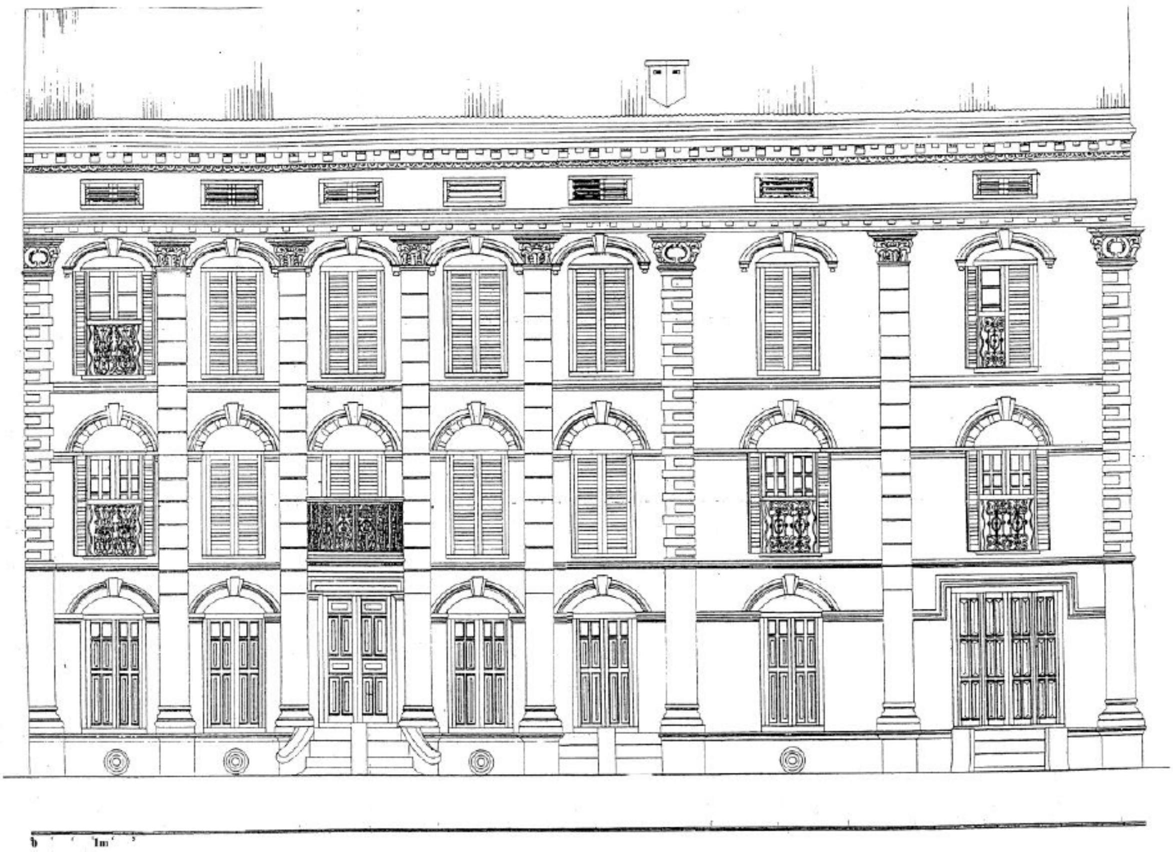


Figure 18: Facade drawing of the Amatya House in Lalitpur (Weiler, 2009).

Figure 19: 'Black capitals, a whitewashed façade, cast-iron balustrades and green Venetian blinds – all characteristics of Rana palace – are represented on the façade of the Amatya House' (Weiler, 2009, p.375)

Figure 20: A Rana-style freestanding house in Patan (Author's own photograph, 2023).

Figure 21: Another Rana-style house, also called the Amatya House, built after 1934 (Weiler, 2009) (Author's own photograph).

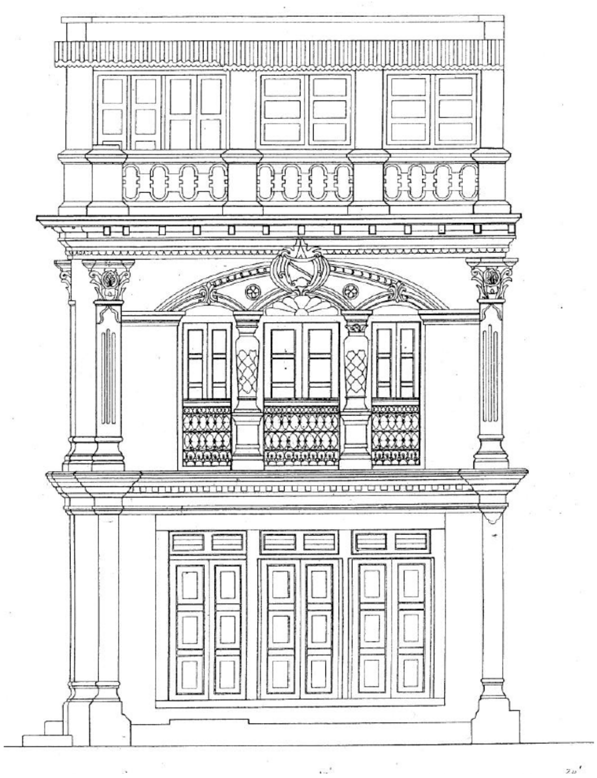


Figure 22: Drawing of the Amatya House, built after 1934 (Weiler, 2009).

4.2 - Earthquake preparedness

The Rana palaces, and the houses inspired by them, typically have very symmetrical facades and same-sized openings throughout the fronts (§4). Due to these many openings – much more than in the typical Newari houses as described before – the seismic resilience of the façade as a whole is greatly reduced (Khadka, 2013). The more horizontal, small windows of the Newari architecture were left behind for larger, vertical windows (Weiler, 2009). The houses most likely used the same earthquake-resilient timber beams as the older Newar housing (§2 and §3). The same mud-mortar was used as the older houses, so no changes can be seen in adhesion quality (§1).

Thanks to Oldfield's descriptions, it is know that they had low floor heights, similar to Newar architecture. One of the reasons why so few Rana-houses are still visible in the Kathmandu Valley has to do with the fragility of the façade: the plastering and ornamentations need maintenance, especially after earthquakes and intense monsoon rains. These façades may have vanished, but the building behind it stayed (Feenstra, 2023). The Amatya House in figures 15 and 16 remained quite similar, while the house in figures 19 and 20 completely almost complete changed facades for unknown reasons. It is very likely that likely that the façades deteriorated over time and the owners replaced them with newer, more resistant fronts.

4.3 – Earthquake of 1934

On the 15th of January, 1934, Nepal was hit by a M_w – 8,1 earthquake, which resulted in 8,5 thousand deaths in Nepal, and the destruction of over 55000 buildings damaged in the Kathmandu Valley (Chaulagain e.a., 2018). The earthquake affected Nepal's capital 'as well as half the kingdom (Rāṇā and Lall, 2013, p.1). In Lalitpur an estimated 5.000 residences were destroyed.

Major General Bahadur Rana wrote 'The Great Earthquake of Nepal' (1934) right after the shock and documented the casualties, damages, psychological effects and reconstruction. Over 40% of the traditional masonry remained unaffected seriously in the 1934 earthquake (Dixit et al., 2004). *Pancake destructions,* the story-on-story total collapse of a building, was much less likely in brick-masonry structures than it was in RC-frame structure. Furthermore, the courtyard building was considered strong because of its symmetry (Dixit et al., 2004).

Rāṇā (2013) devoted an entire chapter to how to reconstruct. He mentions that the engineers were not agreeing on what points to fortify in further constructions, because lessons learnt in one building proved wrong in another. Despite the differences, one lessons was learned: 'houses build of reinforced concrete are the best guarantee against earthquakes' (p.94). At the time, no concrete buildings existed in Nepal, 'but examples in foreign countries amply prove the theory.' (Rāṇā and Lall, 2013, p.95). Based on Japan's reconstruction after earthquakes, Rāṇā argues for a cement factory in Nepal to start development sooner rather than later. Concrete reconstruction allowed for cleaner, safer and healthier cities than before, but it seems like a far stretch to account all these values to concrete alone.

At the same time he writes that houses made of wood, bamboo and wattle showed significant strength in the earthquake. Brick houses built adjacently should have interlocking bricks, so the two buildings can sway as one instead of ramming into each other. 'Clamping devices' should be used to make one wall hold to another. Numerous windows, pillars and arches should be avoided as they weaken the walls, and roofs must be light (Rona and Lall, 2013, p.93).

Although Rana-style houses were already popping up in Kathmandu, 'the great rebuilding after the earthquake, however, was the opportunity for many Newars to jump on the bandwagon of modernity' (Weiler, 2009, p.143).

Figure 23 : *Left: Brick and concrete house with elements influenced by Rana Palaces, that were itself influenced by baroque and colonial architecture. Right: new, modern concrete house. In front of both houses, a Buddhist Stupa temple and prayer wheels can be seen (Author's photograph, 2023).*

Figure 24: A category-3 (ERRRP, 2011) building is constructed in Patan. The columns and beams are of reinforced concrete, with brick infill-walls masoned in between. (Author's own photograph, 2023).

Chapter 5: the modern Nepali architecture of concrete and corrugated sheets (1951 – 2023)

5.1 - The great slumification of Nepal

Unlike the cohesive housing of the original Newar towns, the new houses in the Kathmandu Valley are often individual construction projects, unharmoniously placed on vacant lots. They differ in colour, design, shape and scale to each other (Bhattarai-Upadhyay and Sengupta, 2016a). Often they are constructed slender and multi-storied due to rising land prices (Bhattarai-Upadhyay and Sengupta, 2016b). This is largely due to culture: the land of parents is divided amongst their sons, dividing the land in smaller and smaller bits with each generation (Ranjitkar, 2023). It forces each son to create at least 5 or 6 stories to create a house large enough for his family.

> *'The landscape of uniformity and homogeneity in architectural style and design gave way to a collage of styles driven by images of Western modernity' (Bhattarai-Upadhyay and Sengupta, 2016a, p.7).*

One very common type of modern dwelling is the RC-framed structure: cast in-situ reinforced concrete columns and beams, with brick or concrete-block in-fill walls (Figure 22). After erection of the walls, the facades may be plastered to cover up the brick in-fill (Figure 26, 27) (Shrestha e.a., 2021). Another type, amounting to 9,9% of the houses in the Kathmandu Valley (CBS, 2012), is the full-concrete house, where floors, walls and roofs are all concrete. Very often, these newer houses will also contain a couple of neoclassical elements for decoration.

Especially in commercial areas, tall buildings with soft ground stories are present. The upper floors are divided into small rooms with brick in-fill walls, while the ground floors are open-plan shops or garages. As mentioned in chapter 2, these buildings are very vulnerable for collapsing (Shakya and Kawan, 2016).

These new materials also made way for more technical ignorance among the general public: people started to move away from tradition since it is easier to follow techniques that everyone is building with (Bhattarai-Upadhyay and Sengupta, 2016a). Moreover, the reinforced concrete lobby is strong: with China and India at Nepal's doorstep, the two powers see a big market in Nepal for their concrete producers. After 2015, a lot of international organisations donated money to Nepal for rebuilding purposes, and the concrete markets saw their chance. Instead of promoting local materials, cheap materials from outside Nepal were imported: corrugated sheets, concrete, tarpaulin and some steel. 'This is not active architecture, it is reactive.' (Feenstra, 2023). Roughly 1/3 of the buildings in Nepal are now covered with corrugated sheets (Gautam e.a., 2016). It is a significant and rapid change towards a so-called slumification of Nepal's architecture (Feenstra, 2023).

According to Weiler, (2009, p.143), however, 'the rise of modernity should not be equated with the end of the Rana oligarchy in 1951'. The 'modern' materials like stucco plaster, cement, iron, glass and corrugated iron sheets were introduced even before the sudden clash with other cultures in the 50's. Particularly after the major earthquake in 1934, new houses were built in new ways (Weiler, 2009). After 2015, however, one would not get a building permit if the house-to-built had no concrete (Feenstra, 2023).

5.2 - Earthquake preparedness

After the 2015 earthquake, the popular perception that traditional homes are weak, and concrete homes are strong, was only further developed (Karki e.a., 2022). Though it is true that mainly buildings of stone or brick masonry were destroyed, 'it is way too easy to say: old buildings are weak, concrete buildings are strong. It is much more complicated than that' A lot of the earthquake-protection has to do with proper maintenance of buildings, which is often neglected in older houses (Feenstra, 2023).

The buildings in Figures 28 and 29 as roughly as wide as they are deep, creating a somewhat square floor plan. This definitely helps with the earthquake resistance of the building as a whole (Feenstra 2023). The structure is RC-frames with brick in-fill walls or windows. The floors are also concrete, and they have overhangs that help with its moment of force (Feenstra, 2023). The buildings plans are normally square or rectangular shaped (§4). The floor height ranges from 2,4 to 3 meter. Spans between beams do not exceed 4 meter usually. Poor workmanship and poor construction materials are quite common (§1)(Shakya and Kawan, 2016). Insufficient strength in the loadbearing walls can cause out-of-plane collapses of parts of the masonry (§2). This happens often in unreinforced concrete walls, as they are not strong enough to withstand the internal stress (Vaculik, 2012). Although the houses in figures 26 and 27 are shape-wise earthquake resilient, there is no possibility for movement in its structures. Since most of the RC-framed structured are non-engineered, they lack sufficient seismic protection (Goda e.a., 2015).

From a seismic point of view, tall soft story constructions are very dangerous (§4) (Haque e.a., 2023). The non-engineered majority of structures often contain garages or commercial functions on the ground floor. These so-called *soft story* buildings have a more open, and therefore weaker ground floor (ERRRP, 2011). The chance for the upper floors to collapse on top of the ground floor, a *pancake collapse*, is much greater in the soft story buildings (Vox, 2023). Despite their poor performance, soft story construction is still continuing in many countries (Haque e.a., 2023). The recent earthquake in Turkey showed the horrifying dangers of these buildings (Vox, 2023).

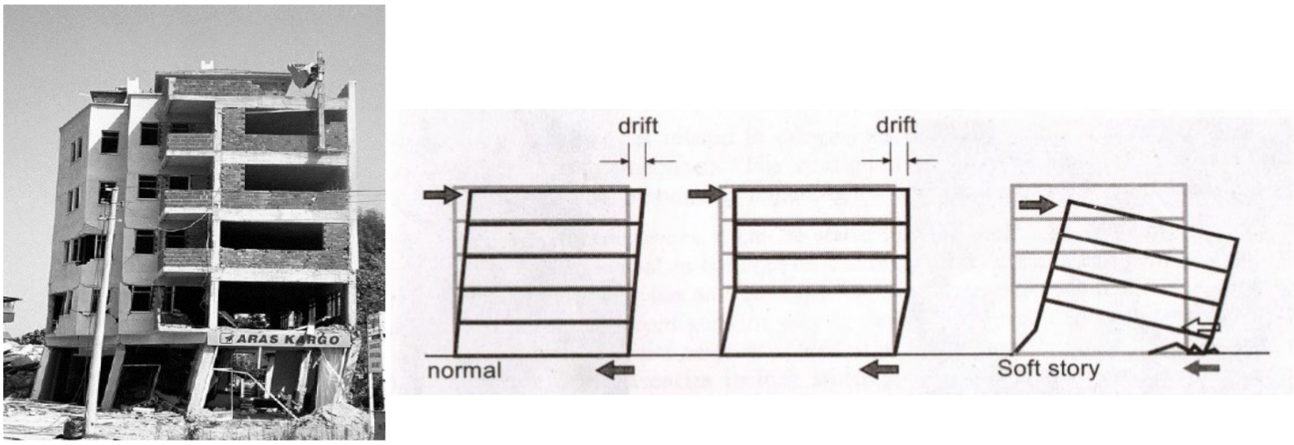


Figure 25: Both images from 'Seismic Vulnerability Evaluation Guideline for Private and Public Buildings' (ERRRP Project, 2011).

5.3 – Earthquake of 1988

A major (6.5 M_w) hit the west of Nepal (Chainpur) in 1980, but no notable damage was documented in the Kathmandu Valley. In 1988 however, the Udaypur Earthquake (6.8 M_w), also known as the Nepal-Bihar earthquake, struck the eastern and central part of Nepal, including Kathmandu (Chaulagain e.a., 2018). In Nepal, the quake claimed over 700 lives and over 12 thousand people were injured. According to Gupta (1988), the earthquake damaged many residential buildings, as well as schools, public buildings, hundreds of kilometres of road, irrigations, canals, bridges and water supply networks. Duggal and Sato surveyed some of the damages in 1989, and wrote that both non-engineered RC-framed buildings and brick with mud-mortar houses suffered damage. Moreover, masonry buildings collapsed due to poor (mud) mortar, weak connections between the roofs and walls and weak window/door openings.

In Lalitpur, 376 houses collapsed, another 137 damaged. In Kathmandu, 'only' 200 houses were damaged, none destroyed. Bhaktapur was hit the hardest with 1477 houses damaged and 274 collapsed (Chaulagain e.a., 2018). In relation to the 1833, 1934 and 2015 earthquakes, the damage in 1988 is therefore comparatively insignificant.

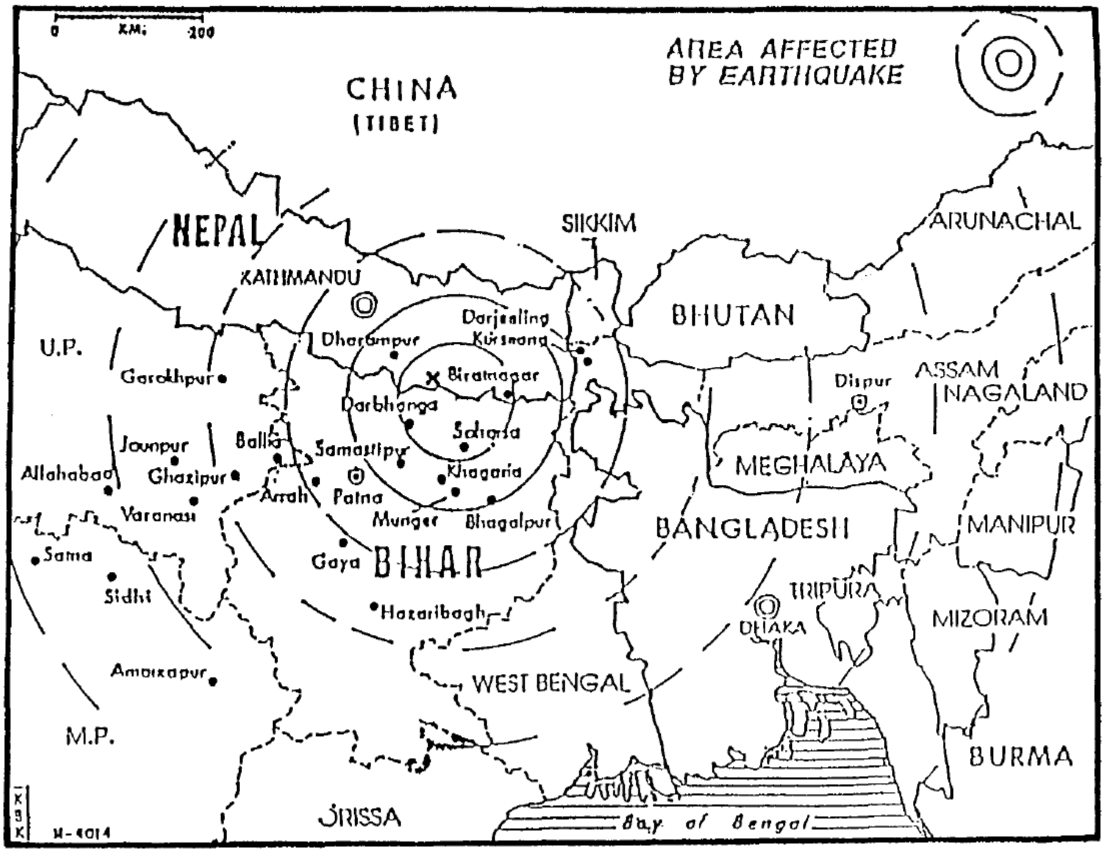


Figure 26: Area affected by the 1988 earthquake (Duggal and Sato, 1989).

5.4 The issue of wood

Typically, *sal* and *sisau* wood is used for building exteriors because of its strength and weather-resistance, and before the last century both types grew richly on the slopes of the Kathmandu Valley. Nowadays, it needs to be brought from the Terai, but that is not enough to meet market demand (Bonapace and Sestini, 2003). Due to a radical policy implemented by the Nepali government 40 years ago, wood is much harder to get by.

That is because in the early 1980's deforestation was a devastating problem, that made floods and landslides more frequent. People kept cutting down trees for houses, firewood and farmland. Luckily enough, the government stepped in and allocated large swaths of land for *community-managed* forests. Thanks to these efforts the total tree cover of Nepal has gone from 26,2% in 1992, to 44,9% percent in 2016 (Singh and Sharma, 2022).

Though that is outstanding for the forest and all that live in it, construction with wood needed to halt down. Timber become more expensive and less available, so less wooden ring-beams and ties were implemented during the 1970's and 1980's (Adhikary and Johnson, 2015; Yeomans, 1996).

5.5 – Earthquake of 2015

On April 25, 2015, a major earthquake (7.8 M_w) shocked Nepal once again. The epicentre was in the Gorkha district, so the tremor is known as the 'Gorkha Earthquake' (Chaulagain e.a., 2018). 17 days after the main shock, an aftershock of 7,3 M_w occurred. Altogether, 315 aftershocks were reported up until July 2nd of 2015 (Shakya, 2016). The earthquakes claimed 9000 lives, injured 23.000 people and estimated to $7 billion in economic damage (Liu e.a., 2021). 'Luckily' enough, the earthquake happened on a Saturday, so schools and public buildings were empty and many people were spending a day outside. Nevertheless, the 2015 earthquake damaged homes, killed family members and caused massive disruptions in people's lives (Limbu e.a., 2019).

The neoclassicist Gaddi Baithak (figure 16) in Kathmandu completely succumbed in the earthquake, while the Newari exposed brick masonry building on opposite site of the square survived, likely due to the use of embedded timber beams in its masonry. These gave the walls a slight capability of deforming, and therefore surviving shakes (Joshi and Kaushik, 2017). In figure 27, a horizontal lintel beam in the façade improves earthquake-safety, as the tradition was: 'always put a wooden (tie) band around the building at sill level, lintel level and at the floor level. Carve it in 'naga' (snake). It will protect your house' (Dixit et al., 2004).

(a) (b)

Figure 27: Visible timber ring beams and beams embedded in the masonry at the Hanuman Dhoka Palace in Kathmandu (Joshi and Kaushik, 2017).

Generally, it was found that both vernacular and modern houses that were negligent in earthquake-resilient elements were severely damaged, while those that incorporated resilient features survived (Karki e.a., 2022). Up until the 2015 earthquake, most homeowners were unfamiliar with the concept of a building code and built according to their preferences and knowledge (Limbu e.a., 2019).

A massive change in client's perspective occurred after the earthquake. Whereas before 2015, clients of larger construction projects tried to crack down on earthquake-resilient elements as much as possible to cut costs, after the quake they became aware of its necessity. People started asking: 'Is this building earthquake-proof for sure?' (Feenstra, 2023).

Even so, post-earthquake reconstruction still produced houses unfit for comfortable living. The imported materials are costly for the local residents, and do not adept to local climatic conditions (Vegas e.a., 2020). By replacing vernacular design with modern methods, concrete houses were created that are 'spatially insufficient, climatically unsuitable and practically inconvenient' (Karki e.a., 2022).

People seem to not accept cheap shortcuts when it comes to the reconstruction of temples. As mentioned in chapter 2, temples were minutely reconstructed. Houses were regarded as rubble and bulldozed over (Feenstra, 2023).

Figure 28: Typical modern concrete 'mushroom' housing, with a soft story on the ground floor containing a shop and a restaurant (Author's own photograph, 2023).

Figure 29: Similarly to figure 25; a concrete-framed and brick-infill house in Chakupat, Lalitpur.

6.1 – Conclusion

The present thesis aimed to answer the question: *What changes can be documented in the use of earthquake-resilient elements of vernacular houses in the Kathmandu Valley cities from 1833 until 2015?* By looking at three eras of residential architecture, a development throughout history can be assessed.

Generally, it was found that both vernacular and modern houses that were negligent in earthquake-resilient elements were severely damaged, while those that incorporated resilient features survived earthquake-safety.

	§1) *Good quality of materials and craftsmanship*	**§2) *Proper structural integrity and connections between elements***	**§3)*Implementation of earthquake-reinforcing elements***	**§4)*Reduction of building size and level height***
Malla-era Newar houses	*Often poor materials, but good craftsmanship* +−	*Timber-on-timber connections that allow flexibility* + +	*Extensive use of timber to allow flexibility in the structure* +++	*Low-height floors and compact building sizes* +++
Rana-era neoclassical houses	*Often poor materials, but good craftsmanship* +−	*Timber-on-timber connections that allow flexibility* + +	*Extensive use of timber to allow flexibility in the structure* +++	*Higher floor heights, larger rooms but still compact building sizes* +
Modern concrete (-framed) houses	*Often poor materials and poor craftsmanship* −−	*Reinforcement in columns and beams, which make the structure strong* +	*No implementation of earthquake reinforcing elements* − −	*Tall and large buildings, but often short spans. Often square or rectangular plans.* + −

The current residential architecture of the Kathmandu Valley "stands disengaged from its glorious past and remains disoriented" (Bhattarai-Upadhyay and Sengupta, 2016b). Centuries of trial-and-error have created vernacular architectures that can resist earthquakes, while at the same time providing comfortable spaces to live in. But ever since the modernization of Nepal, not enough focus has been on protecting this vernacular knowledge.

There are multiple reasons for a loss of knowledge, awareness and implementation of earthquake-resilient features:

- The partial loss of the occupational caste system has stopped the generational transfer of knowledge about construction techniques.
- The rising land prices and subdivision of land amongst brothers forces people to build higher, more slender, and more 'stacked'. The importance of compact building typologies is ignored.
- The risen prices of wood forced people to get rid of timber in the architecture, reducing the amount of earthquake-resilient features in walls and frame structures.
- The earthquakes of 1988 and 2015 have caused devastating destructions, which created growing necessities for new housing. To do this rapidly, international aid provided cheap materials. China's and India's concrete producers quickly jumped in the gap and presented themselves as the new, safe go-to building material.

- The culture of self-building allows for people to follow trends rather than urban designers.
- The neoclassical influences created palaces that were very earthquake-unsafe, only adding to the ignorance of earthquake safety.
- A lack of maintenance of older houses create vulnerable structures that have a higher chance of collapsing in earthquakes, only adding to the prevalent misconception that older buildings are weak.

To disregard the use of new technologies and materials as the problem would be ignorant. There are very valid reasons for building with concrete, as it is fast, readily available and strong. But builders should not forget the absolute basics of building earthquake-safe.

The answer to earthquake-prepared housing is not something to be invented: it is to be reignited. The techniques already lie in Nepal's backyard: embedded in the monumental houses of the Newari (Joshi and Kaushik, 2017). External, as well as internal changes, have thrown dust into the gears of safe Nepali architecture development and knowledge-transfer. The craftspeople in the Hills still know these vernacular techniques today, but the question can be raised for how long this knowledge will keep living in Nepal's rapidly modernizing urban fabric. Modernisation is not the enemy; use of new materials and techniques was necessary for providing homes after disasters, but along the way essential knowledge was lost. Luckily enough, organisations like ABARI are promoting indigenous building techniques, and promote the usage of treated bamboo to bypass the high timber prices (Adhikary and Johnson, 2015). Perhaps the answer lies in an architecture that is based on traditional techniques for safe housing, but mixed with newer materials and trends that are preferred now.

> *"Before homes in the Hills are replaced by pre-fabricated housing or one-story concrete bunkers in the name of "building back better," we should consider whether the weakness in the structures which fell during earthquakes and aftershocks is due to design and materials or to the techniques used to build them?"* – Adhikary and Johnson, 2015

6.2 – Discussion

Some very important conclusions can be drawn in this thesis, but the work should also be seen through the scope in which it was made. The more questions were answered, the more new questions arose. Assessing the entire residential architecture of the Kathmandu Valley on earthquake resilience is a very complicated assignment. Since Nepal does not have a detailed history of documenting the built environment, many sources are very recent. The architecture literature of the 18^{th} and 19^{th} century is mostly focused on cultural sites, less so on residences.

Furthermore, the conclusions should also be seen through a certain lens: first of all, taking care of heritage and traditional building technologies is a luxury, not a first need for a country like Nepal. With the recent 2015 earthquake, the COVID-19 pandemic and the 2022 Dengue endemic, it is most reasonable that more importance is placed in creating enough proper housing and healthcare, not doing so in the most culturally-sensitive and safe way. Earthquakes are frequent, but 99 percent of the time, people's minds are not set to the next earthquake; rather to taking care of their families and work. Additionally, persistent social inequality, mass emigrations (of primarily young people), (political) corruption and casteism are not uncommon in Nepal.

Secondly, although styles and traditions are definitely recognizable, every house is still different from the next. Because of the self-building tradition in Nepal, large housing projects are uncommon. Every family builds according to their wishes, accessible materials, budget and trends. It makes the skyline of Kathmandu a chaotic mix of undefinable styles and architectural choices, and very difficult to grasp in academic research. Conclusions drawn in this thesis may not hold ground when trying to assess them on single houses. It is essential to take a bird's eye view.

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APPENDIX I - Interview with prof. Anne Feenstra - 27-03-2023

The following is a transcript of an interview held with prof. Anne Feenstra on 27-03-2023. As the former dean of CEPT Ahmedabad and a laureate of the Global Award for Sustainable Architecture (2012, Paris), he is a very knowledgeable source of information regarding earthquakes and architecture in South Asia. He is the founder of architecture firm Sustainable Mountain Architecture in Kathmandu, and has worked in the Netherlands, the UK, Afghanistan, India, Sri Lanka and Nepal. The interview was voice-recorded and afterwards translated from Dutch to English down below.

When did you arrive in Nepal for the first time?

"I think in 2009. Three years later we moved from Kabul to Kathmandu, in 2012. My wife started working in Kathmandu, but I was still finishing off projects in Afghanistan with AFIR. I was teaching at the Tribhuvan University in Kathmandu in 2012-13. In the winter of 2013 we founded SMA, following an exhibition at the Nepal Art Council."

And what are some of the biggest changes in residential architecture that you have seen since 2009?

"Because of the 2015 earthquake, a massive change occurred in perspective occurred. Before 2015 it was an enormous task as an architect to convince people to build earthquake-proof. Clients asked us to take it easy on the earthquake-resilient features, and we even denied a couple of clients because they refused to consider earthquakes in their buildings. 'Find another architect', we said, 'we don't do that'. I also saw this with happening with a lot of other architects. Then the earthquake in 2015 happened, with the first one being a quite long tremor. About 50-60 seconds. The second was much shorter, but more intense. An aftershock. Ever since, Nepal has been struck by about 700 earthquakes, that only really get documented once they're a magnitude of 6-7. The same process of awareness happened in Afghanistan, where I got my first earthquake-architecture lessons together with engineers."

"Before 2015, the most recent major earthquake was quite long ago. People forget. After the earthquake of 2015, however, people really started asking: 'Is this building earthquake-proof for sure?' A 100% earthquake proof building does not exist. But the perspectives of clients changed radically: 9000 people just died, that is quite a shake-up."

Why did people refuse to build earthquake proof before 2015? Is that purely because of money?

"Yes. Purely because of budget. If you just build a house, it's the cheapest to stack blocks. If you need to stack on top of a timber/concrete ringbeam, it will get more expensive. Then the roof: if you make a one-story building, the roof structure + ringbeam is quite easy and cheap. If you do two, or three floors, you need an extra ringbeam per floor."

I remember you once told me about the corrugated sheet being introduced into Nepal, and how bad it was for the Nepali architecture. Why is that so?

"Corrugated sheets don't matter as much when it comes to earthquakes. What happened after a disaster is the following: the world looks at Nepal and they're thinking 'we need to do something'. Countries suddenly think they need to help Nepal, more than in other times. 'Help the poor Nepali'. A lot of money is raised with the best intentions. But it is also the biggest slumification in the history of Nepal."

"Instead of using and promoting local materials, cheap materials from outside were imported. With corrugated sheets, a bit of steel, some tarpaulin and bamboo they glued buildings togethers. This is not active architecture, but reactive. Once that shabby shack is there, people won't quickly change it. You will keep on improvising when things start leaking for example. Whether it's the UN, or the Nepal government, or embassies, in my opinion, the entire international community is guilty towards a substantial part of the slumification of Nepal. If you look how temples are being rebuild, the process is so much better. In temples, the people don't accept cheap shortcuts. The documentation of many temples was outstanding; the drawings, the techniques, the materials. Even if it would take years, people want these to be rebuild correctly."

"The National Reconstruction Authority (NRA) was founded after the earthquake, which already took 9 months because of politics. Then a chairman needed to be found, which took a couple of months. And then the chairman took some more months to come up with a logo first. A very inefficient process."

"The concrete lobby is very strong in Nepal. That is partly because of the surrounding countries: from China and India, they see Nepal as a market. A lot of money from international donors was suddenly available, and the concrete lobby saw their chance. It became almost mandatory to use concrete in your new building after that. The slumification is not only the corrugated sheets, but also way too much concrete. Organisation like the UNDP, a wretched organisation within the UN, are very influenceable by lobbyist and donors. They only look at: where is the money / the budgets and how can we be of importance there. Other parts of the UN, like UNICEF and UNHCR (Refugee) have fantastic people and intentions. The UNDP started a very large program called 'Rubble Removal'. They saw all the partly-collapsed buildings that still had very good materials like strong, dried wood. The UNDP would then bulldoze those rubbles to build a concrete house on the spot. This is a high contrast to temples, which were minutely documented, all the materials sorted and coded with a system, to then rebuild them precisely. The houses were regarded as rubble by the UNDP. It's criminal, really."

So the owners would get nothing for their materials?

"A problem for the owners is that the government gives them a little money for some cement-bags, but that is not nearly enough to build a house. In the meantime, they lost their 'rubble' materials. Since 2015, if you do not build with cement, you will not get a building permit. The NRA will not allow it, they have a lot of power. And of course the cement industry is happy with that. It's a quite corrupt system."

"In earlier times, a barter-system was used for building houses. For example, 25 families would come together to build one house and finish it. Then they would move to the next one, until all the families had a house. This was a system without money, just trading of materials. The introduction of cement also suddenly introduced the necessity of money for construction. Global wealth is measured in GDP, which is all based on money, not actual wealth. So community-based societies like Nepal are suddenly very poor. If you are suddenly forced to buy things, with money, externally, the story gets quite complicated. I saw the same in Afghanistan, which is less connected to the global industry as Nepal. If you visit a remote community in Afghanistan, the people there will have everything: food, water, clothes, but their monetary 'revenue', that is necessary for a good GDP, is extremely low. Their wealth is not measurable by money. The UN is working on improving parameters for measuring wealth, but hasn't yet so."

We talked about concrete and its lobby, and the devastating effects of that on Nepali architecture. But I cannot imagine it is only a bad story. According to many sources I have found, concrete is known for surviving earthquakes better. What are the positive sides of using concrete in residential architecture?

"Is that so? Did you find any sources that show how well-maintained masonry building compare to concrete buildings? Concrete only came to Nepal when the border opened: around the 50s. Most of them went to Kathmandu. Then in the 70s and 80s it really started to be used. It is still the 'new kid on the block'. If you visit other places in Nepal, like Taplejung and East Nepal, most buildings are stone, brick and wood. This has been done for centuries. Concrete is super new."

"It all has to do with maintenance. Before the earthquake, you would see a lot of 200, 250, 300 year old buildings, that only really needed some good maintenance. It has nothing to do with the materials, all with maintenance. It is way too easy to say: old buildings are weak, concrete buildings are strong. It is much more complicated than that."

And they did not get their maintenance, so they collapsed?

"Yes, they did. If the building was getting weak, and the earthquake hit, of course they collapsed. However, this is not proof that concrete is a fantastic building material. I am not against concrete, but the way it is used in Nepal, is really really stupid. There is a very large amount of buildings where concrete is overdimensioned. When using concrete, it is still very important that the building can sway a little. It is important to use it wisely, but that is not important to the government of Nepal. They copied India and China, where an immense amount of concrete is used. 'If we use a lot of concrete, maybe we'll also become a developed country'"

That is exactly what I read in the Rana's 'The Great Earthquake of 1934', where the general Rana explained how concrete will solve all of Nepal's earthquake issues, just because other countries use it. I can imagine how he planted a seed back then, for the concrete lobby to start movement.

I have sent you two images that I would like to analyse with you. They are of concrete constructions in Chakupat, Lalitpur. What do you think about these in regards to earthquake resilience and construction methods? (Figures 26 and 27).

"Concrete is quite expensive, so mostly concrete beams and columns are used, with masonry-infills. A beam-structure is sticking out of the façade, so this is a concrete brick-infill building. The floors are also concrete. It is typical in concrete buildings to have floors with an overhang, that is good for the *moment /* strength. The building looks as wide as it is deep, so rectangle. That is good for earthquake-preparedness. It is important to build compact. In Newar buildings, long buildings are used, but that is a wood construction so it is very flexible. In these concrete houses, it is smart to build with a square floor plan. In the second picture, the structure looks the same. It is a concrete-grid, slightly smaller, plastered, and with brick infills probably."

What do you know about the Rana-style architecture and its earthquake resilience?

"The Rana palaces are often very big and long. This is horrible for earthquake resistance. The Rana rulers saw these palaces in Europe, in countries that do not have earthquakes, and decided to copy them in Nepal. Many of these palaces have collapsed beyond repair because of their earthquake-vulnerability. If they placed Versailles in Kathmandu, it would have collapsed. They would make spans that are too large to make in an earthquake-prone place. One of our assignments in Nepal, for the German NGO 'GIZ', was inside a Rana palace in Sanepa. They did not check their building for earthquake-preparedness. When I convinced them to research the safety, the engineers found out that the large, posh neoclassical conference room would collapse in 5,5 seconds in an earthquake. As well as the L-shaped corner of the buildings, which would collapse in 8 seconds. The NGO moved to a different building six weeks before the 2015 earthquake, and the palace collapsed, sadly still killing 7 people. And as predicted: the conference room collapsed."

"The Singha Durbar in Kathmandu, built by one of the vain Rana rulers, was in a very bad shape after the earthquake. To renovate the palace, a massive amount of reinforcement was needed to safeguard the building. It cost loads of money, but it is one of the few Rana palaces that is still standing. Back when they were built, the rulers did not have or use the engineers or knowledge to build these palaces earthquake-resistant. They only cared about showing off wealth, through large Versailles-like halls and plastered ornamentations.

“Not a lot has been written about the structure of the palaces. When you have a long building like those palaces; if the earthquake shocks through the long façade, the shock is only 1 sec, for example. If the earthquake shocks in the longer direction, it might shock the building for 8 seconds and rip the building apart. The palaces are way too long, while the Malla architecture is often also long-shaped, but they implement great hybrid of stone, brick and wood. By doing so, the building can move a little. Then after the earthquake, maintenance is needed.”

This whole story is, however, about the Rana palaces. What about the regular houses that were inspired by these palaces? They were, I found out, constructed in similar ways as the traditional building, but with Rana-style facades.

“Those look like purely façade-architecture. There is one in Patan, that you can maybe visit.”

Thank you for all the information. There will be a lot of ‘Feenstra (2023)’s in my thesis now.

APPENDIX II - Interview with Rohit Ranjitkar - 28-03-2023

The following is a transcript of an interview held with Rohit Ranjitkar on 28-03-2023. He is the director of the Kathmandu Valley Preservation Trust, an organization that rebuilds and safeguards cultural heritage in the Kathmandu Valley. After the 2015, he has worked on the reconstruction of several temples on Patan's Durbar Square, including the Harishankara Temple mentioned on page 15. The interview was held in the middle of Patan's Durbar Square, in between his surveillance tasks on the remaining temples to be reconstructed. It was voice recorded and later transcribed below.

My guesthouse here in Patan, Hira Guesthouse, is a really good example of a building that has survived three earthquakes already.

"How do you know that? Look at the temple behind you, the big temple. That is built in 1680's. In writing, we still say 1680, but the building is completely rebuild after 1934. It is important to distinguish the present condition and the original building. Same goes for the Hira Guesthouse: I know it is 300 year olds, but I have no record of how it has been changed and reconstructed. There is no record of 1833, that is 190 years ago, at least five generations. So you can trust some historical facts, but personally I do not trust everything. I work in this field, and what I see is: no building is completely original. Many parts got reconstructed, changed and improvised over time. Some times you see in old houses they added a new floor on top, which has been there for many generations. This is my opinion about it."

I know the guesthouse survived after 2015 with just a bit of cracks, but I do not know about 1833 and 1934 of course.

"Most of the photography you see is of the landmark buildings, the cultural sites. You will not find many photos of residential places. There must be damages there as well, as the landmarks were also damaged. Due to the lack of documentation, in my opinion, you cannot say 'this building is 300 years old'. Our ancestors have been working on these buildings for maybe a thousand years, it is not built overnight like new architecture. With every earthquake they saw problems, and then they improve the structure. I am pretty sure many technologies changed over time."

"Even Nepalese scholars talk that way: oh this building is 300 years old. But I am a practitioner and I do not see it that way. After parts of the building were damaged, I do not believe they rebuilt in the same way: it needed improvement to not be destroyed with the next earthquake. Look at the temple behind you, the Taleju Temple that was destroyed by the 1934 earthquake. As you can see, not all bricks are dachi-appa, the top ones are newer since not every brick could be salvaged. It was built in lime-surkhi mortar. People used to say that it is the traditional way, but that is not true."

Didn't lime-surkhi mortar and dachi-appa bricks start in the Rana period?

"No, every Rana-period building is built with mud-mortar, and then plastered with lime-surkhi mortar. It is a very large misconception, also among scholars. Lime-surkhi is not traditional. Lime-surkhi mortar was used for bridges and tunnels, but not for the masonry work."

So what changed in the Rana period when it comes to the houses? I know the façades turned into neo-classicist white-plastered palaces, but what about the interiors?

"The interiors did not change much. The insides were simple, not decorated. Some things changed in the windows, and minor changes inside, but not much. The Rana period houses are very similar to the Malla period. I think only a handful of buildings survived from the Malla period, due to the earthquakes. The neoclassical design came in the 19th century, and there are no craftspeople that can do that in the Valley. They brought craftspeople from Calcutta, and British architecture. But they need a huge team to build the palaces and houses, so they also used the local workpeople to build it. While building these palaces, they were also experimenting with the houses. The houses are not exactly copied as the Rana palaces. I am pretty sure that the palaces were built with pattern books, but the local people did not have access to these books. But the workers could not remember all the patterns, so the ornamentations also got local patterns and deities in it. It is very hybrid. It is way more interesting to me than the real classical palaces. Every single house is different. Unfortunately lots of the Rana houses got lost in the last, I don't know, 10-20 years."

Why is that? Is it because the façade got destroyed, or the whole building?

"The whole building. There are newer trends now, like much glass and modern materials, people like that more now. It is human nature to want the new, so they demolish the old house and build a new one. Concrete is new for us, so everybody wants concrete now. Also they wanted lots of new facilities, like higher ceilings."

"Also, the houses needed to be divided amongst brothers. So the housing plots became smaller and smaller, so concrete allows for higher houses to regain some floor area, including cantilevers and thin walls. This is why all the concrete buildings are popping up.

So taller buildings with tinner walls and cantilevers, that sounds very unsafe.

"Yes, I care about that, you care about that, but most of the people don't. We had an earthquake 7 years ago, and again they built really big houses. The human nature is that they forget about the earthquake, they don't remember. This is how it is. I do not always blame the house owner, also the engineer. No calculations are done for older houses, but for newer houses it's more simple with computer programs. Engineers can charge much more money if they build a new house, instead of renovating the old one. So they go to people and say: your house is unsafe, we'll build you a new one that is much safer according to our calculation program."

If we go back to the Newar housing. I found two terms I cannot find the meaning for. They're only mentioned by the architects of Abari: *sur-milaune*, and *chukul*. Do you know what it means?

Sur-milaune is when you put the bricks in the corner like a herringbone pattern, interlocking the walls together with corner stones. Chukul are the timber pegs that tie the timber elements between walls, these hold the masonry walls connected with the timber. These are not materials, but techniques for building.

How can we make earthquake-proof buildings by blending traditional and modern techniques?

"I do not believe in earthquake-proof housing, because you never know how the earthquake will come. It also depends on soil conditions, direction of the earthquake, how big, how deep, so many factors. But certainly we can make houses safer. There might be cracks and damages, but the house should not fall or collapse on people. It is natural for houses to have cracks. We do not use any concrete in traditional houses, but whatever we reconstruct, does not need to be built in the exact way. You can use concrete now, or newer windows, but do not call the building historical then."

"The main thing people need to learn is to be aware of our heritage. And the heritage is an accumulation of many things, you cannot put a new Newar-style window in a house and call it heritage. That is not traditional design."

"Back then, every single house used to be different, We did not have a copy-paste culture. Now every house is the same."

Why is it that many of the Newari buildings contain a lot of earthquake-safe elements, but they still collapsed? Is it due to a lack of maintenance?

"The Newari houses have thick walls, which are very good for earthquake resistance. In many places you see timber beams and timber frames inside the walls. I don't know whether these were there from the beginning, or added later on after damages. The thick walls exist of dachi-appa in the front and ma-appa brick in the inside, and a brick in-fill. But these walls are not strongly connected inside. So now when we rebuild, we put more connections between the dachi-appa and ma-appa to make it stronger."