RESILIENT MODEL SCHOOL IN NEPAL

RESEARCH & DESIGN PROPOSAL

ARCHITECTURE MASTER THESIS

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SPRING 2018

Lund University

Master Thesis in Architecture 2018
Advanced Architectural Design
LTH, Lund University
Sweden

Project title
Resilient Model School in Nepal - Research & Design proposal

Project period
January 15th - May 25th 2018

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0 | ABSTRACT

During the Gorkha Earthquake in 2015 and its aftershocks, many schools have been damaged or collapsed in Nepal. Reconstruction of schools is still in progress. The lack of funding, resources, engineering skills, knowledge and accessibility makes it difficult for a lot of schools to reopen. My aim with this thesis project is to contribute to the resiliency of Nepal by proposing a design for a specific school in need.

Kitini High Secondary School is a secondary level school in Godavari, Lalitpur. The school has around 600 students, divided over four building blocks. One of the of the buildings is marked as unsafe after the earthquake. Two other blocks need to be demolished in the future due to road extension. The school owns land approximately 300 metres southwest of the current location which is available for construction of new facilities. The school is aiming towards becoming a model school, designed according to the standards set by the government of Nepal and guidelines for safe school design in seismic regions.

I travelled to Nepal to visit the school, meet the local people and to develop a tentative design proposal which we submitted to the Department of Education. After my trip, I have been working in Sweden on the final design to add spatial and architectural quality to the pragmatic model school proposal resulting in a proposal that is disaster resilient and a comfortable learning environment for the children.

0 INDEX

1 | INTRODUCTION

1.1 BACKGROUND

"Earthquakes don't kill people, buildings do."

Earthquakes have a great impact on the built environment. They can destroy and impact social, physical and economic systems. But in most cases, it is not the earthquake itself that causes so much loss. The collapse of poorly constructed and unsafe located buildings is the cause of most human and economic loss. The built environment in seismic risk areas needs to be resistant and resilient for future disasters. Certain countries and regions are very prone to earthquakes due to their geographical location. Nepal is one of the risk regions that is frequently and severely hit. The main earthquake in 2015 killed nearly 9,000 people and left over 20,000 injured and 3.5 million homeless. Entire villages were flattened, and centuries-old architecture has been destroyed. Not only that, it is estimated that more than 5,000 schools were affected by the earthquake and its aftershocks, 1,000 of them collapsed.

The school system, which was already vulnerable before the earthquake, has been severely disrupted. It is important to rebuild schools to provide safe shelter and distraction for traumatized children. Personally, I am really interested in humanitarian (architecture) projects that help people in need. In my thesis I want to focus on a region threatened by natural disasters and propose a design for a safe (model) school which is resistant to future disasters.

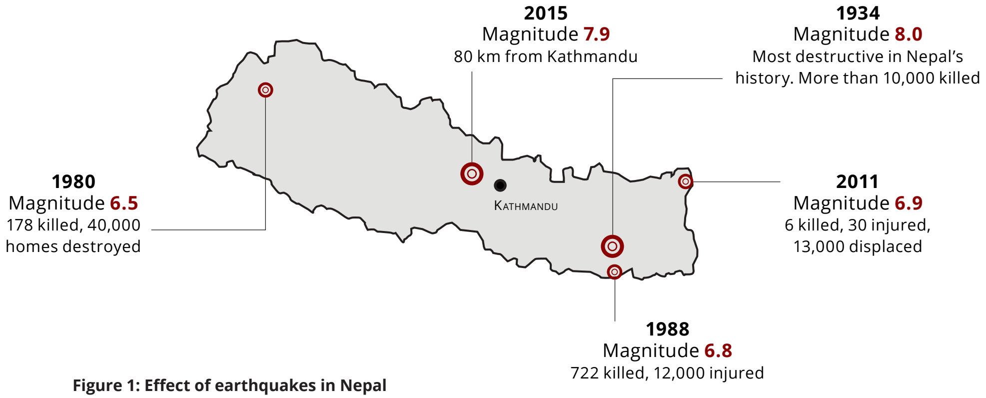


Figure 1: Effect of earthquakes in Nepal

1.2 RESEARCH AND DESIGN PROJECT

The aim of my thesis project is to develop a design proposal for a school complex which is resistant to seismic forces and other context-specific hazards. This project consists of two parts. First, a thorough background research into the theory of seismology, seismic design and in particular safe school design according to the standards set by the government of Nepal. Secondly, a design project in which the acquired knowledge is applied.

I got in contact with Mr. Dinesh Thapa who is a teacher at Kitini Higher Secondary School in Godavari via the organization ETC (Educate the children) Nepal. This school has been damaged by the earthquake in 2015 and has been planning to propose the construction of a new model school as per standards of the Department of Education in Nepal. The proposal includes plans for the social, financial, educational, administrative and physical structures of the envisioned model school.

In March 2018, I have travelled to Nepal to visit the site and experience the context. I developed a design proposal for the new model school during my stay in Nepal as part of the proposal report, which we submitted on the 22th of March, 2018 at the Department of Education in Nepal.

The type design requirements for the model school are rather pragmatic in order to result in an affordable proposal. However, for this thesis project I developed several additional features in the design of the model school that will increase the architectural quality and comfort. The main key points in my design proposal are disaster resiliency and environmental sustainability.

1.3 SCOPE OF THESIS

The theoretical part of my thesis answers the questions how and where earthquakes are caused and how they affect the built environment (2.1 & 2.2). This research covers both general and detailed guidelines for constructing building structures in seismic regions for different commonly used construction materials in section 2.3. The focus of the guidelines will be on seismic measurements. Other context-specific hazards will also be discussed shortly in section 2.4. The guidelines given in 2.3 and 2.4 will result in a design toolbox for the design project.

In section 2.5, the historical, geographical, cultural and architectural context will be discussed with information about Nepal and specific information about the design region, the Kathmandu Valley. The final part of the theory will cover school design (2.6). This section discusses the school context in Nepal, their program and curriculum. Section 2.6 is a pre-section that leads up to the design project, since it addresses specific guidelines for safe school design including norms and standards that are given by the government of Nepal after the major earthquakes in 2015.

So, the main aim of the background research is to develop a solid foundation from which I will be able to design a disaster resilient school as per standards given by the Department of Education of Nepal. The project will be discussed in chapters 3-5. Chapter 3 discusses information about the program and location of the project. The results of the project will be displayed in chapter 4. The project has developed in roughly two phases. First the tentative design phase which covers the proposal that has been submitted in Nepal and secondly the final design phase which includes an additional alternative to the standard model school that has been proposed in the previous phase. How this alternative proposal can be of use will be discussed in the concluding remarks in chapter 5.

2.1.1 *Earthquakes explained*

The earth consists of several layers: the inner core, outer core, mantle and the crust. The crust is the upper skin on the surface of the earth and is divided into several pieces called tectonic plates. The tectonic plates are constantly in motion. The plate boundaries are rough and have many faults. An earthquake happens when these plates suddenly slip past each other due to these faults. Energy that is stored overcomes friction and is being released, radiating outwards as seismic waves from the fault in all directions. The starting location of the earthquake is called the hypocentre. The epicentre is the location on the surface of the earth directly above the hypocentre. The surface where the plates slip is called the fault plane. The main and largest earthquakes are called mainshocks. Smaller earthquakes before and after the mainshock are called foreshocks and aftershocks.

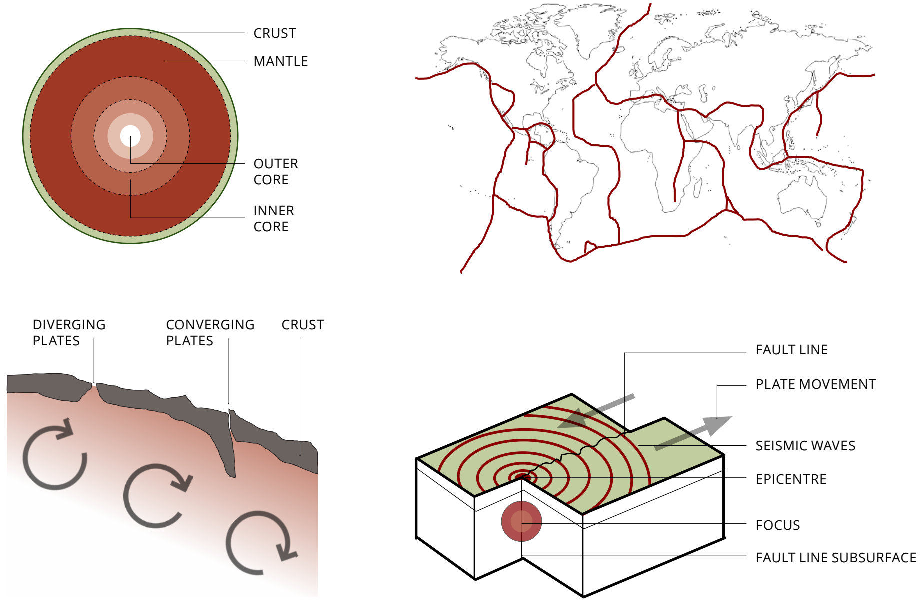


Figure 2: Earthquakes explained

| *Types of faults*

Faults are basically cracks in the earth where different parts, crustal blocks, are moving in different directions relative to each other. There are different types of faults with different types of movement of the blocks (USGS, n.d.-b).

Normal fault

Normal faulting occurs when the crust is pulled apart. The main block, the footwall, moves upwards relative to the overlying block, the hanging wall, which moves downwards.

Reverse fault

Reverse faulting is the opposite of normal faulting and occurs when the crust is compressed together. So here the footwall moves downwards, and the hanging wall is pushed upwards.

Sinistral strike-slip fault
Left-lateral strike-slip fault

Strike-slipping occurs when crustal blocks move sideways past each other. Left-lateral strike-slip or sinistral strike-slip means that the far side moves to the left no matter which side you are on.

Dextral strike-slip fault
Right-lateral strike-slip fault

Dextral strike-slip movement occurs when the far side moves to the right. Strike-slips usually have a nearly-vertical fault.

Faults can vary from hundreds of kilometres to a few metres and are not always straight. Ruptures of faults can have significant bends and offsets.

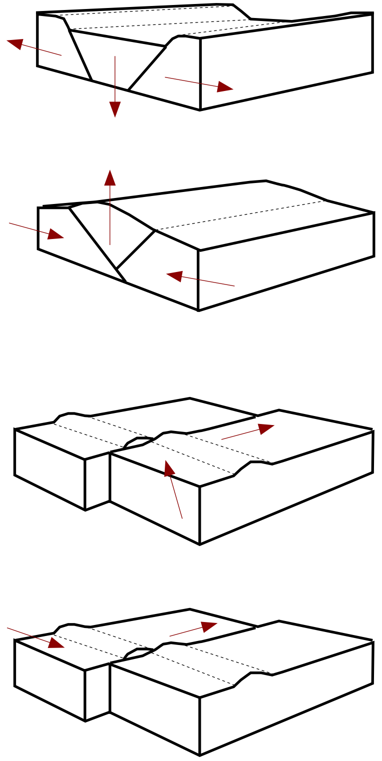
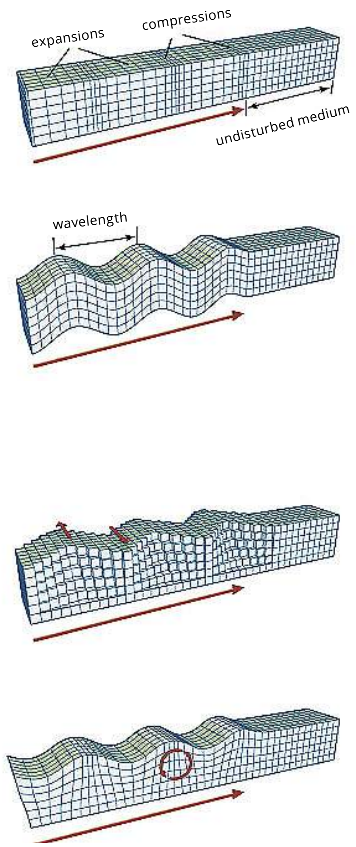


Figure 3: Types of faults

| *Types of seismic waves*

Figure 4: Types of waves (Britannica Inc., n.d.)



There are two main types of seismic waves: body waves and surface waves. The body waves travel through the inner layer of the earth. They are faster and have a higher frequency than surface waves. (Michigan Techonogical University, 2007)

There are two types of body waves. P waves and S waves.

P waves

Also called primary waves or compressional waves. The particle motion is parallel to the propagation direction and travels through the earth by compression and dilation. They are in that way similar to sound waves.

S waves

Also called secondary waves or shear waves. The particle motion here is perpendicular to the propagation direction. These waves can only move through solid rock.

Surface waves travel mainly along the surface of the earth. They are the main cause of destruction during earthquakes. There are two kinds of surface waves: Love waves and Rayleigh waves.

Love waves

Love waves are the fastest surface waves and move the ground side-to-side with only horizontal motions. The particle motion is perpendicular to the propagation direction. They are the most destructive waves.

Rayleigh waves

Rayleigh waves have an elliptical motion perpendicular to the surface. This motion is retrograde, which means that the motion is counter-clockwise.

| *Measuring and locating earthquakes*

The vibrations of seismic waves can be registered by seismographs. Seismographs can register the amplitude of the ground oscillations. Very sensitive seismograph stations can record strong earthquakes that occur anywhere in the world. The exact location of an earthquake can be determined by triangulation. The body waves and surface waves that were mentioned in the previous section have different speeds. The distance between the centre of an earthquake and a seismograph station can be determined by the time it takes for the two types of waves to reach the seismograph. With three seismograph stations it is possible to determine the exact location of the earthquake by drawing radius circles around the seismographic stations and see where they intersect. (QRG Northwestern University, n.d.)

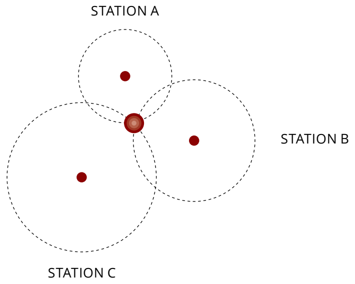


Figure 5: Triangulation

The magnitude of an earthquake is a number that characterizes the relative size and is based on the maximum motion that is recorded at a seismograph station. Different scales have been developed to measure an earthquake's magnitude: (USGS, n.d.-a)

Local magnitude (M_L)
- Surface-wave magnitude (M_S)
- Body-wave magnitude (m_b)

Moment magnitude (M_w)

The first and widely-used method is the Richter scale (M_L). The formula for this method uses the amplitude of the largest wave and the distance between the seismometer and the centre of the earthquake. The two different types of waves have separate formulas. (Spence, Sipkin, & Choy, 1889)

The standard body wave magnitude formula: $m_b = \log^{10}(A/T) + Q(D,h)$
The standard surface wave magnitude formula: $M_S = \log^{10}(A/T) + 1.66 \log^{10}(D) + 3.30$

A:	Amplitude of ground motion (microns)
T:	Corresponding time (seconds)
Q (D, h):	Correction factor which is a function of distance (D in degrees) between epicentre and station and focal depth (h in kilometres)

Recently, 1 s-period body P-waves are used for the calculations with the m_b scale and 18-22 s-period surface Rayleigh waves for the M_s scale (Spence et al., 1889). There are different variations of these formulas that are specific for geographic locations by considering their specific local factors. Earthquakes with a magnitude of 2.0 or less are called micro-earthquakes and can barely be felt. Magnitudes of 4.5 and higher can be felt by a sensitive seismograph anywhere in the world. The following table provides a rough idea of the occurrence frequency of larger earthquakes:

M_s	Earthquakes per year
8,5 – 8,9	0,3
8,0 – 8,4	1,1
7,5 – 7,9	3,1
7,0 – 7,4	15
6,5 – 6,9	56
6,0 – 6,4	210

Table 1: Frequency of occurrence of large earthquakes (Spence et al., 1889)

The Richter scale (M_L) and the two magnitude scales that evolved from this scale (M_s and m_b) can still be used for smaller and more local earthquakes but nowadays it is more common to use the Moment magnitude scale (M_w). This method can be used globally and can handle a wider range of earthquake sizes. This method is based on the total moment force of the earthquake as the name suggests. Moment is the product of the applied force and the distance of the movement that is created by the force. The moment magnitude scale is defined as following (Spence et al., 1889):

$M_W = 2/3 \log10(M_O) - 10.7$ With the seismic moment ($M_O = \mu S \langle d \rangle$).

So, the magnitude scales M_L, M_s and m_b are limited to smaller earthquakes of a magnitude lesser than M5. M_W is applicable to all sizes but is more complicated. All scales should result in approximately the same value for any given earthquake. (USGS, n.d.-a)

2 RESEARCH
2.1 EARTHQUAKES

2.1.2 Earthquake effects

The main damage that is induced by earthquakes is caused by the shaking of the ground (Arya et al., 2014, p. 23). It is hard to design with seismic factors in consideration due to the random effects of earthquakes. The effect of earthquakes on the built environment will be discussed further in section 2.2.

Earthquakes can cause ground failure. There are different types of ground failure. For example, rupture along the fault line at the boundaries of tectonic plates. Ground displacement can stretch from a few centimetres to several meters horizontally and vertically. Earthquakes can also induce landslides and falling of rocks due to loose material at hill slopes. Ground settlement, which is lowering of the ground surface due to compaction, only damages buildings to a certain extent (BRANZ, n.d.). Another type of ground failure is soil liquefaction which causes solid soil to act as viscous liquid. It can occur when there is low density water-saturated sand with uniform grain size within a depth of 8 metres. Heavy constructions will sink, and sand, sill and water will be pushed upwards to the surface by underground pressure. Ground settlement and liquefaction are visualized in the following figures:

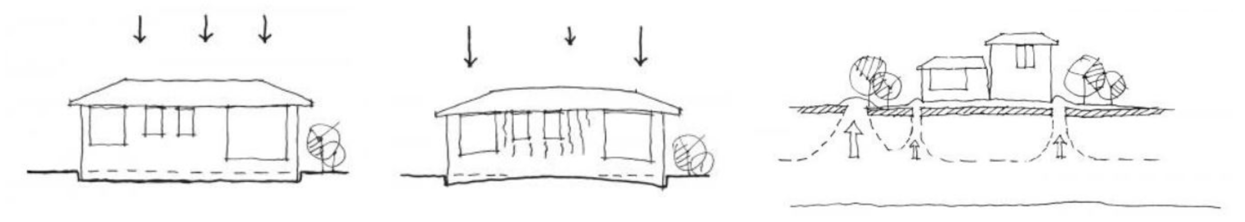


Figure 6: Uniform settlement, differential settlement and liquefaction (BRANZ, n.d.)

2.1.3 Risk zones

Seismic activity varies depending on the geographical location and the distance from tectonic plate boundaries. The global tectonic activity map (figure 8) made by NASA shows the main tectonic plates and their type of movement.

Countries that are located at the boundaries of tectonic plates where there is frequent seismic activity are prone to earthquakes. This connection can be seen by comparing the global tectonic activity map (figure 8) and the global seismic hazard map (figure 9).

Seismic zones can be categorized in four zones:

Zone	Possible risk	MSK intensity scale
A	Widespread collapse and destruction	IX or greater
B	Collapse and heavy damage	VIII
C	Damage	VII
D	Minor damage	VI maximum

Table 2: Seismic zones (Arya et al., 2014, p. 48)

My thesis project focuses on one of the most seismic active regions in the world, Nepal, which is located on the border between the Indian plate and the Eurasian plate and therefore highly prone to seismic activity. The Indian plate has been moving towards the north against the Eurasian plate. The collision of these two plates caused the Indian plate (subducting plate) to slip underneath the Eurasian plate (overriding plate) and resulted in the formation of the Himalayas. Tectonic plates are in constant movement and therefore cause frequent earthquakes in this region.

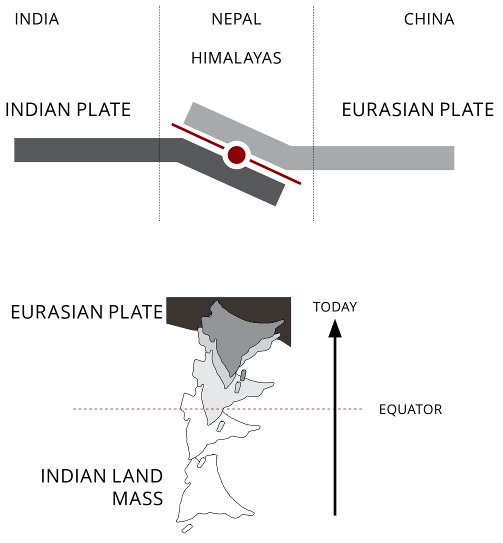


Figure 7: Plate's collision in Nepal

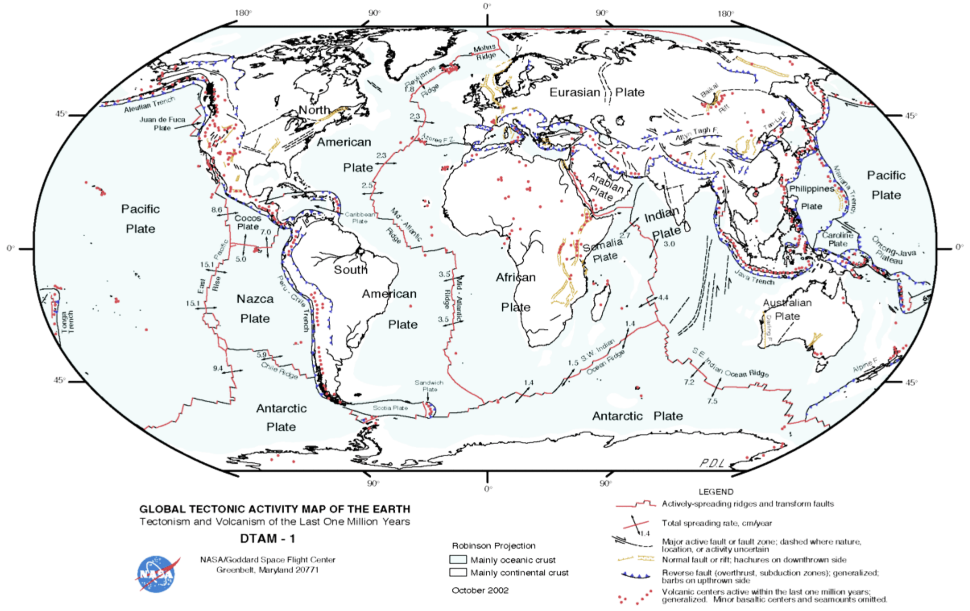


Figure 8: Global tectonic activity map of the earth (NASA, 2002)

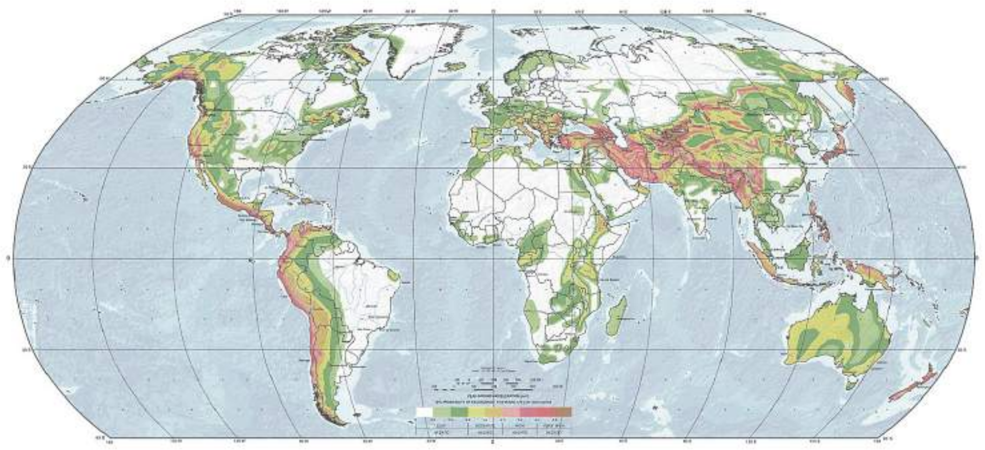


Figure 9: Global seismic hazard map (Global Seismic Hazard Assessment Program [GSHAP], 1999))

2.1.4 *Gorkha Earthquake 2015*

The Gorkha Earthquake that hit Nepal in 2015 was the worst earthquake in the country since 1934. The earthquake is named after the region where the epicentre of the earthquake was located, the Gorkha district, 85 kilometres north-west of the capital Kathmandu. The earthquake took place on Saturday, the 25th of April 2015 at 11:56 (NST) with a magnitude of M_L 7.6 (M_W 7.8, Ms 8.1). The earthquake killed nearly 9,000 people and injured 22,000 people.

The Indian plate which has been mentioned in the previous section is traveling with 45 millimetres per year. The collision between this plate and the Eurasian plate caused a thrust faulting. The rupture of the fault line was directed towards the east with a length of 120 km and width of 80 km (Hayes et al., 2017). It was the first major earthquake since the establishment of the National Seismological Center (NSC). This governmental organization continuously monitors earthquakes in Nepal. Up until today it has been recording hundreds of aftershocks of the Gorkha Earthquake. The most recent aftershock was at the 19th of January 2018 (M_L 4.3) with the Epicentre in Dolakha, a region east of Kathmandu, according to the website of the NSC (National Seismological Centre, 2015, retrieved 21st of January 2018).

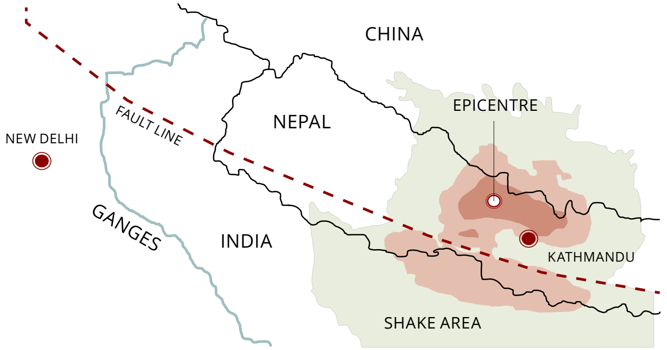


Figure 10: Fault rupture Gorkha Earthquake 2015

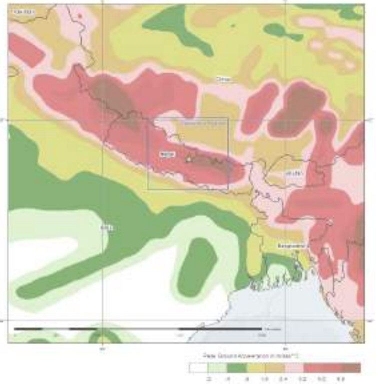


Figure 11: Seismic hazard map Nepal (U.S. Geological Survey National Earthquake Information Center, 2015)

When an earthquake occurs, and the ground starts moving in random directions, masses connected to the ground also move irregularly due to the inertia of the mass. When the ground moves to the left, the mass on the surface will move to the opposite direction relative to the ground. It is if it is being pushed that way by a force which is called inertia force. The building mass resists motion because of its mass. The inertia force is also called Seismic or Lateral Load and is a horizontal reversible force acting on the building which is mainly responsible for damage or collapse of building structures. Besides horizontal forces, also vertical forces caused by vertical vibrations of the ground can cause damage to the building by temporarily increasing and decreasing the effective load.

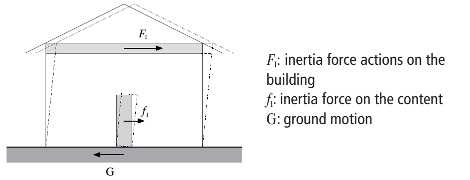


Figure 12: Inertia forces on a building (Arya et al., 2014, p. 29)

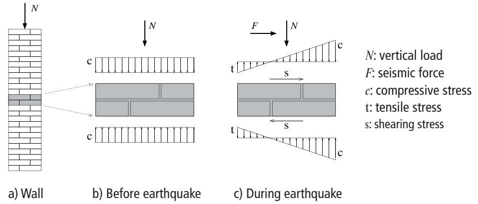


Figure 13: Tensile stress in wall element (Arya et al., 2014, p. 32)

The lateral force F can be expressed as a product of mass (m) and acceleration (a) or the seismic coefficient (k) and the weight of the structure (W): F = ma = kW. So, the seismic force is smaller when the structure is lighter. The seismic coefficient k can be defined as following: k = Ag S D I. The higher the value of any these factors, the higher the seismic force.

Ag	The design ground acceleration divided by the acceleration due to gravity
S	The normalized design response spectrum, depending on soil profile and the vibration period of a building
D	Structural factor depending on the ductility and damping of the structure. The larger the ductility and/or damping, the more force the structure can absorb and the smaller the value of D
I	The occupancy importance factor or hazard factor

Structural elements are originally not meant to carry horizontal load. If the bending tension caused by horizontal reversible seismic forces exceeds the vertical forces in a structure, tensile stress will occur within the structural elements. This is shown in figure 13.

Therefore it is important in seismic design to use materials that can cope with tension and shear forces (Arya et al., 2014, p.31).

2.2.1 *Physical damage*

Building structures are mainly meant to cope with vertical forces and therefore suffer damage when horizontal forces are applied which happens during an earthquake. Examples of damage to buildings are:

- Falling plaster / cracks in plaster
- Falling of inner and outer layers of the wall
- Horizontal and vertical cracks in walls
- Diagonal cracks in walls between openings
- Falling of other non-structural elements
- Dislocation of roof support
- Collapse due to foundation / soil failure
- Collapse due to deterioration of joints
- Collapse due to torsional failure of unsymmetrical buildings

There are different categories of damage induced by earthquakes with recommendations for what to do about it. These damage categories are shown in table 3.

Damage category		Extent of damage in general	Suggested post-earthquake action
0	No damage	No damage	No action required
1	Slight non-structural damage	Cracks in plaster, falling plaster	Only architectural repair needed
2	Slight structural damage	Cracks in wall, damage to non-structural parts, load carrying capacity not reduced	Architectural repair needed to achieve durability
3	Moderate structural damage	Large and deep cracks in walls, load carrying capacity partially reduced	Buildings needs to be vacated and reoccupied after restorations and strengthening
4	Severe structural damage	Gaps in walls, inner/outer walls collapse, 50% of main structural elements fail	Buildings needs to be vacated and either demolished or extensively restored
5	Collapse	Large part or whole building collapses	Clearing site and reconstruct

Table 3: Categories of damage (Arya et al., 2014, p. 44)

2.2.2 *Factors affecting damage*

How much damage a building suffers during an earthquake depends on the strength of the structure, the ductility and integrity of the building and the stiffness of the underlying soil (Arya et al., 2014, p. 33).

An important factor that influences the damage to buildings is the building configuration. The perfect stable shape for a building would be a box. So, buildings that are rectangular in both plan and elevation are much stronger and more able to endure earthquakes than L- or U-shaped buildings. Horizontal forces during an earthquake will twist a building with wings that are too long.

Another factor which is important are the openings in the building. Openings usually weaken the walls. The dimensions of openings should be restricted, or special measurements need to be taken to maintain structural integrity.

Also, a building should be stiff from bottom to top. Chance of damage increases if the transition between floors are interrupted or have a different material. Columns and shear walls should therefore be continuous from the foundation all the way to the roof.

Ductile buildings can absorb external forces by bending, swaying and deforming. Brittle buildings work the opposite, they break when overloaded during an earthquake. Examples of brittle materials are adobe, brick and concrete blocks. Reinforcement with steel or other ductile materials can add ductility to a building.

The ‘rocking effect’ can occur in rigid structures during an earthquake. If structural elements are not sufficiently tied together, the structure will fall apart. Rigid structures should act as an integral unit during earthquake shaking.

The foundation is the base of a building and is of great importance when it comes to the structural safety of a building. Ground failure can damage the foundation and indirectly the building structure. Isolated footings of columns as foundation can be problematic when the supporting soil is not uniform. Also, mixed foundation types within the same building structure can cause damage because of differential settlement. In cold and wet climates, the foundation cannot be too shallow.

Other factors that can lead to damage are poor construction quality and the quality of the used materials. Also poor workmanship and the lack of the right bonding units are factors that compromise structural integrity (Arya et al., 2014, p.35).

2.3.1 Guidelines for earthquake-resistant building

| *Site conditions*

The density of the soil is very important when choosing a site for construction. Soil that contains very loose sands and sensitive clays is prone to liquefying and should be avoided. It is possible to compact soil that is vulnerable for liquefaction, but that procedure is very expensive. Therefore, it is better to avoid such soils at all. Locations on slopes should be carefully analysed for potential landslides. Buildings should be placed on stable ground. It is better to divide the building into several blocks and put them on terraces than to have one large building with footings at different elevations (Arya et al., 2014, p. 53). Liquefaction occurs when the soil is saturated. Also, landslides can occur when the soil is saturated with water. For those reasons the site should be drained well at all time. The foundation must be protected against water with waterproof aprons. Pile foundation of 8 to 10 metres can be used on sites where saturated soil cannot be avoided (Arya, 1987. p. 11).

The types of soil should be classified as following:

	Foundation material	Foundation classification	Presumed safe bearing capacity in kN/m^2
1	Rocks in different state of weathering, boulder bed, gravel, sandy gravel and sand gravel mixture, dense or loose coarse to medium sand offering high resistance to penetration when excavated by tools, stiff to medium clay which is readily indented with a thumb nail.	HARD	≥ 200
2	Fine sand and silt (dry lumps easily pulverised by the finger), moist clay and sand clay mixture which can be indented with strong thumb pressure	MEDIUM	≥ 150 < 200
3	Fine sand, loose and dry; soft clay indented with moderate thumb pressure	SOFT	≥ 100 < 150
4	Very soft clay which can be penetrated several centimetres with the thumb, wet clays	WEAK	≥ 50 < 100

Table 4: Foundation soil classification and safe bearing capacity (MPPW, 1994, 7)

| *Building structure*

Guidelines for the building structures highly depend on the materials that are used for the construction. In this section, general guidelines for seismic design will be given. Specific and material dependant guidelines will be discussed in section 2.3.2. Construction Materials.

For the plan of the building it is important that the building is symmetrical. If a building is asymmetrical, the random movements of the ground during earthquakes can lead to torsion. Also openings should preferably be placed symmetrical (Arya et al., 2014, p. 50).

Rectangular plans are more desirable in seismic design since projections and buildings that are too narrow can also cause torsional effect. The length of a building should therefore be restricted to three times the width (Arya et al., 2014, p. 51).

If a building needs to be longer, it is possible to use separation. With separation it is possible to have symmetry and regularity in each block when it comes to large buildings. There should be 30 to 40 millimetres between the blocks above the plinth level to prevent the blocks to hammer and pound each other during earthquakes. The separation can be filled with a material that can easily crumble so it works as a buffer material (Arya et al., 2014, p. 51).

Simplicity is also desirable for seismic design. Ornamentation can break or fall and create dangerous situations. Only reinforced ornamentation which is securely tied to the main building structure can be used (Arya et al., 2014, p. 52).

A box is the most ideal shape for a building in a seismic active area. It is therefore important to have interconnecting walls to enclose areas that act as a rigid box. This will increase the lateral strength of the walls. The ratio for masonry walls with wall spacing (a) and thickness (t) should be maximum a/t = 40 (Arya et al., 2014, p. 53).

In countries where there is not much money available for reconstruction, like Nepal, it could be good to separate functions considering their importance. It can save a lot of money to only strengthen buildings according to their importance. The importance of buildings is defined as following:

IMPORTANT	ORDINARY
Hospitals, clinics, communication buildings, fire and police stations, water supply facilities, cinemas, theatres and meeting halls, schools, dormitories, cultural treasures such as museums, monuments and temples, etc.	Houses, hostels, offices, warehouses, factories, etc.

Table 5: Importance of buildings (Arya et al., 2014, p. 48)

Combining the importance of buildings (table 5) together with the seismic zones (table 2) and the soil classification (table 4) gives the categories of buildings (table 6) that are commonly referred to when discussing seismic design guidelines for specific materials.

Building category	Seismic zone	Importance of building	Soil classification
I	A	important	Soft
II	A A B	important ordinary important	Medium to hard Soft Soft
III	A B B C	ordinary Important ordinary important	Medium to hard Medium to hard Soft Soft
IV	B C C	ordinary important ordinary	Medium to hard Medium to hard Soft

Table 6: Building categories for seismic strength purposes (Arya et al., 2014, p. 50)

| Foundation

The type of foundation is dependent on the material that is used for construction and will be discussed in the separate sections of the materials. However, there is a general concept that can be used for foundations. A way for buildings to absorb and mitigate the effects of an earthquake is to let the structure and foundation move separately from each other. This concept is called base-isolation. It basically isolates the structure from the shaking ground. Base-isolation can be applied by reducing the friction between the structure and the foundation by placing two layers of plastic membrane between them. It is also possible to have a flexible connection between structure and foundation such as short posts that are pin-connected to large stones. In this case the structure can rock to a certain extent but cannot cope with large displacements (Arya et al., 2014, p. 58).

2.3.2 Construction materials

Materials that can bear both tensile and compression forces are more suitable for resistant building. Often a combination of compression and tension strength is used, like reinforced concrete. Materials can be categorized according to their suitability for seismic design. Steel, wood and reinforced concrete are highly suitable. Masonry, reinforced brickwork, wood with brick nogging and reinforced adobe are moderately suitable. Unreinforced bricks, blocks and stone masonry with good mortar are slightly suitable. But unreinforced masonry with mud mortar, unreinforced earthen walls and wood logs without anchoring are unsuitable (Arya, 1987, p. 15).

The most commonly used construction materials that are suitable in seismic active areas, provided that seismic improvements are applied, will be discussed in the following sections.

| *(Reinforced) concrete*

Unreinforced concrete is brittle and cannot handle lateral forces that well. However, reinforced concrete (RC) is able to cope with the shear and tensile stresses during earthquakes and is therefore highly suitable for seismic design. Construction in various rural areas in earthquake-prone regions is often dependent on experience of local and small contractors. Lack of knowledge of how to properly build with reinforced concrete can compromise the strength of the building structure significantly. The guidelines given here are working guidelines for non-engineered, small and low-rise buildings (up to three storeys).

Common damage to RC buildings are for example sliding of roofs, falling of infill walls, crushing of column ends, diagonal cracking in columns or column-beam joint, collapse of gable frames and sinking or tilting of the foundation. Also, in RC constructions with infill walls and wide openings, the short column effect can occur which is visualized in the following figure:

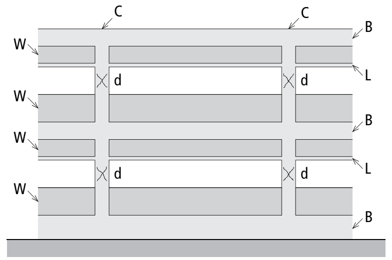


Figure 15: Shear failure of short columns (Arya et al., 2014, p. 144)

The quality of the concrete is the most important factor in RC constructions. The final strength of the concrete is highly dependent on how the concrete is measured, mixed, reinforced, casted, compacted and cured.
The proportion of the concrete mix for (non-engineered concrete) is usually 1 : 2 : 3 or 1 : 2 : 4 (cement : sand : aggregate). River shingle or crushed stones of maximum 20 mm can be used as aggregate. The easiest way is to calculate per sack of cement and use a wooden box of the same volume to measure the sand and aggregates. A 50 kg sack of cement has a volume of 0.0317 m^3. The materials should be mixed directly before casting. If a driven mixer is not available in rural areas, then an impervious platform (iron sheets or concrete floor) can be used. First the aggregates should be spread out, then the sand and finally the cement on top. Everything must be mixed thoroughly in dry state before adding the water. The consistency is good when it is possible to make a soft ball of concrete that does not fall apart (Arya et al., 2014, p. 146).

The quality of the surface of the concrete depends on the formwork. The formwork should be impervious, water and cement should not be able to leak. Water resistant plywood is suitable for this.

Reinforcement should be covered with concrete with a minimum thickness of 15 mm in slabs, 25 mm in beams and columns and 40 mm in columns thicker than 450 mm. Overlap between bars should be minimum 45 times the diameter of the bar for plain mild steel bars and 50 times the

diameter for high strength deformed bars. The ends of the bars in stirrups should be bend in 180 degrees in mild steel boards and 135 in deformed bars (Arya et al., 2014, p. 148).
Casting should be done in a continuous process. Mixed concrete should not be let untouched longer than 45 minutes before casting. Compacting the concrete is important for the final strength of the concrete. Hand compaction can be done by rodding the fresh concrete with a rod of 0.5 m and 16 mm in diameter.

The concrete needs 14 days of water-curing to gain full strength. Which means that the surface of the concrete needs to be wet during the curing process for maximum density and impermeability of the outer layer.

The strength of concrete is defined as the 28 days age cube or cylinder crushing strength. A cube strength of 15-20 N/mm^2 is sufficient. The tensile strength is only a tenth of the compressive strength. The brittleness of concrete can be compensated by reinforcing steel bars that take up the tensile and shear forces due to its ductility. Reinforcing steel bars can either be mild steel / medium tensile steel bars (MS) or high strength deformed steel bars (HSD).

Details of reinforced concrete beams and columns are given in the following figures. Reinforcement in beams should be applied as following:

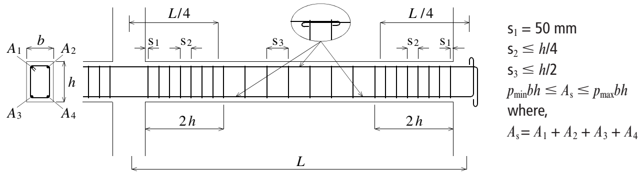


Figure 16: Reinforcement in beam (Arya et al., 2014, p. 153)

This beam construction has the following recommended limits on steel area ratio:

Concrete	Steel	Pmax	Pmin
1 : 2 : 4 (Fc = 15 MPa)	MS (Fy = 250 MPa) HSD (Fy = 415 MPa)	0.011 0.007	0.0035 0.0048
1 : 1½ : 3 (Fc = 20 MPa)	MS (Fy = 250 MPa) HSD (Fy = 415 MPa)	0.015 0.009	0.0048 0.0029

Table 7: Limits on steel area ratio in beam (Arya et al., 2014, p. 153)

Reinforcement in columns can either have lateral ties (a) or spirals (b), of which the latter is much stronger and ductile:

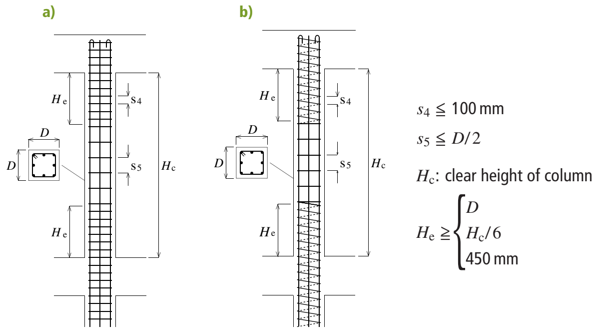


Figure 17: Reinforcement in column (Arya et al., 2014, p. 154)

The following figures give recommended details of connections in earthquake resistant RC structures. The following notations are used:

b : beam width	Le ≥ 2h and 4L – D/2
D : column depth or width	s1 ≤ 50 mm
d : bar diameter of reinforcement	s2 ≤ 24d, h/4, 8d and 300 mm
h : beam height	s3 ≤ h/2 and 150 mm
Hc : clear height of column	s4 ≤ D/4, 6d and 100 m
He ≥ D, Hc/6 and 450 mm	s5 ≤ 6d and 150 mmm
L : span of beam	s6 ≤ h/2 and 300 mm

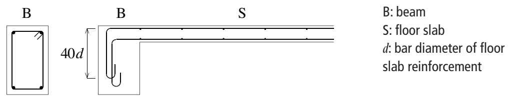


Figure 18: Connection between beam and girder (Arya et al., 2014, p. 155)

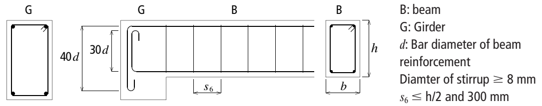


Figure 19: Connection between floor and beam (Arya et al., 2014, p. 155)

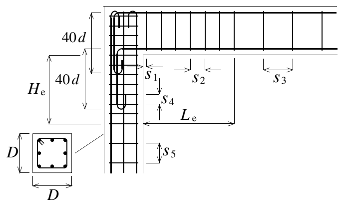


Figure 20: Connection between roof beam and exterior column (Arya et al., 2014, p. 156)

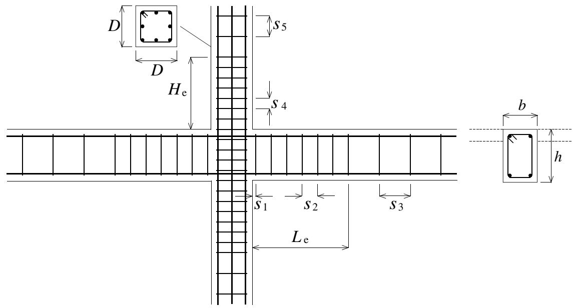


Figure 21: Connection between floor beam and interior column (Arya et al., 2014, p. 156)

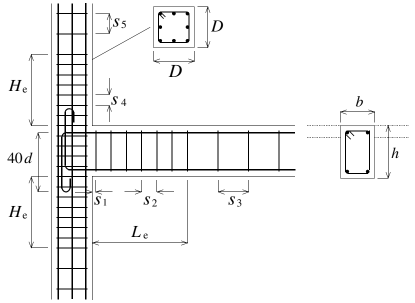


Figure 22: Connection between floor beam and exterior column (Arya et al., 2014, p. 157)

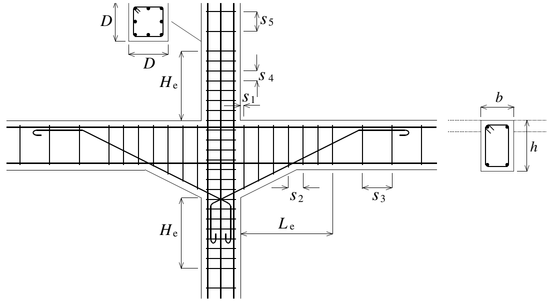


Figure 23: Interior joint between haunched beam and column (Arya et al., 2014, p. 157)

| Masonry

Masonry is a brittle material which makes it prone to damage under tensile and shearing stresses. Damage in unreinforced masonry buildings are caused by the heavy and stiff structure, the low tensile strength, brittle behaviour in tension and compression, weak connections, stress concentration at corners of openings and any asymmetry in plan and elevation. However, with measurements like reinforcement or addition of RC members, masonry can be very suitable for seismic design.

The quality of construction is important for the strength of the building. Good bonding and adequate connections must be made. Therefore, the following guidelines should be followed for mortar (see table 6 for the definition of the building categories):

Building category	Cement-sand	Cement-lime-sand
I	1 : 4	1 : ½ : 4½
II	1 : 5	1 : 1 : 6
III	1 : 6	1 : 2 : 9
IV	1 : 7	1: 3 : 12

For wall connections it is recommended to avoid continuous straight or toothed joints in only one wall. It is better to have sloping walls in the corner of 600 mm and building the walls from there (see figure 25) or to have alternating tooth joints in both walls with a height of 450 mm (see figure 26).

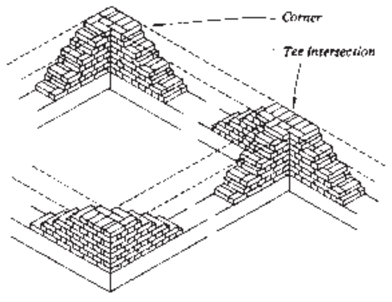


Figure 24: Sloping joint (Arya, 1987, p. 25)

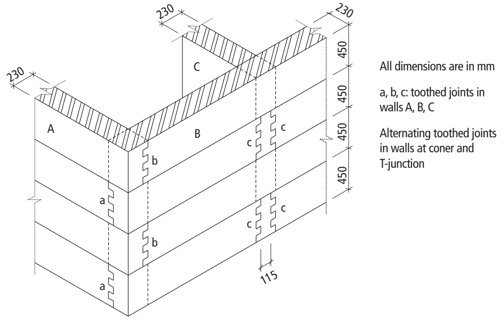
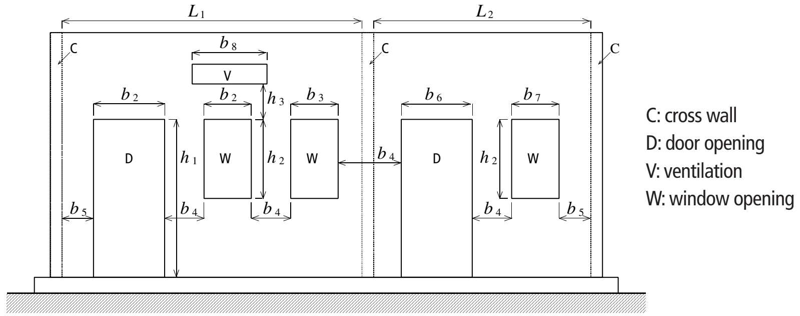


Figure 25: Toothed joint (Arya et al., 2014, p. 74)

Walls should have a thickness (t) of at least 190 mm in a load bearing construction. The wall height should be restricted to 20 t and the length to 40 t. Openings in masonry walls should be restricted to certain dimensions. Guidelines are given in the following figure:



$b_1 + b_2 + b_3 \leqslant 0.5L1$ for one storey, 0.42 for two storey, 0.33 for three storey,
$b_6 + b_7 \leqslant 0.5L_2$ for one storey, 0.42 for two storey, 0.33 for three storey,
$b_4 \geqslant 0.5h_2$ but not less than 0.6 m, $b_5 \geqslant 0.25h_1$ but not less than 0.6 m,
$h_3 \geqslant 0.6$ m or 0.5 (b_2 or b_8 whichever is more).

Figure 26: Guidelines openings in bearing walls (Arya et al., 2014, p. 72)

Roofs and floors should be as light as structurally and functionally possible since heavy structures have more inertia force during earthquake shaking. For schools, it is preferable to have pitched trussed roofs from a seismic point of view. The trusses need to lean on the eaves band or roof band. Flat roofs and floors can be constructed according to the jack arch roof/floor principle. The last span, or in large construction every fourth span, should be tied, see figure 28:

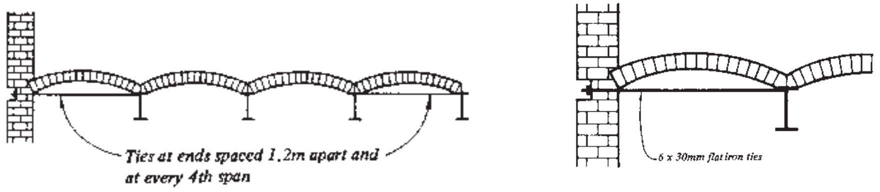


Figure 27: Ties in jack arch roofs and floors (Arya, 1987, p. 27)

Reinforced concrete slabs as floors have a binding effect and rigid diaphragm action and therefore do not necessarily need a rood band. However, for floors with joists and planks, a roof band is essential (Arya, 1987, p. 27).

Since masonry is a brittle material, reinforcement is essential for buildings that undergo seismic forces. Reinforcement should be placed in trussed roofs, gable ends, connections between roof and walls and between walls and foundation. Also, if openings do not follow the given guidelines, they should be reinforced. To resist lateral out-of-plane bending of walls, horizontal reinforcements are needed which are called horizontal bands or ring beams. Ring beams, also called 'collar beams', tie the walls together at a defined level. There are different types of rings beams at different levels (Arya, 1987, p. 28):

- Gable band, as enclosure of the masonry gable ends (triangular part). Connected to the eave level band
- Eave level band or roof band, placed at eave level of trussed roofs and below roofs or floors that consist of joists.
- Lintel band, placed above door and window openings.
- Plinth band, placed when soil is soft or non-uniform.

Vertical reinforcement needs to be placed at critical sections such as corners of walls, T junctions and jambs of doors and windows.

An alternative to these reinforcement methods is the confined masonry construction principle. Confined masonry consists of masonry walls, confined by horizontal (tie beams) and vertical (tie columns) RC confining members on all four sides of the masonry wall panels (Arya et al., 2014, p. 83). The sections of these RC member are much smaller than those in a RC frame construction. They do not work and transfer forces as in RC frames but rather function as ties that are resisting tensile stresses. Confined masonry can use different types of masonry such as burnt clay brick, concrete hollow or solid blocks or rectangularised stones. The following figure shows a typical two-storey confined masonry building:

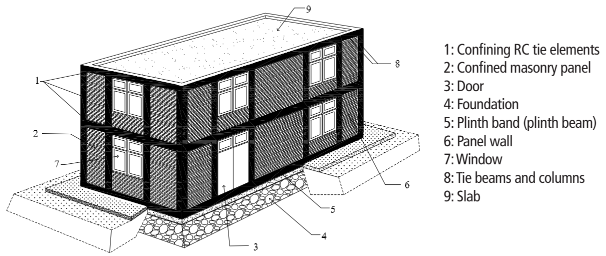


Figure 28: Confined masonry (Arya et al., 2014, p. 87)

Both reinforcing methods and confined masonry rely on the joint action between the reinforcement and the masonry to resist lateral forces. So, both techniques are suitable for seismic design, even in earthquakes with large magnitudes (Arya et al., 2014, p. 91).

The concept of separation which has been discussed in the previous section 2.3.1, applies to masonry buildings to prevent hammering and pounding. Construction details of the gaps are displayed in the following figures:

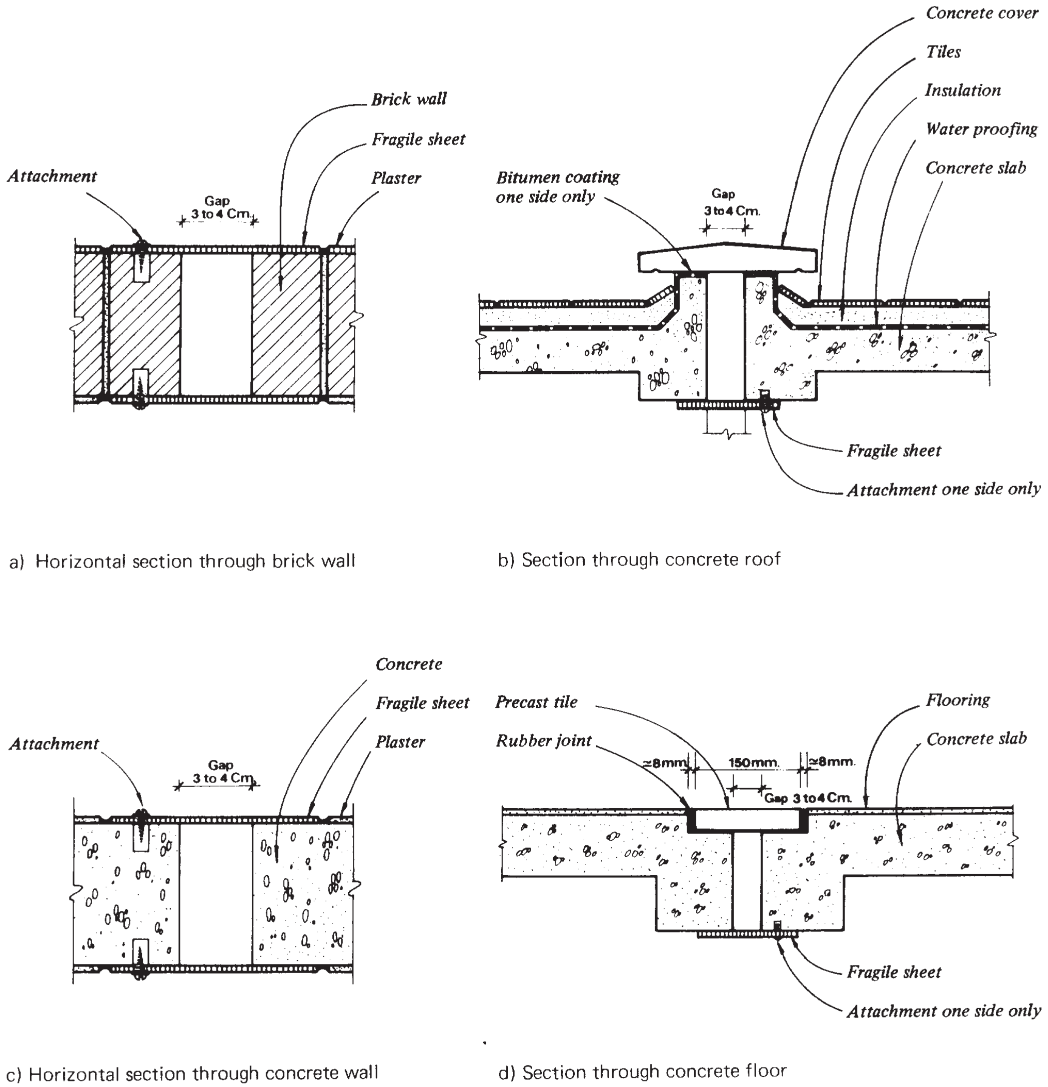
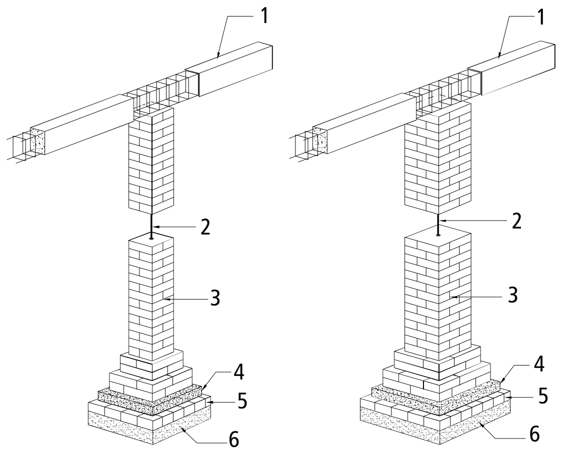


Figure 29: Crumple sections in separation (Arya, 1987, p. 35)

As foundation, strip footing of masonry, plain concrete or reinforced concrete can be used. For seismic design, reinforced concrete is the most effective. However, masonry foundations are most commonly used. The depth of the footing should be around 75-90 centimetres below ground level to go below the weathering zone. In non-cohesive and soft soils, a minimum depth of 1.5 metres is recommended for pedestal footing. Pile foundations of 4 to 8 metres are recommended in case of liquefaction during earthquakes. The distance between two pedestal or pile foundations shall not exceed 1.5 metres (Arya et al., 2014, p. 94). The footing should have a width of at least 75 centimetres for a one-storey building. For a two-storey building a width of 100 centimetres is needed and for a three-storey building a width of 120 centimetres is recommended (Arya, 1987, p. 34). However, it is recommended for school buildings to restrict the height to two storeys. An example of a brick pedestal foundation looks like is shown in the following figure:



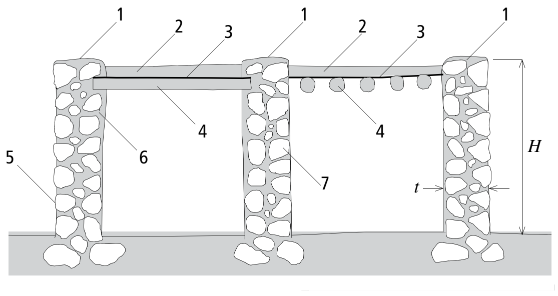
1: Plinth/ groundlevel beam
2: Steel bar from foundation to plinth beam
3: Brick pedestal
4: Plain cement concrete
5: One-brick flat layer
6: 150 mm thick sand filling

Figure 30: Brick pedestal foundation (Arya et al., 2014, p. 93)

| *Rubble masonry*

Stone buildings are quite common in poor rural areas since the availability and transportability of other building materials is difficult there. Stone buildings without seismic improvements are very dangerous and have killed many people in the past under large magnitude earthquakes. It is recommended to use other building materials that are more suitable and safe. But if it is unavoidable to use this material due to transport and economic difficulties, seismic improvements should be applied.

The following figure shows a schematic cross section of a traditional stone building:



1: Stone wall with mud mortar,
2: Mud fill at roof and floor 150 to 300 mm thick,
3: Branches, reeds
4: Log beams,
5: Hammer crossed face,
6: Chip and mud filling,
7: Random rubble,
H: Wall height 3 to 4 m
t : Wall thickness 0.5 to 0.9 m

Figure 31: Cross section of stone building (Arya et al., 2014, p. 97)

There are guidelines for the general construction and overall dimensions of stone buildings. First, the height of the construction should be restricted to one storey for building categories I and II, or two storeys for categories III and IV (see table 6 in 2.3.1). The height of one storey should be restricted to 3.5 metres and the wall thickness to 350-450 mm. The length of an unsupported wall, between cross walls, is restricted to 7 metres. If walls are longer, buttresses can be placed 3 metres apart from each other (Arya et al., 2014, p. 99).

Clay and mud mortar that is commonly used in these kinds of buildings should be avoided. Mixes as defined in table 7 in the previous section 'Stone' should be used.

Openings should be as central as possible in the wall and as small as possible. Ventilation openings are restricted to 450 x 450 mm. Guidelines for the recommended opening dimensions in stone building bearing walls are given in the following figure:

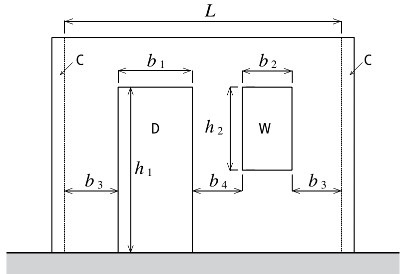


Figure 32: Recommended openings in rubble masonry bearing wall (Arya et al., 2014, p. 100)

Stones should be laid in courses not higher than 60 centimetres. Stones that are equal to the wall thickness, so called 'through stones', should be laid in every 60 centimetres and maximum 1.2 metres apart from each other horizontally. Long stones should be used at corners and junctions of walls to bond perpendicular walls. If through stones are not available, the following elements can be used:

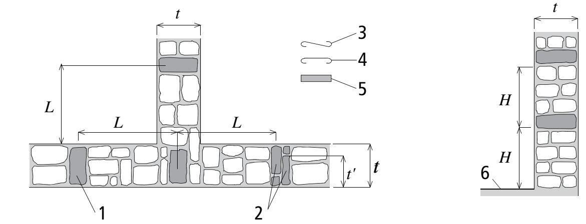


Figure 33: Through stones and other bond elements (Arya et al., 2014, p. 101)

Regarding reinforcement, the horizontal reinforcement which has been discussed for masonry buildings in the previous section can be used for rubble masonry as well. As alternative, if steel is not available, wooden planks can be used as shown in the following figures:

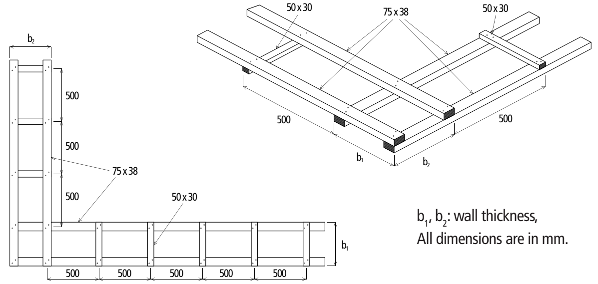


Figure 34: Lintel level wooden band on all load bearing walls (Arya et al., 2014, p. 102)

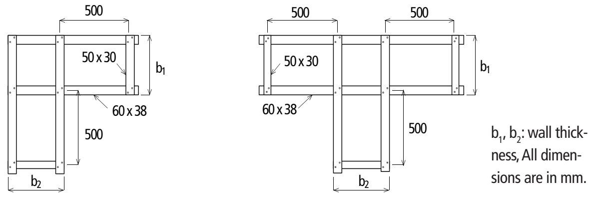


Figure 35: Wood reinforcement at corners and T-junctions (Arya et al., 2014, p. 102)

How vertical reinforcement is placed, is shown in the following figure. Vertical reinforcement is not needed for category IV buildings.

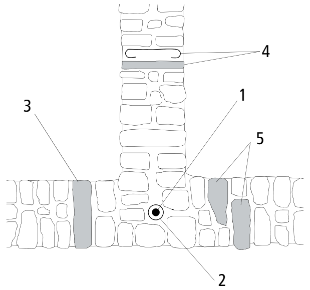


Figure 36: Vertical steel in rubble masonry (Arya et al., 2014, p. 103)

For foundations, the guidelines given for masonry in the previous section and the general guidelines for foundations (2.3.1. > Foundation) applies. An example of a stone foundation is shown below:

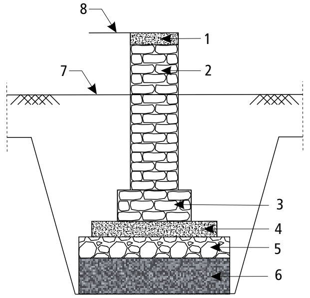


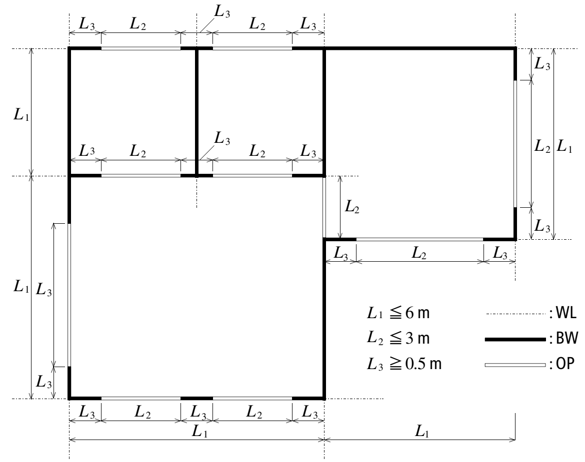
Figure 37: Open foundation stone wall footing (Arya et al., 2014, p. 104)

| Wood

Wood is very suitable for earthquake resistant building because of its high strength per unit weight. Although because of deforestation, it would be good to restrict the use of timber in seismic design. It is suitable in areas where there is still an abundancy of this material.

The main advantages of constructing with timber is the lightness, the easy workability and the safe transportability which makes this material mainly suitable for post-earthquake relief (Arya et al., 2014, p. 111). However, there are several disadvantages such as the fact that it is a non-homogeneous and anisotropic material. The tension and compression strength are therefore not always the same within a timber member. The strength properties of timber vary and depend on many different factors. Also, shrinkage of wood can loosen joints easily. Seasoned wood, with less than 20% moisture, is needed if this material is used. Due to the small elastic modulus, wood can easily show large deformations. Also, defects and notches in the wood can decrease its strength and stiffness significantly. The length of the material is also restricted. The material should also be treated to avoid rotting and insect attack. One of the most important disadvantage is the combustibility of wood. Fires after an earthquake can be more destructive than the earthquake itself.

The following guidelines apply to the building plan of wooden buildings:



WL: bearing wall line, BW: bearing wall, OP: opening

Figure 38: Floor plan dividede by bearing wall lines (Arya et al., 2014, p. 113)

A stud wall construction consists of timber studs and corner posts framed into sills, top plates and wall plates. Diagonal bracing stiffens the frame and absorbs lateral loads. The following figure shows the elements that are used in a stud wall:

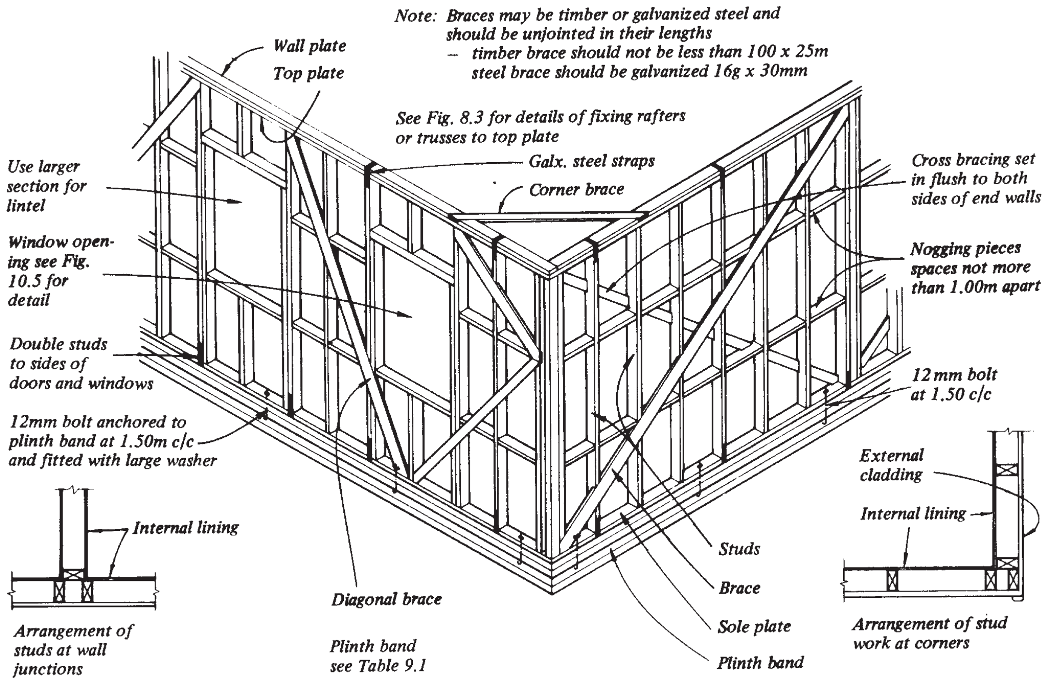


Figure 39: Stud wall construction (Arya, 1987, p .20)

The timber studs should be at least 40 x 90 millimetres and the maximum spacing is 40 centimetres on ground floors and 80 centimetres on upper floors, or 80 centimetres on ground floor if the building is single storey. The storey height should not exceed 2.7 metres. The timber bracing should be at least 20 x 90 millimetres. The wall covering that will be connected to the frame can be bamboo, reed matting with plaster, wooden boards, asbestos cement sheets or galvanized steel sheets (Arya, 1987, p. 20).

A brick nogged timber frame construction consists of studs, columns, sills, wall plates, nogging members and masonry in the space between the framing members. The following figure shows the elements used in brick nogged constructions:

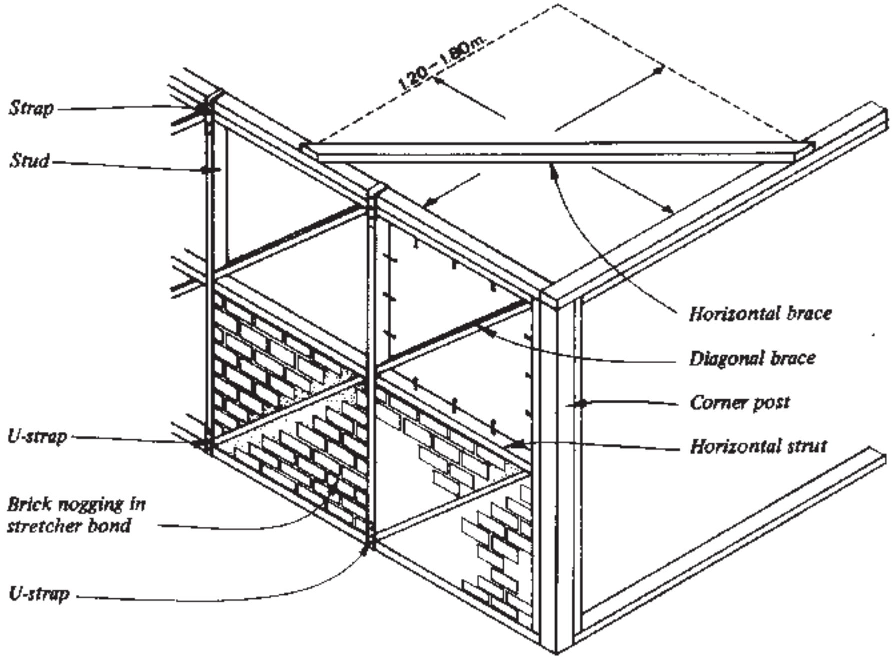


Figure 40: Brick nogged timber frame (Arya, 1987, p. 21)

The vertical framing in brick nogged constructions should be at least 60 x 100 millimetres. The horizontal nogging should be at least 50 x 100 millimetres, when the vertical spacing is 1 metre (Arya, 1987, p. 20).

Buildings in seismic active regions should act as an integral unity in order to absorb the lateral forces due to earthquakes. Bracing and securely connecting members of the walls and the roof is therefore very important. The following figures show where buildings need to be braced:

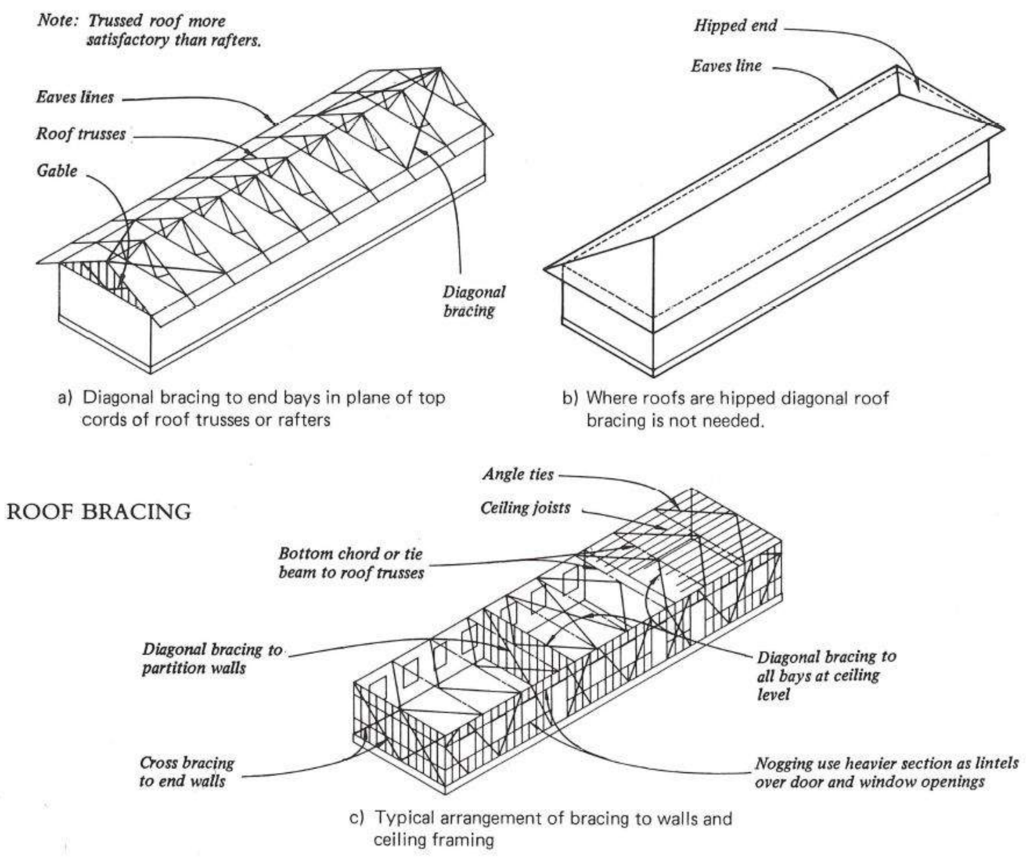


Figure 41: Roof bracing (Beynon, 1990, p. 69)

It is very important for the roof to be securely connected to the main structure. The weight of the roof can cause the joints to fail with complete collapse of the building as result. Roof trusses are preferred over rafters and sheets over tiles. The following figure shows how rafters can be connected to the wall plate:

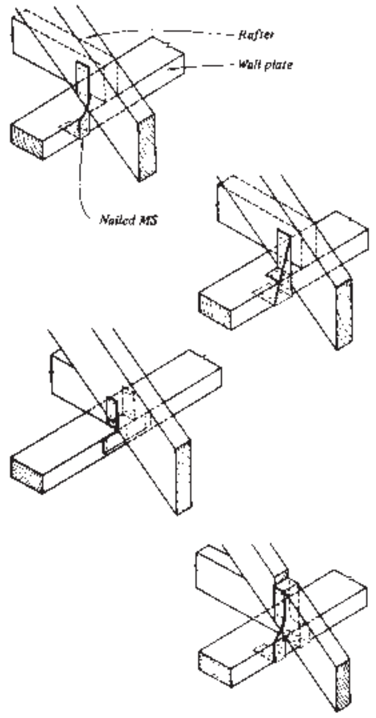


Figure 42: Rafter to wall plate connection (Arya, 1987, p. 18)

Timber buildings should be rigidly fixed into plinth masonry or a concrete foundation. If the foundation is continuous, ventilation openings should be made. Reinforcement is recommended in soft soils that are prone to liquefaction. On medium to hard soils, isolated footing can be used as shown in the following figure:

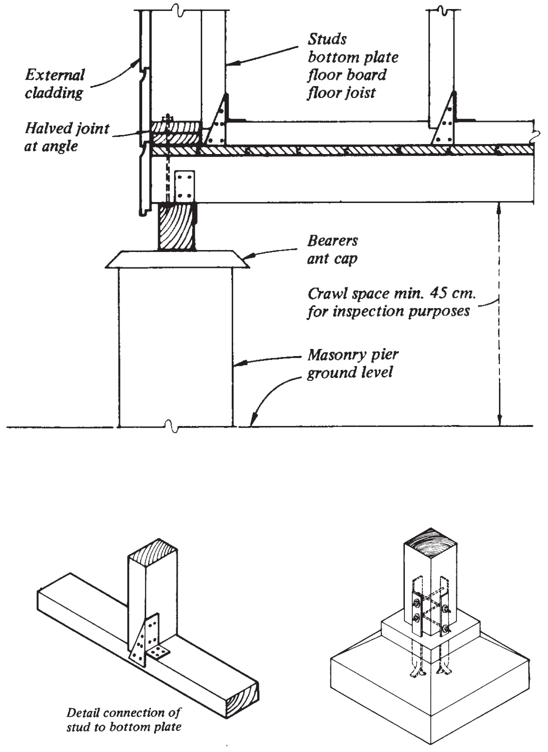


Figure 43: Footings for wooden buildings (Arya, 1987, p. 21)

| *Innovative construction technologies*

The government of Nepal (Ministry of Urban Development, Department of Urban Development and Building Construction (DUDBC)) published a design catalogue for reconstruction of earthquake resistant houses in March 2017. This catalogue consists of 17 seismic designs with 12 alternative materials and technologies which have not been covered by the Nepal National Building Code (The National Building Code will be discussed in the next section, 2.3.3.). This catalogue provides information about a variety of different materials, technologies, costs, sizes and layouts for both rural and urban residences. The designs in this publication includes architectural design, structural detailing and an estimation of the materials used. The following 11 technologies are covered (DUDBC, 2017):

Interlocking Brick Masonry

This technology consists of unburnt bricks that interlock each other and thereby reduce the mortar usage. Vertical reinforcement is possible on strategic locations. These bricks are economical, quick and environment friendly.

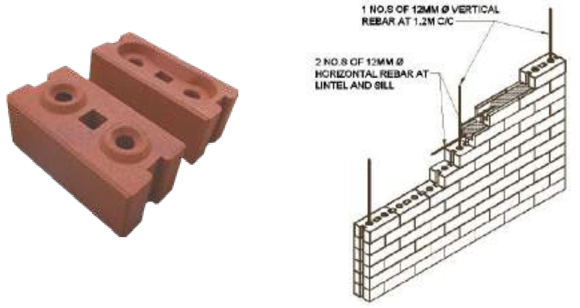


Figure 44: Interlocking brick wall (DUDBC, 2017, p. 17)

(Confined) Hollow Concrete Block Masonry

Load bearing structure of hollow concrete blocks is a good alternative to conventional brick masonry since they can be locally manufactured. And they are cheaper and environment friendly. In the confined variation, hollow concrete blocks carry the seismic loads and are confined by RC columns.

Random Rubble Masonry with GI Wire Containment

In this construction, wires are added to a rubble masonry structure to contain the stones. The wires are provided at both sides of the wall to prevent flexural failure. The reinforcement on both sides are connected to each other with ties that are going through the wall. This system does not require many changes to the local traditional way of building.

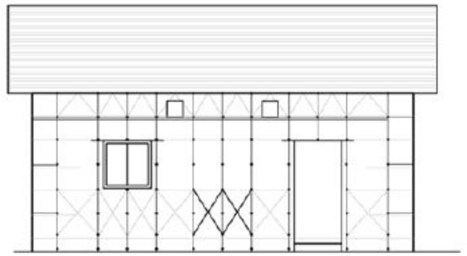


Figure 45: Example of wire reinforcement in rubble masonry (DUDBC, 2017, p. 76)

Compressed Stabilized Earth Block Masonry

This technology is based on mud as construction material with added stabilizers like cement. This material is suitable for rural areas where transport of materials is difficult. Only a small amount of non-local material is needed.

Bamboo and Stone Masonry Hybrid Structure

This technology uses seasoned and treated bamboo for the structural frame. Wattle and daub panels are used for the walls on the upper floor. Wattle is made of woven bamboo and daubed with a sticky soil-based material. The frame on the ground floor will be surrounding with a stone masonry wall with mud mortar.

Figure 46: Bamboo and stone masonry hybrid structure (DUDBC, 2017, p. 102)

Rat Trap Bond Masonry

In a Rat Trap Bond, all bricks are laid on their edges. Hereby an internal cavity is created within the wall. This will improve the thermal insulation. It is a modular type of construction. Therefore, heights and lengths are restricted to certain dimensions. The figures show how this technology works in T-junctions and corner junctions.

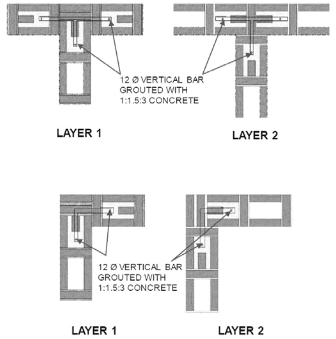


Figure 47: Rat Trap Bond in junctions (DUDBC, 2017, p. 113)

Earth Bag Masonry

This technology is probably the most simple, sustainable and cheapest method using ordinary soil that is present at the construction site. The soil found on site is put into Polypropylene bags and piled on each other with barbed wire as 'mortar'. The wire will take up the shear and tensile strength, just like reinforcement in masonry walls.

Figure 48: Earthbag masonry with 4-point barbed wire and wall ties (DUDBC, 2017, p. 128)

Light Gauge Steel Structure

This construction is made of thin steel sections, called cold form sections since they are shaped at room temperature, cladded with light panels such as light gauge steel panels, cellular light weight concrete, cement fibre board, gypsum board or calcium silicate board. This technology requires good planning and precision skills regarding execution since the cold form sections are pre-fabricated.

Steel Structure

This construction is made of mild steel columns and beams, resulting in a steel moment resisting frame. Vertical and horizontal loads are resisted by this moment resisting frame. The floors have profile metal decking and the roof has steel tube trusses.

Debris block Masonry

In this technology blocks are made from stone or brick debris and stabilized with cement. This will help in debris management in post-disaster scenarios and improve the pre-disaster situation of the built environment.

Timber Structure

This system is made of vertical elements called timber studs and horizontal members. The vertical load is resisted by the studs and the lateral load by the cross bracing (see previous section 'wood'). The floors have joists covered with planks and the roof is a wooden truss system. The figures show details of how to brace in wooden structures and how to connect the floor to the studs.

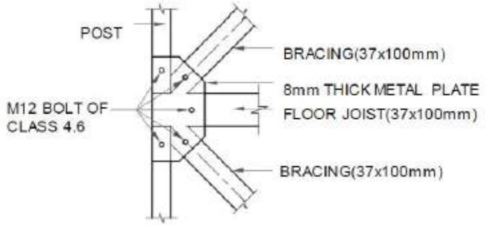


Figure 49: Connection brace and stud (DUDBC, 2017, p. 169)

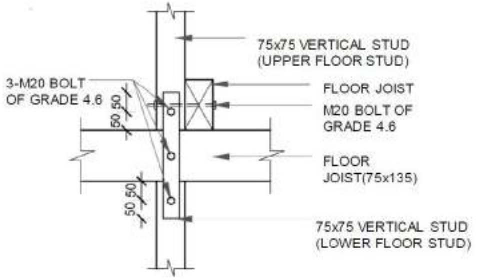


Figure 50: Connection stud and floor (DUDBC, 2017, p. 169)

2.3.3 Nepal National Building Code

The government of Nepal, Ministry of Physical Planning and Works (MPPW), published the Nepal National Building code (NBC) in 1994 as a standard of good building practice. It covers mandatory rules of thumb for different construction materials. This publication was established after the 1988 earthquake and was the first initiative to develop such regulations.

| Site conditions

There are several conditions that should be considered before choosing a construction site. A site is suitable unless the site is water-logged, a rock-falling area, a landslide-prone area, a subsidence and/or fill area, a river bed or swamp area (Ministry of Physical Planning and Works [MPPW], 1994, p.6). Local knowledge should be considered, especially the history of the built environment and its performance during past disasters is of importance. The MPPW suggests to carry out site exploration by digging test pits. The minimum requirements are two pits with a minimum depth of 2 metres. The allowable bearing pressure depends on the soil type.

The NBC uses the following division of seismic zoning in Nepal:

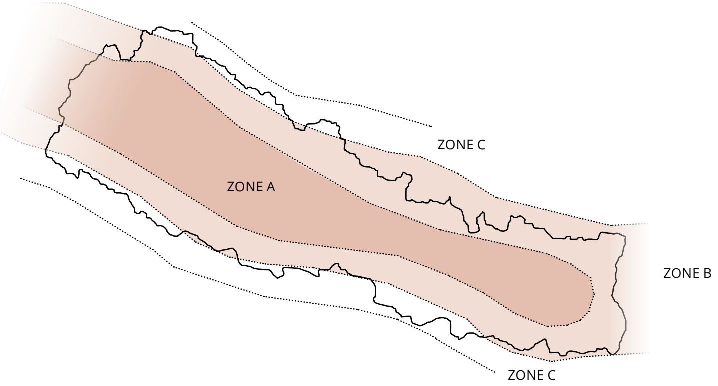


Figure 51: Seismic zoning map of Nepal

| *Building structure*

The following figure shows guidelines that are set up by the MPPW for structures with reinforced concrete frame and without masonry infill walls.

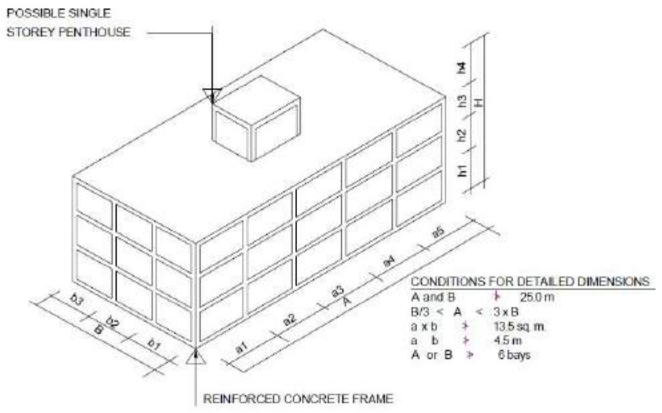


Figure 52: Restrictions on the building structure layout (MPPW, 1994, p.8)

In addition to the shown restrictions, the height (H) shall not exceed 3A or 3B and the maximum height is set to 11 metres or 3 storeys (MPPW, 1994c).

The main building layout plan should have a rectangular shape according to the NBC. The building may have wings, but they have restrictions to their dimensions. The length of the wings K1 and K2 should be less than 0,25A or 0,25B. The width restrictions of the wings are shown in figure 2 (MPPW, 1994c).

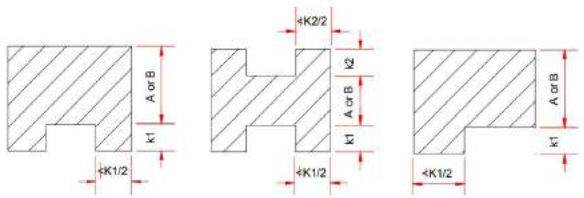


Figure 53: Restrictions on plan projection (MPPW, 1994, p.9)

For reinforced concrete with masonry walls, the following guidelines apply to openings in the bearing infill wall.

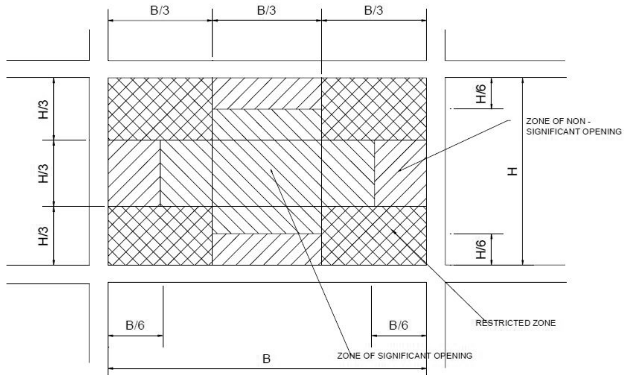


Figure 54: Possible location of openings in bearing infill walls (MPPW, 1994a, p. 11)

The NBC has set up guidelines for building sizes in load-bearing masonry structures.
The following table gives an overview of these limitations:

	Floor	Min. wall thickness (mm)	Max. height (m)	Max. short span of floor (m)	Cantilever (m)
Load-bearing brick in cement mortar	2nd	230	2.8	3.5	1.0
	1st	230	3.0	3.5	1.0
	Ground	350	3.2	3.5	no
Load-bearing stone in cement mortar	1st	350	3.0	3.2	no
	Ground	400	3.2	3.2	no
Load bearing brick/ stone in mud mortar	1st	350	3.0	3.2	no
	Ground	350	3.2	3.2	no

Table 9: Building size limitation for load bearing masonry (MPPW, 1994, p. 2)

For earthen buildings and buildings that are constructed with low strength masonry, the following guidelines are important:

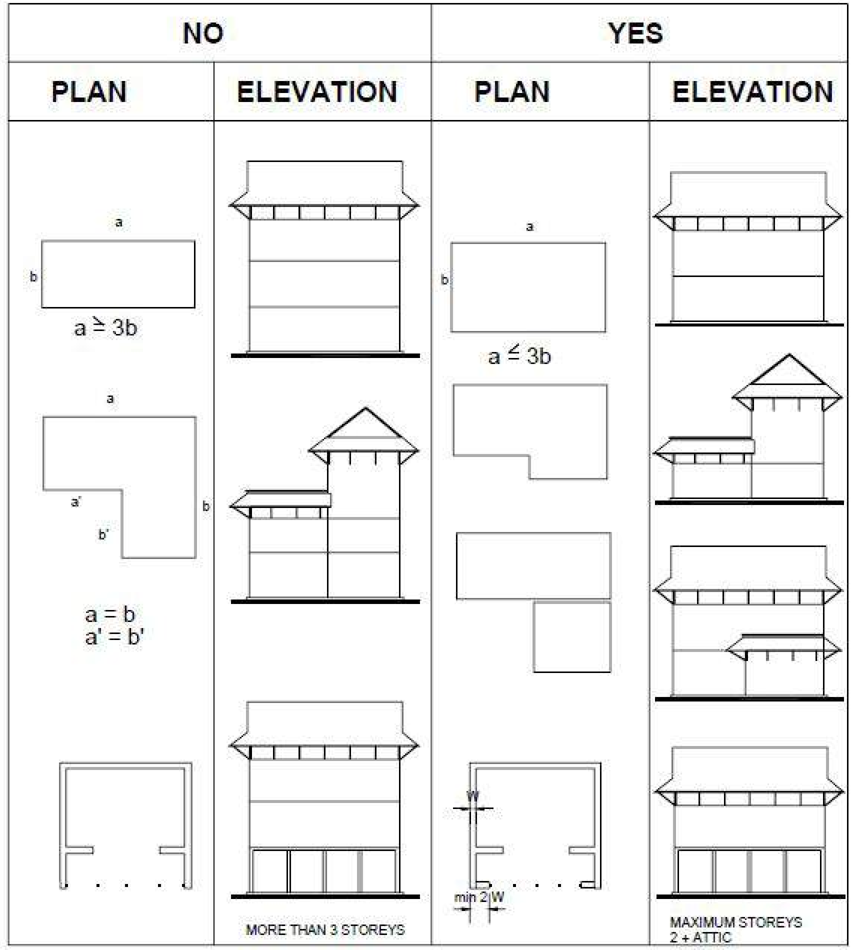


Figure 55: Recommended form of earthen and low masonry buildings (Mahal, 1993, p. 7)

2.4 CLIMATE-INDUCED DISASTERS

The chance of earthquakes is the main hazard in Nepal. Seismic forces have been proven extremely destructive in the past and are the cause of many indirect disasters such as landslides and fires. However, earthquakes are not the only hazards that Nepal is facing. Different regions in Nepal have to deal with other location specific hazards. These hazards are mostly climate-induced. Examples of climate-induced disasters are floods, storms and fire. Since the climate change is expected to progress, it is important to take these dynamic factors into consideration. The amount of construction measurements that can be taken in order to mitigate the effects of these hazards is limited. However, seismic design guidelines for connecting construction member can be used to also mitigate the effect of wind loads besides lateral seismic loads. Chances of fire spreading can be reduced by choosing the right materials and apply compartmentalization in the building layout for passive fire safety. It is important to be aware of the multi-hazard context when designing a school in Nepal. Floods, windstorms, thunderstorms and fire will be discussed in the following sections. Information about where they occur in Nepal and how to deal with these hazards in building construction will be given.

2.4.1 Floods

Nepal has more than 6,000 rivers that flow between different elevations from north to south. Flooding occurs every year around the end of the summer monsoon. The soil is saturated and surface runoff increases during that period. Earthquakes has proven to be the most destructive in terms of casualties. However, the number of people affected by floods is higher than any other disaster (Salike & Fee, 2015, p. 8). Due to climate change and the resulting increase in precipitation, climate-induced hazards such as floods are expected to increase in occurrence frequency. There are two types of floods in Nepal. Regular floods happen when a full river overflows during a few days of heavy rainfall. Flash floods do not happen gradually but occur when there is a sudden outburst after extreme heavy rainfall.
Floods are most common in the southern, lower part of Nepal, the Terai. Every year, physical infrastructures are damaged and social structures disrupted. In the research area of my project, the Kathmandu Valley, floods do not occur as much as in the Terai but are still an issue to consider when constructing buildings. The following figure shows a study of flood risk in the Kathmandu Valley. Godavari, where the design site is located, can be considered safe from flooding.

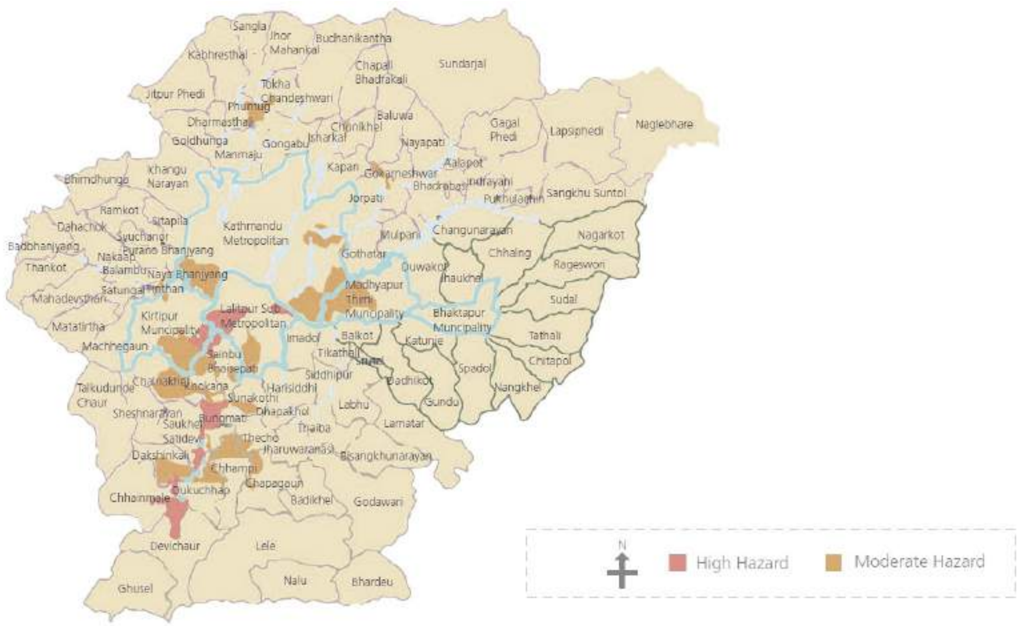


Figure 56: Flood hazard in Kathmandu Valley (Salike & Fee, 2015, p. 9)

There is not so much that can be done to protect schools from the effects of flooding as with earthquakes. The only thing possible to prevent the effects of flooding is to choose a suitable site which is not prone to flooding. If flood areas cannot be avoided, water resistant materials should be used and sleeping and living areas should be located above the flood level (Department of Education (DOE), Ministry of Education, 2016, p. 21).

Floods are caused by extreme heavy rainfall. Another type of disaster which is induced by this climate-related issue is landslides.

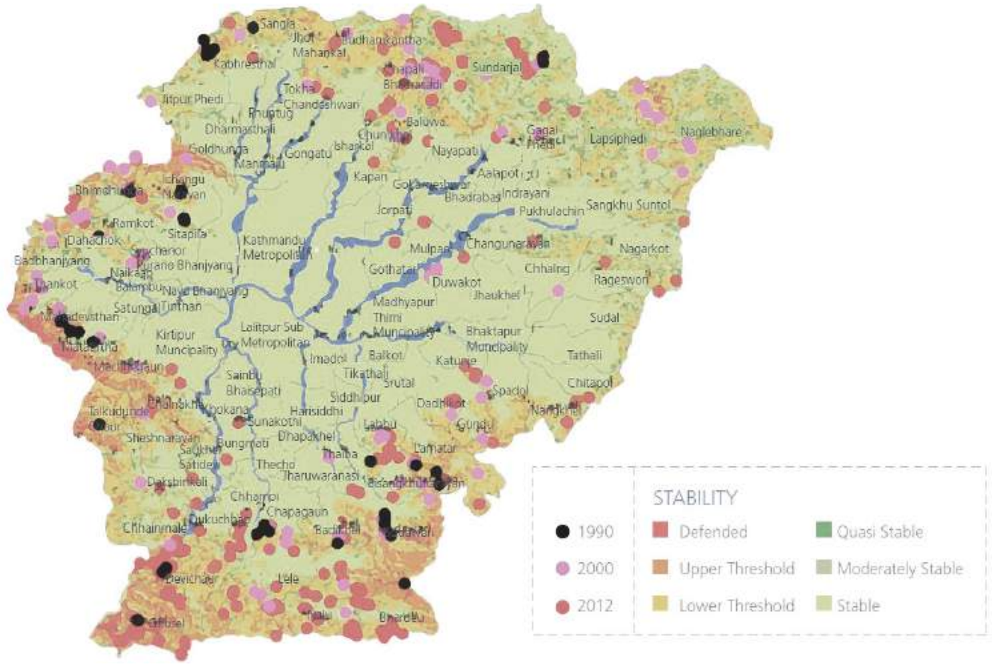


Figure 57: Landslide hazard in Kathmandu Valley (Salike & Fee, 2015, p. 10)

2.4.2 Wind and thunder storms

Windstorms are mainly common in the flat Terai region from March to May. Casualties caused by storms are not as high as for earthquakes and floods and therefore, storms are not ranked as major disaster (Schools & Communities, 2012, p. 12). However, windstorms can be quite damaging to properties, so measurements need to be taken to prevent unnecessary damage. Windstorms and lighting strikes usually happen together at the same time.

Like in seismic design, all structural members should be properly tied together in order to ensure structural integrity during storms. Roofs that are susceptible to wind uplift should be avoided. It is also important to pick the right location, out of storm prone areas and with possible falling trees and flying debris in consideration. The walls and main structural system should be able to resist high wind loads and windows and doors should have proper locking systems. To protect against damage induced by lighting, lighting protection rods and earthing should be provided, especially when the building is located at exposed and high areas (Department of Education (DOE), Ministry of Education, 2016, p. 22).

2.4.3 Fire

Earthquakes can cause electric wires and gas pipes to break and cause fires. To decrease the chance of fire, fire proof materials or coatings should be used in the construction. Firefighting equipment and emergency exits should be wisely located at critical points and marked clearly. Compartmentalization is a design concept in which a building is divided into several fire compartments. Fires will be contained for a certain amount of time within these compartments. This is a passive concept of fire safety.

In order to design a building in Nepal, it is important to have obtained background knowledge of the context. This section will discuss Nepal’s historical and cultural context, its geographical and demographical division and its infrastructural systems.

2.5.1 History

Nepal has a long history. The country was known to the Ancient Indians since it has been mentioned in classical Indian literature. The Indian Emperor introduced Buddhism in Nepal around the 3rd century BC. The Lichavis started to rule in Nepal from 200 AD. Nepal flourished under their power with impressive Buddhist and Hindu temples. After 879 AD, a series of kings, called the Thakuris, took over the power. After the Thakuris kings, a new series of kings emerged in the 12th century, the Malla. The caste system was introduced by them in the 14th century. In 1482, Nepal was divided into three kingdoms, but the country was reunited again in the 18th century by Privthi Nayan Shah who isolated to country to protect it from the growing power of the British in India. In the 19th century however, Nepal was forced to comprise with the British. The war in 1814 till 1816 resulted in the current country boundaries. In 1846, Rang Bahadur took power and became prime minister, or so-called Rana. Kings in Nepal have only a symbolic meaning, the Rana had the new power from then on. In 1932, Great Britain and Nepal signed a new treaty (Lambert, 2017).

From 1950 on until 2015, the constitution has changed many times. From royal authority, to democracy, communism, coalition government, monarchy and republic. In 2015, Nepal gained a new constitution. Nepal is since this new constitution divided into 7 states with 77 districts. It is nowadays a poor country with 29 million people of which most live by farming.

2.5.2 Geography

Nepal Is about 800 kilometres along the Himalaya and 150 to 200 kilometres wide. The country is landlocked between India and China. Its total area is 147,181 km2 of which 92,9% land. The highest point is the Mount Everest which reaches 8,848 metres. The country is divided into three physiographic areas: the Himal, Pahad and Terai. Himal is located in the Great Himalayan Range in the north of Nepal. It is a cold snow dominated region with high elevations. Pahad is another mountain region ranging from altitudes between 800 and 4,000 metres but does not have that much snow. Terai is the southern part of Nepal with lowland plains and some hill ranges which are formed and irrigated by the three major Himalayan rivers.

There are five climatic zones in Nepal that are more or less corresponding with the altitudes. Below 1,200 metres is a tropical and subtropical zone. Between 1,200 and 2,400 metres there is the temperate zone. The cold zone is between 2,400 and 3,600 metres and the subarctic zone between 3,600 and 4,400 metres and finally the artic zone above 4,400 metres. There are five seasons in Nepal: The summer, the monsoon, the autumn, the winter and the spring.
The differences in elevation result not only in different climates but also in different types of environments. At the highest elevation there is rock and ice and high-altitude grasslands and shrublands. There are coniferous forests on the Himalaya slope and in the hill region. In the south along the Indian border, tropical savannas can be found.

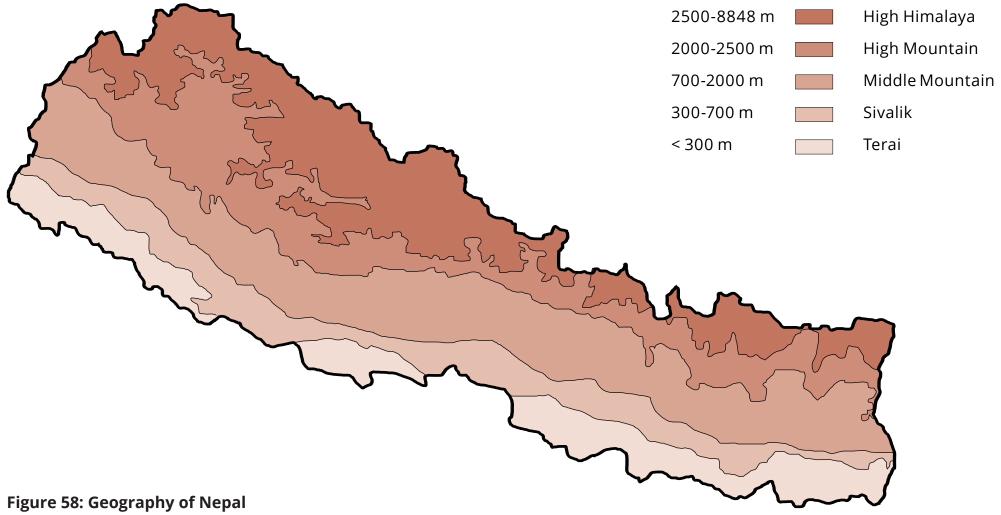


Figure 58: Geography of Nepal

2.5.3 Infrastructure and resources

There are 47 airports and one railway in the south of the country. The rough terrain in Nepal makes it very difficult and expensive to develop transport infrastructure. Also, most of the roads in rural areas are not accessible during the monsoon season which makes it very hard for some people to reach markets, schools and health clinics. Natural disasters even worsen the accessibility to these facilities. In 2007, the Ministry of Physical Planning and Works of the Nepali government published a vision paper of the new physical infrastructure foundation in which the following map has been published of envisioned infrastructure in Nepal:

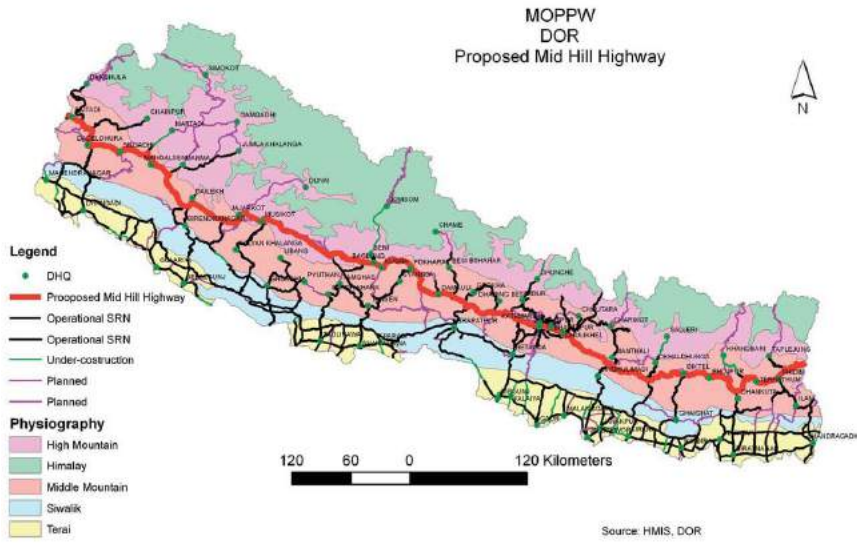


Figure 59: Infrastructure of Nepal (MPPW, 2007, p. 2)

Most energy in Nepal comes from fuel wood with 68%. Followed by agricultural waste with 15%, animal dung at 8%, and 8% of imported fossil fuels (USAID, 2011). Nepal has no gas, coal or oil sources, these resources are imported from India or China. The topography of Nepal is ideal for hydroelectric projects due to its steep varying altitudes. There is a lot of potential in this field for the economy and welfare of the country. However, currently only 40% of all people in Nepal has access to electricity. In urban areas, 90% has electricity available while in rural areas only 5% has access. Power cuts are a daily phenomenon in Nepal due to poor installations.

2.5.4 Nepali architecture

Newar style and its building concepts and materials is Nepal's original building style and has remained nearly unchanged over the centuries. Nepali architecture reflects characteristics from India, Tibet and China since the country is located on the trade routes between those countries. The ancient Nepali architecture, established by the Newar people, is mostly present in the Kathmandu Valley with its three medieval city-states (Katmandu, Bhaktapur and Patan). Newar art and architectural style is mainly religious art but the traditional valley architecture can be categorized as both sacred and secular. The style is used for temples, monasteries, sacred houses and simple houses. The characteristics of this style are impressive brickwork and wooden carving. Newar houses have pitched roofs, usually three storeys, narrow latticed windows, doors barred with large wooden planks and a courtyard (Build Abroad, n.d.). The Nepali architect Arniko (1245-1306) has been very influential in exporting this style across Asia.

Figure 60: Newa architecture in Kathmandu (wikipedia: Newa architecture)

Unfortunately, most ancient works have been destroyed during the centuries either by natural causes or by people. Many works were lost after events during the 14th century. In the 15th century, the Malla took power and a period of stability began. The Newar society became part of the Hindu cast system. Several Newar families continued working on specific building methods and became well-known for their craftmanship with local materials. The main materials available in Nepal for construction are stone/bricks and wood. Local clay soil is used for the production of bricks in the Kathmandu Valley. This soil is excavated from a dried-out lake in the Valley. The next section, 2.5.5, will discuss all the main traditional materials that are used for construction in the Kathmandu Valley.

A new historic stylistic period started in the 18th century which is referred to as the Gurkhali period. During this period, many palaces and temples underwent reconstruction in eclectic style with characteristics of Islamic and Hindu style.

In the 19th century, there was more focus on urban planning with the development of fountains, gardens and streets. This took place after the Rana family took power. They established an isolationism policy by closing the borders to other countries except for Great Britain. Architecture from this period was strongly influenced by the British with neo-classical characteristics such as white plastered surfaces.

When monarchy was restored in 1951 and Nepal reconnected to other countries, there was a revival of interest in original Newar and Malla architecture. The development of new constructions was however more dependent on trade demands rather than traditions. The new organization of the Newar cast system is now adapted to the different specializations with flexibility to be able to switch between different skills to meet the needs and trade demands. Newar craftsmen were no longer limited to a specific field which allowed them to broaden their knowledge and find work more easily (Bonpace & Sestini, 2003, p. 15).

Nowadays, Nepali architects combine traditional styles and textures with modern aesthetics and comforts. This approach conserves and respects the architectural heritage of Nepal, while also contributing to a resilient built environment by improving buildings with seismic measurements.

| *Sacred architecture*

The three prominent styles that can be distinguished in Nepali sacred architecture are the Pagoda Style, the Stupa Style and the Shikhara style.
The pagoda style is mostly visible in Nepalese temples. Pagodas consists of multiple roofs with wide eaves which are supported by artistically carved wooden struts. Windows are mostly latticed or grilled in these kinds of buildings. This style evolved from the dome-shaped stupa and travelled across Asia and blended with Chinese traditional architecture (Build Abroad, n.d.). One of the most impressive pagodas is the one that Kathmandu is named for: The Kasthamandap. Unfortunately, this temple did not survive the earthquake in 2015. Reconstruction is in progress, it is estimated that the reconstruction will be finished in 2019.

Figure 61: Kasthamandap before the earthquake (www.defietstoerist.nl)

The stupa style is originated in ancient India as part of the Buddhist architectural culture. The shape of stupa buildings represents Buddha and the five Buddhist elements. The earth is represented by the square base, the water by the hemispherical dome, fire by the conical spire, air by the upper lotus parasol and the space by the sun and the dissolving point (Build Abroad, n.d.). One of the most impressive example of stupa architecture is the Swayambhu which is seen as the most sacred pilgrimage site for Newar Buddhists.

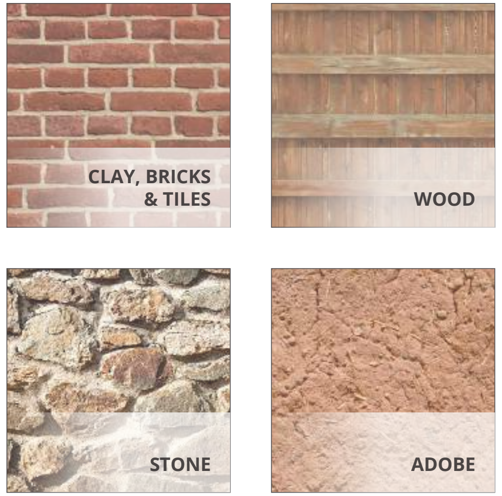
Figure 62: Swayambhu Stupa (www.swayambhu.buddhism-foundation.org)

Shikhara style is a characteristic of Hindu temple architecture. Buildings in this style are tall curvilinear or pyramidal towers and has a many exterior ornaments (Build Abroad, n.d.). Shikhara can be translated as mountain peak which is represented in the shape of the building. An impressive example of Shikhara architecture is the Patan's Krishna Temple.

Figure 63: Patan's Krishna Temple (photo by Cheryl Marland)

2.5.5 Traditional materials & construction methods

The most important traditional materials that are found in Nepal and used for construction of buildings will be discussed in this section. Clay, bricks & tiles, wood, stone, adobe and plaster are the main local materials found and processed in the Kathmandu Valley by the local people.



| *Clay, bricks & tiles*

Bricks is the main building material used in Nepal which gives an overall unified character in Nepali urban spaces. Bricks are used for walls, roofs, pavements for streets and squares and some other parts of buildings as decoration in different patterns. The bricks are made from different types of clay that can be found in the Kathmandu Valley. The clays are dug from either river beds or from agricultural terraces on slopes. There are different clay colours with different purposes. Grey and black clays are used for common bricks and tiles. For plaster, grey and brown clays can be used. Grey clay can also be applied in mortar. Red clay is commonly used for pavement. Wall painting is done with white clays and joints can be plastered with yellow clays. Bricks are fired in kilns that are installed in situ and dismantled when the construction is finished to let the soil function as farmland again. Hundreds of kilns can be found in the Valley during the dry season. They are dismantled during the monsoon season to resume rice production.

The walls of buildings commonly consist of two leaves with clay and brick pieces in the space between them. The wall thickness is not always even since there are no standard brick dimensions in Nepal. The bricks are laid in regular bond and special tapered bricks, daci apa brick, are used to create very thin joints for aesthetic and technological purposes. The thin joints filled with an oil and clay based mortar, called silay, ensure good water resistance during the monsoon season (Bonpace & Sestini, 2003, p. 33). Special brick laying patterns are used above openings in Newar buildings. Also, the support of the corner pillars and base plinths of temples are decorated with symbolic decorative patterns.

The tiles used for roofs are flat and have grooves on both sides, so they fit into each other. Special formed brick tiles are used for ridge tops and hips which gives Nepali roofs a distinctive character. Tiles are also used as decoration of facades of some buildings. For this purpose, mostly ceramic glazed tiles are used. Terracotta is common in Bhaktapur and its surrounding villages.

The production of bricks and tiles happens during the drying of rice in open air which is part of the identity and character of public spaces in both urban and rural areas in Nepal. The similar colours of the building elements made by clay results in uniformity in urban and rural architecture and integrates the architecture with its environment.

| *Wood*

Buildings were typically built up with a structural wooden frame filled with masonry. This building system is the original expression of the Newar building style. Kathmandu means ‘city of wood’. Unfortunately, many original wooden buildings have been destroyed in the past. The wooden construction combined with bricks can be found in both Newar houses and temples. They both have a central square cell made of thick walls as a rigid core. The Kasthamandap, mentioned in the section ‘2.5.4. Nepali architecture’, is built with this system. As with many of these buildings, the wooden structure appears to have a more decorative rather than structural purpose.

The wood used in construction comes mostly from the Sal and Sisau forests in the southern part of the country, the Terai region. Sal is a very durable type of wood which is suitable for structural construction elements but also for non-loadbearing elements such as windows and doors. The wood is commonly protected with oil that also comes from the Sal tree for better durability. Other tree types that can be found around the Kathmandu Valley and are suitable for externally exposed construction elements are Gwaisasi, Salla, Utis and Sisau. Softer types of wood such as Bakaina, Alp, Padke, Simal, Karma ad Sisame are more suitable for furniture. Nowadays, the Valley region struggles with deforestation. Therefore, tree cutting is limited to the Terai region.
Since most building proportions of details are the same in Nepali architecture, it is easy to identify basic and common construction details of traditional buildings (Bonpace & Sestini, 2003, p. 53). In wooden buildings, joints are mostly made by wood. Other fixing materials are avoided in most cases.
Roofs are typically made with the wood technology. Nepali roofs are steep and have large overhanging eaves to protect the building against rainfall and sun during the different seasons. Climate has a significant influence on the form of Nepali buildings. roofs for residences have commonly two steep pitches of 40-50 degrees. A ridge beam is supported by a central column and the lateral gable walls. Two main rafters are tied to the central column and are supported by the lateral walls on wooden wall plates which transfer forces to the walls. On the main rafter, purlins are attached. Secondary rafters follow the slope of the roof and extend into the overhanging eaves. The following figure shows a axonometric section of a typical Newar house.

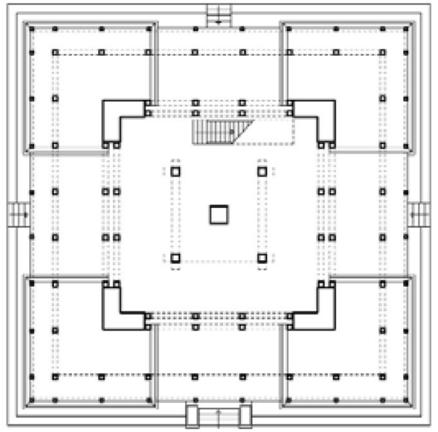


Figure 64: Kasthamandap floor plan (Bonpace & Sestini, 2003, p. 48)

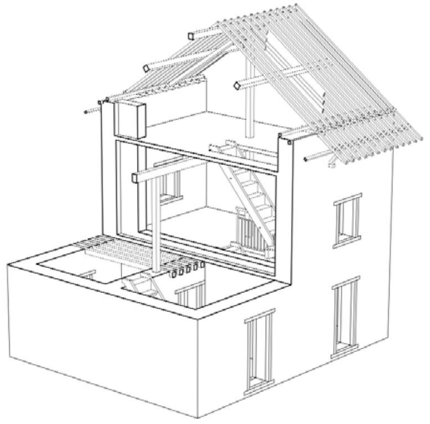


Figure 65: Typical Newar house with wooden construction (Bonpace & Sestini, 2003, p. 58)

Another characteristic of Nepali architecture is the common use of vertical components. Columns are lined up in parallel rows and joined to a beam on top and a wooden beam or stone plinth at the bottom which results in a simple structural system supporting a thick brick wall. The structure has both an aesthetic and structural function. Examples of connections in this structure system are shown in the following figure:

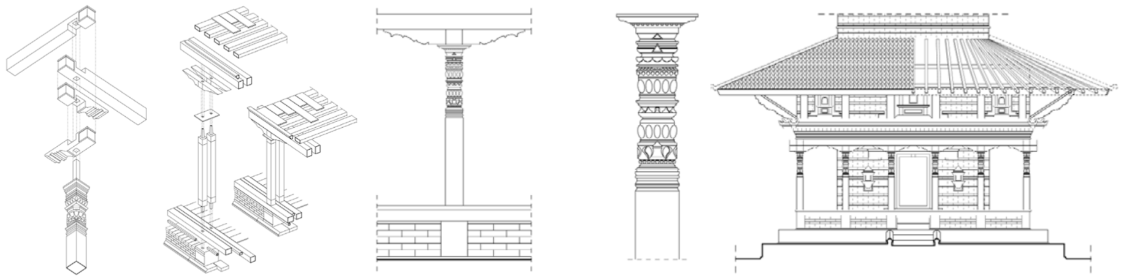


Figure 66: Traditional wooden frame construction system (Bonpace & Sestini, 2003, p. 61-64)

Stairs are always made of wood in traditional buildings. They are quite steep and narrow and can be built in one continuous flight since the height of the stories are limited. Usually, 2-3 steps and landing are made out of bricks at the beginning of the flight (Bonpace & Sestini, 2003, p. 65).

Floors are usually made with rectangular battens with planks and the floor finish on top. Newar craftmen developed construction methods to cope with the seismic forces. These methods use additional bracing by tying vertical and horizontal elements together with wedges that are connected through the wall so that the outer and inner joists that run around the building are connected. The following figures visualizes this concept:

Windows and doors are also commonly built with wood. They are always assembled in such a way that they are always structurally compressed. doors and windows usually consist of an internal and external frame that are connected with wooden ties. Openings have an aesthetic function. They are commonly decorated and are characterised by a grill. Windows on the storey are quite simple. This floor is usually used for sleeping in residential houses. The second storey usually has more impressive carvings and decorations where the main living area can be found.

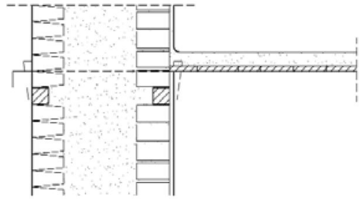


Figure 67: Connection between floor and wall in wooden Newar building (Bonpace & Sestini, 2003, p. 66)

| *Stone*

Stone is commonly used in Nepal for the construction of temples, such as the shikhara temples, and public works, such as water tanks, squares, fountains and bridges. Also, religious sculptures representing animals or figures are usually made from stone.

Houses in Newar style, built with bricks, are supported by stone foundations. The stones used for this purpose are usually found along river beds and are usually used in their original state. Stone foundations have a symbolic meaning as well, it represents the base of the universe. A ceremony is usually held when the stone plates are laid. In some houses, also the walls and the entrance ways are made in stone as well. Stone plates are also very suitable for pavement of roads and squares due to their durability in heavy traffic and extreme climate.

Mines where stone were originally excavated can be found around the hills of the Kathmandu Valley. Due to the collapse of many of these mines, new quarries are in operation in the surrounding hills and mountains of the Valley. Most quarries can be found in the south near Parping village and Kirtipur city and Chobar gorge. Near Godavari, the place where my design site is located, marble stone can be found.
There are two types of stone. A black stone that is very strong and used for statues and a white stone which is mainly used for pavements. Because stones are quite difficult to transport due to its weight, most processing works are done in the countryside, where the stones are found.

Nowadays, most stone production is mainly for tourism purposes like hotels and such. Stone for religious purposes is not so much demanded anymore.

2 | RESEARCH
2.5 NEPAL

| *Adobe*

Earth is used in several different ways in building construction. Adobe buildings constructed with the rammed earth method (pisé) are very common in rural areas of Nepal, especially along the Bagmati river. However, this method is rarely used in (semi) urban areas. Bricks made of earth are commonly used in these areas. Adobe bricks are sun dried in contrast to fired bricks. Mortar is also based on earth. As mentioned before, earth is also used to fill the gap between two brick leaves in wall constructions. The total thickness of adobe brick walls is never less than 50 centimetres. Earth is also used for the interior such as flooring, wall covering, fireplaces and other fixed furniture, resulting in a visual unity of the internal space. Earth has an essential practical function in roofing. It is spread on the wooden boarding to support the tiles on top of the steep pitched slopes. To prevent damage due to long term humidity near the wooden boards, bitumen should be applied in between the boards and the earth.

Many rural villages in the Valley are entirely constructed in adobe brick because of economic reasons. In some buildings in urban areas, the outer leaf or only the visible part of the building is constructed with fired bricks. The other parts of the building are made with adobe bricks.

Research results showed that the seismic resistance in adobe buildings is sufficient providing that the building has an adapted building layout and adequate connections between vertical and horizontal structural elements (Bonpace & Sestini, 2003, 121).

Nowadays, adobe is still quite common as construction material in rural areas. People usually construct their own houses with the local materials that are readily available. This saves money and reduces the damage to the environment. The adobe architecture, dominant in rural areas and along the Bagmati River, blends in with the local environment, is ecological and part of the cultural patrimony of the Kathmandu Valley. UNESCO states that it should be conserved and protected as monumental architecture (Bonpace & Sestini, 2003, p. 120).

| Plaster

Plaster has two main functions: protection against water penetration and aesthetics. Plaster is made from a local red or white clay. Houses are commonly decorated by using two different colours for the ground and the upper floors. The ground floor is usually lighter of colour. The inner walls usually have a red clay coating which makes it damp-proof and insecticidal.

The colour of the clay also depends on the ethnic group. The original Newar building tradition used daci apa bricks without plaster. The Rana family introduced neoclassical style in the 19th century which is characterized by the plastering technique based on air-hardening lime mortar (Bonpace & Sestini, 2003, p. 127).

Stucco is referred to as external covering while plaster is used for inside works. There are different types of plaster. Brick dust plaster consists of 2 parts of brick dust, 1 part of black pulse and 1 part of lime. Lime mortar, also called bajra mortar, consists of 2 parts brick powder, 1 part of sand and 1 part of lime.

Many traditional Nepali architectural works such as stupas and shikhara temples are covered with plaster. Covering with plaster gives a uniform character. Plastering is also part of a religious ritual. Temples, statues and houses are restored on the first day of the Dasain festival in September/October.

There are no special mines were limestone is excavated for lime production. Nowadays, hydrated lime is readily available in powder form. The Rana architecture and its neoclassical characteristics are often considered unimportant and overlooked, while it should be considered as a significant component of Nepali architecture according to UNESCO (Bonpace & Sestini, 2003, p. 135).

2 RESEARCH
2.5 NEPAL

2.5.6 School system

In the past, education in Nepal was based on home-schooling and gurukulas. In 1853, the first formal school was established. In 1951 the Nepalese democracy made it possible for more children to go to school. Before, school was mainly for the elite. The educational system is based on the Indian system. The enrolment has increased significantly from 1951 onwards. In 1951, there were 10,000 students in 300 schools and the literacy rate was 5% which increased to 63.9% in 2010 with 49,000 schools (Parajuli & Das, 2013). Public schools have received a lot of criticism on the quality of the education and social exclusion. Also the lack of infrastructure, centralized curriculum, textbooks, pedagogical strategies and poverty are factors that contribute to the poor education quality (Parajuli & Das, 2013).

There are two types of schools in Nepal, community schools and institutional schools. The former is funded by the government and receive government grands, the latter is self-funded. The structure of education in Nepal is as following. First, there is primary education with grades 1-5. Then there is lower secondary level education from grade 6 to 8. It is possible for students to start vocational education after this which leads to a two-year program and results in a Technical School Leaving Certificate. Or it is possible to go further into secondary level which covers grade 9 and 10. Students can continue into grade 11 and 12 which is called higher secondary level. These schools are mostly private though. Higher education cover bachelor's, master's and PhD level education. Children usually start grade 1 at the age of six. Examinations are given after grade 8 (District Level Examination), grade 10 (Secondary Education Examination) and grade 12 (the national School Leaving Certificate).

School years in Nepal run from late April to late February/early March with break in the summer and October. April is when the new calendar year starts. Since the summer is the monsoon season, many roads and bridges will be washed out by then. The major national holidays in Nepal take place around October.

2.6.1 *Challenge of Nepali schools*

Nepali schools face many challenges to remain open. They have especially been struggling after the earthquake in 2015. The school system has always been vulnerable. The literacy rate in Nepal is low and the drop-out rate of schools high. Schools in Nepal are unevenly distributed and, in some cases, hard to access. Many children have no access to education past primary level in remote areas. The earthquake in 2015 and the 2015 Nepal blockade (economic and humanitarian crisis since September 2015) have made it even worse. Schools were destroyed and the it has been tough for the country to keep remaining schools open. Schools are few and far in many rural areas, for example in Chitwan. Children have to travel far to get to school, but even then, they are most likely to drop out after grade 3 or 5 and forget what they have learned due to the lack of high schools and lack of funding to be send to higher studies in town schools (Khatiwada, 2015). The quality of the education system has received a lot of criticism due to lack of teachers, teaching material, tools and a proper curriculum. Also, funding can be a struggle. According to Lisa Lyons of ETC, it is unclear which schools have priority when it comes to funding. There are a lot of political issues involved.

The school as building faces many challenges as well in a multi-hazard context. School buildings in Nepal face seismic hazards and in some regions risks for flood and landslides. Windstorms and thunderstorms occur mainly in the southern part of Nepal and can blow off entire roofs of school buildings. More information about the specific climate-induced disasters can be found in section 2.4. Reconstruction of destroyed school buildings require a lot of time, money, effort and material. In some areas, mainly rural, it is hard to get resources for reconstruction.

2.6.2 *Guidelines for safe school design*

For the construction and reconstruction of schools after the earthquake, guidelines for structural safety in a multi-hazard context should be followed. I refer to section 2.3 and 2.4 for physical guidelines for coping with seismic and climate-induced hazards.

| *Type design*

The Department of Education (DOE) of the Nepalese government has, in collaboration with JICA and The Asian Development Bank, published guidelines for developing type designs for school buildings in Nepal in April 2016. This document presents the recommended procedures for the development of Type Designs for new school buildings in post-earthquake reconstruction of education facilities (Department of Education (DOE), Ministry of Education, 2016). Their philosophy is to use all resources efficiently, such as time and money. They strive for a balance between high functionality and cost effectiveness. The term 'Type Design' can be defined as the functional, architectural, structural and infrastructural design of standard new school buildings which covers around 80% of all common needs. Standardization and modularization will reduce cost and improve quality. Modularizations includes modular sizing of the buildings, the classrooms and building components such as doors, windows, building elements, fitting and fixtures.

| *Type design number & sizes*

The following table shows the recommended room size categories given in this document. The table shows that 1 m^2 per student for primary schools is recommended and 1.2 m^2 per secondary school student. RP room types refer to primary school rooms and RS to secondary school rooms.

Room type	Number of students			Grades	Area (m^2)
	Design	Min	Max		
RP1	12	5	15	1-5	12
RP2	25	20	30	1-5	25
RP3	40	30	45	1-5	40
RS1	25	20	35	6-12	35
RS2	40	30	45	6-12	45
RS3	60	40	70	6-12	70

Table 10: Classroom size categories (Department of Education (DOE), Ministry of Education, 2016, p. 11)

Schools can be categorized by number of students. The following table shows an overview of this categorization and their requirements. However, Higher Secondary Schools (HSS) with over 900 students may be designed as individual cases with additional requirements for specific needs other than given in this overview. The 'Room combinations' uses the room type codes given in the previous table 10.

School type	Type code	Design number of students	Grade	Rooms	Room combinations	Student capacity
Primary 1	TD-PS1	40	5	4	4RP1	48
Primary 2	TD-PS2	90	5	4	4RP2	100
Lower secondary 1	TD-LS1	140	8	8	8RS1	200
Lower secondary 2	TD-LS2	220	8	8	4RS1+2RS2+2RS3	300
Secondary 1	TD-SS1	160	10	10	6RS1+2RS2+2RS3	350
Secondary 2	TD-SS2	300	10	10	4RS1+3RS2+3RS3	400
Secondary 3	TD-SS3	480	10	14	6RS1+4RS2+4RS3	550
Higher secondary 1	TD-HS1	400	12	12	4RS1+4RS2+4RS3	500
Higher secondary 2	TD-HS2	600	12	16	6RS1+5RS2+5RS3	650

Table 11: School type and room size combination (Department of Education (DOE), Ministry of Education, 2016, p. 12)

The DOE set up an overview of the overall facilities that needs to be provided at the different school types. These facilities are needed in addition to the basic classrooms. See table 12.

The first aid kit codes mean as following:

N1: A cupboard with first aid kits to be provided in the library

N2: A cupboard with first aid kits to be provided in the library and labs

N3: A cupboard with first aid kits to be provided in labs, a separate counter with a nurse is preferred

Larger regional schools should also be considered as emergency facility to provide resources as immediate response to natural disasters. More about this can be read in the next section, 2.6.3.

School type	Primary		Lower secondary		Secondary			Higher secondary	
Type code	TD-PS1	TD-PS2	TD-LS1	TD-LS2	TD-SS1	TD-SS2	TD-SS3	TD-HS1	TD-HS2
Grade	5	5	8	8	10	10	10	12	12
Design student capacity	40	90	140	220	160	300	480	400	600
Floors	Depends on geographical location (rural, semi-rural: 2 stories. Urban: 3 stories)								
Labs and other facilities (m^2)									
Library	30	40	50	60	50	70	90	90	120
Music	30	40	30	60	30	50	60	60	80
Drawing	30	40	30	60	30	50	60	60	80
Computer	30	40	30	60	30	60	90	90	120
Physics	-	-	40	60	40	50	60	60	90
Chemistry	-	-	40	60	40	50	60	60	90
Biology	-	-	40	60	40	50	60	60	90
Multi-purpose	-	-	-	-	80	100	120	120	150
Offices area (m^2)									
Head master	20	25	15	15	20	20	20	25	25
Teachers	20	25	30	40	40	50	60	50	90
Admin	-	-	-	-	-	15	15	15	25
Store	20	25	20	20	30	40	40	40	50
Kitchen	20	25	20	30	30	30	40	40	50
Boy toilet facilities									
Urinals	1	2	3	5	4	7	12	10	15
WC	1	1	1	2	2	3	6	5	7
Wash basins	1	1	1	1	1	2	4	3	5
Girls toilet facilities									
WC	1	1	2	4	3	6	9	8	12
Wash basins	1	1	1	2	2	3	6	5	7
Other facilities									
Water fountains	1	1	2	4	3	6	9	8	12
First aid/clinic	N1	N1	N2	N2	N2	N3	N3	N3	N3
Circulation									
Stairs width (m)	-	-	2	2-2.5	2-2.5	2-2.5	2-2.5	2-2.5	2-2.5
Number of stairways	-	-	1	2	2	2	3	3	4
Single loaded corridor (m)	1.8	1.8-2.5	1.8-2.5	1.8-2.5	1.8-3	1.8-3	1.8-3	1.8-3	1.8-3
Double loaded corridor (m)	-	-	2-3	2-3	2.4-3.5	2.4-3.5	2.4-3.5	2.4-3.5	2.4-3.5
Open assembly space (m^2)	60	135	210	330	240	450	720	600	900

Table 12: Type design requirements for various schools (Department of Education (DOE), Ministry of Education, 2016, p. 13)

| *Program considerations*

The following sections will discuss considerations that need to be taken for the specific facilities. Also, disaster resilience and environmental sustainability will be discussed.

I have summarized the guidelines given by the DOE in their Type Design publication in the following points for each function (Department of Education (DOE), Ministry of Education, 2016).

| *Classroom size and space*

- Width : length = 1 : 1 – 1 : 2
- Student-teacher interaction
- Viewing distance 2- 7 m
- Exit corridor minimum 1.5 m
- Ceiling height minimum 2.75 in hills/mountains and 3.6 m in Terai
- All rooms visible from outside
- School size based on student number
- Multi-functional / flexibility
- Direct access to outdoor space
- Doors easy to open/close. Provide vision panels
- All doors open outwards to nearest exit
- Minimum area of opening for natural light is 1/10 of room area
- North oriented openings preferred

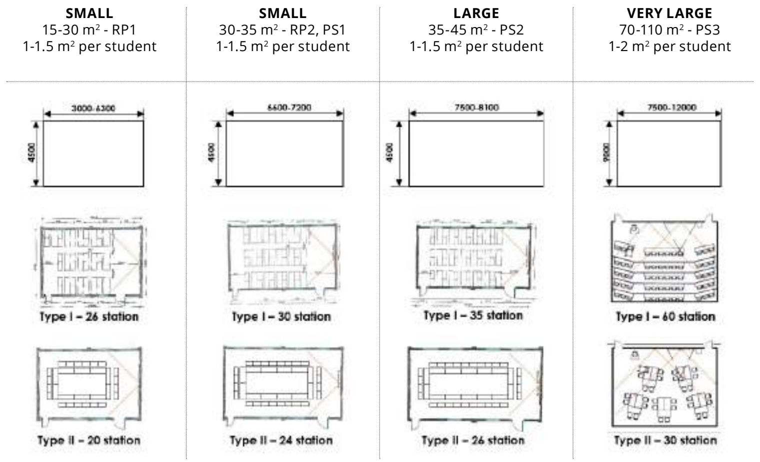


Figure 68: Classroom standards (Department of Education (DOE), Ministry of Education, 2016, p. 17)

2 RESEARCH
2.6 SCHOOL DESIGN

| *Access*

- Equal access to all
- Emergency and fire exit
- Stairs width of minimal 2 m
- Maximum distance to exit from any point on single level is 30 m

| *Library*

- Mandatory for schools with over 500 students
- Should be able to host 10% of all students at any time, 2.4 m^2 per student
- Flexible layout
- Ceiling height minimum 2.75 m in hills/mountains and 3.6 in Terai
- Separate space for storing, reserving and repairing books

| *Laboratory*

- Science lab 4 m^2 per student, computer lab 2.4 m^2 per student
- 3 types: fixed layout with services in perimeter, fixed benches with services or island layout
- Demo table for teacher and means for visual communication
- Space for sensitive apparatus
- Firefighting equipment, eye and face spray and first aid kit

| *School administration*

- General office next to main entrance
- Principle office near general office
- Acoustic separation between offices and corridor or other rooms

| *Staff room*

- Near administration area/reception/general office
- Overlook playing area

| *Sanitary facilities*

- Boys and girls separate
- Naturally ventilated
- Lobbies to toilets also naturally ventilated
- Toilets for disabled
- In large schools, separate toilet for staff and visitors
- Non-slip tile floor
- Doors easy to open/close, undercut for air movement
- Septic tank at least 30 m away from ground water

| *Circulation and social spaces*

- Clear internal signage
- All ground floor areas should be accessible to all
- Use of natural light, space and colour
- Durable floor and wall finishes
- Draught-proof lobbies
- Maximum distance to exit from any point on single level is 30 m
- Maximum distance to door from any point in passage is 20 m

| *Site infrastructure considerations*

- Green spaces around school
- Proper playing ground
- Site selection considering soil condition, seismic zone, flood risk, wind risk etc.
- Hygienic sanitation
- Water should be tested against arsenic content in case of underground water supply
- Prominent entrance
- Good access for all from parking area
- Optional: Early childcare facility nearby for younger siblings
- Optional: Emergency shelter with proper equipment
- Optional: linked to early warning system

| *Space diagrams*

The publication has provided three space diagrams that show the distribution and the relation between the various facilities within a school building. The space diagrams are provided for Primary School with < 100 students, Lower Secondary and Secondary School with < 480 students and Higher Secondary School with students up to 650.

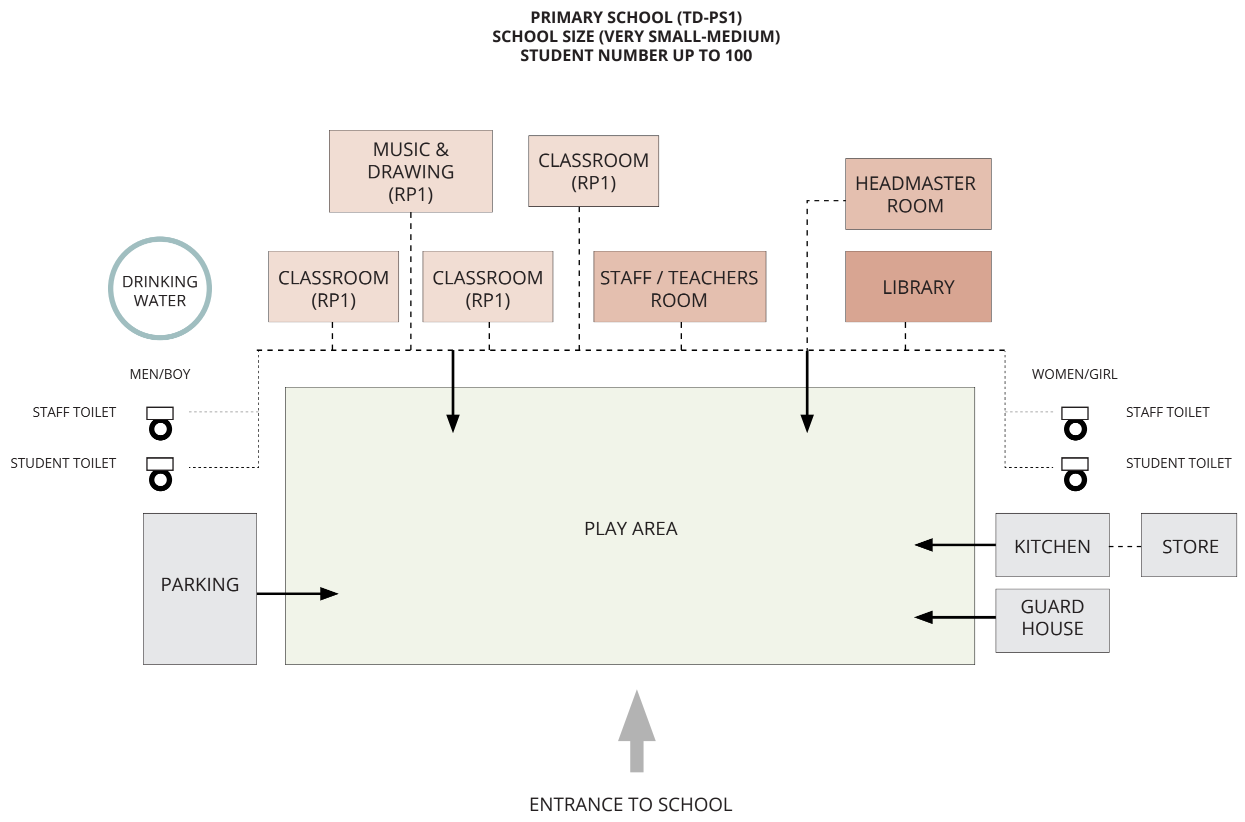


Figure 69: Space diagram Primary School (Redrawn from: Department of Education (DOE), Ministry of Education, 2016, p. 40)

LOWER SECONDARY AND SECONDARY SCHOOL (TD-LS1, TD-LS2, TD-SS1, TD-SS2 & TD-SS3)
SCHOOL SIZE (SMALL-LARGE)
STUDENT NUMBER UP TO 480

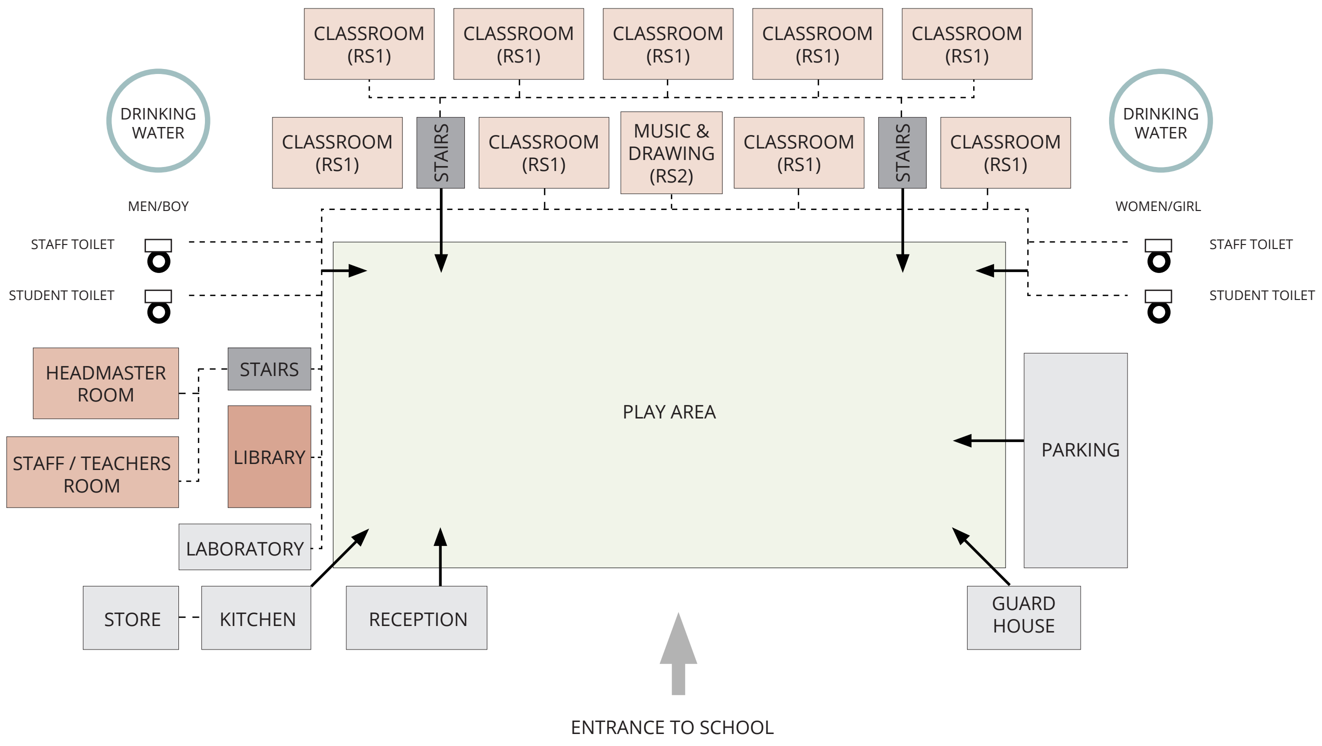


Figure 70: Space diagram (Lower) Secondary School (Redrawn from: Department of Education (DOE), Ministry of Education, 2016, p. 41)

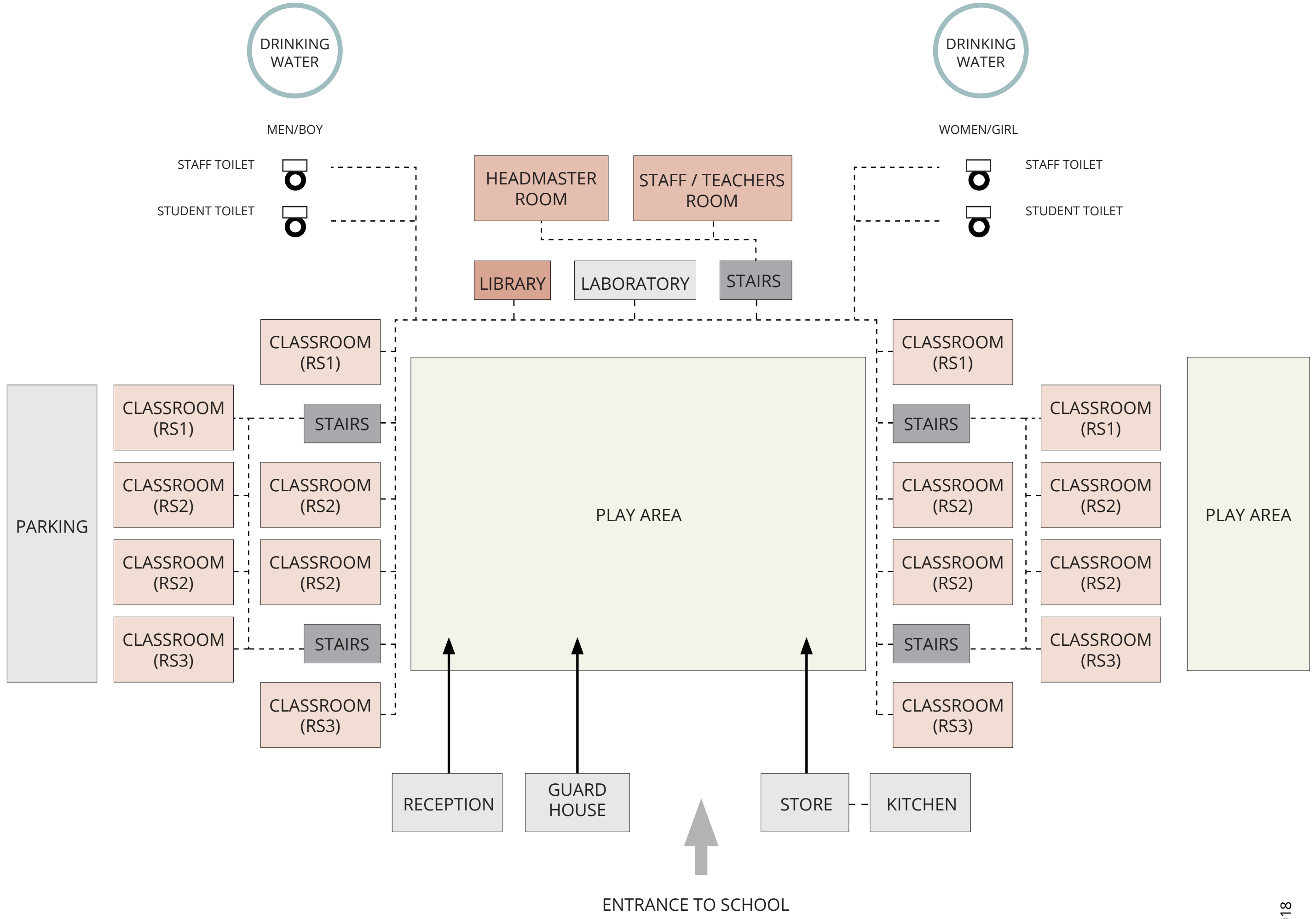


Figure 71: Space diagram Higher Secondary School (Redrawn from: Department of Education (DOE), Ministry of Education, 2016, p. 42)

| *DR and ES considerations*

The DOE also provides considerations for disaster resilience (DR) and environmental sustainability (ES). Considerations for disaster resilience have already been discussed in 2.3 with guidelines for seismic design and 2.4 for climate-induced hazards. Regarding environmental sustainability, the following considerations are important:

Trees should be left untouched as much as possible for soil stabilisation and to reduce the extent of damage to land vegetation and the soil at the site. It is also recommended to plant additional trees and other vegetation around the building for shade. Trees are preferred over high walls. Trees and proper storm water drainage will also prevent soil erosion. The building should follow the existing land profile as much as possible and any natural waterways should be left the way they are (Department of Education (DOE), Ministry of Education, 2016, p. 23).

To conserve energy, the orientation of the building and its openings should be designed properly. The orientation of buildings has influence on the natural light, shade and natural cooling and heating of the buildings. Another important aspect for energy conservation is insulation of building materials. Energy can also be conversed by reusing waste and use it for example as compost in school gardens. Choosing local materials and material with low embodied energy for construction of school buildings will save transportation efforts and hereby energy as well. If funding permits, solar PV cells on the roof can be used to generate energy. The roof can also be used to harvest rain water. If possible, waste-water should be recycled (Department of Education (DOE), Ministry of Education, 2016, p. 24).

Material can be conserved by an efficient design which is modularized and standardized. Reused and recycled materials will contribute even more to material conservation. Also, proper construction practices can save material during construction. In Nepal, it is important to choose materials from sustainable sources since some areas are struggling with deforestation (Department of Education (DOE), Ministry of Education, 2016, p. 25).

The DOE also suggests construction materials in this publication. Materials that are suitable for the present context and are present in Nepal. However, the choice of material is highly dependent on availability and transportability in some regions and also the available budget. The following table shows the construction materials recommended by the DOE.

Building element	Material
Foundation	Brick or stone on cement, concrete reinforced footing
Wall	Brick or stone on cement, interlocking stabilised soil block, UPVC, ferrocement, bamboo-wire mesh-plaster, fibre reinforced composite, cement board
Floor	RCC slab, wooden, precast system, marble, tiles, IPC
Door/windows	Timber, aluminium, UPVC, galvanised iron
Roof	CGI sheet on wooden joists or steel truss, RCC slab
Staircase	RCC, timber, steel

Table 13: Recommended construction materials (Department of Education (DOE), Ministry of Education, 2016, p. 26)

2.6.3 Role of school in resilient community

Larger schools that are located on critical spots in a region can function as community centres that serve the entire community by providing various facilities and services. In that way, school buildings can be used more efficiently and can serve more people throughout the year. Providing these additional facilities such as emergency equipment, healthcare resources and extracurricular knowledge provision will contribute to a resilient future for the community. Various optional additional functions will be further discussed.

| *Emergency centre*

The school can function as an emergency centre with equipment and facilities that provide immediate response to natural disasters. Rescue tools such as shovels, ropes, firefighting equipment and flashlights et cetera are recommended in a place which is easily accessible. Shelter can be ensured for all people living in the community during crisis if beds and other necessities are provided. In that case, additional toilets, more than the number of students required should be installed and resources like blankets, emergency food and drinking water should be available.

| *Health centre*

By providing beds and other equipment, the building can also act as health centre in post-disaster situations. Injured people can be brought to this safe shelter where they can be treated. In this case, first aid kits and other medical equipment such as medicine and sterile tools and bandages should be provided.

| *Knowledge centre*

The school can also educate adults by teaching them how to improve their houses to sustain in a multi-hazard context. Some parents keep their children from school, so they can work on their farmland. Providing lectures and workshops for both students and parents about practical matters like agriculture and craftsmanship can help families to improve their knowledge and skills in various fields and will motivate parents to send their children to school.

| *Leisure centre*

Schools have limited opening hours. To use the building efficiently, it is possible to provide after school activities for the students. Also, during summer breaks, the school can still function as a leisure centre where children, students and parents can meet and organize activities together.

Photo: Lydia Koedoot 2018

During the Gorkha Earthquake in 2015 and its aftershocks, many schools have been damaged or collapsed. Reconstruction of schools is still in progress. The lack of funding, resources, engineering skills and knowledge and accessibility make it difficult for a lot of schools to reopen.

Lisa Lyons, US director of ETC Nepal, has helped me to get in contact with people in Nepal. Her colleague, Mr. Laxmi Basukala, has contacted people in his network to help me find a location for my project and found a valuable connection, Mr. Dinesh Thapa. Mr. Thapa is a teacher at Kitini Higher Secondary School in Godavari. The school has been hit by the earthquake and they are looking to build new facilities and become one of the leading model schools in the region.

I visited Nepal from the 10th to the 24th of March, 2018 to visit the school, experience the context and develop a design proposal for the construction of the new facilities.

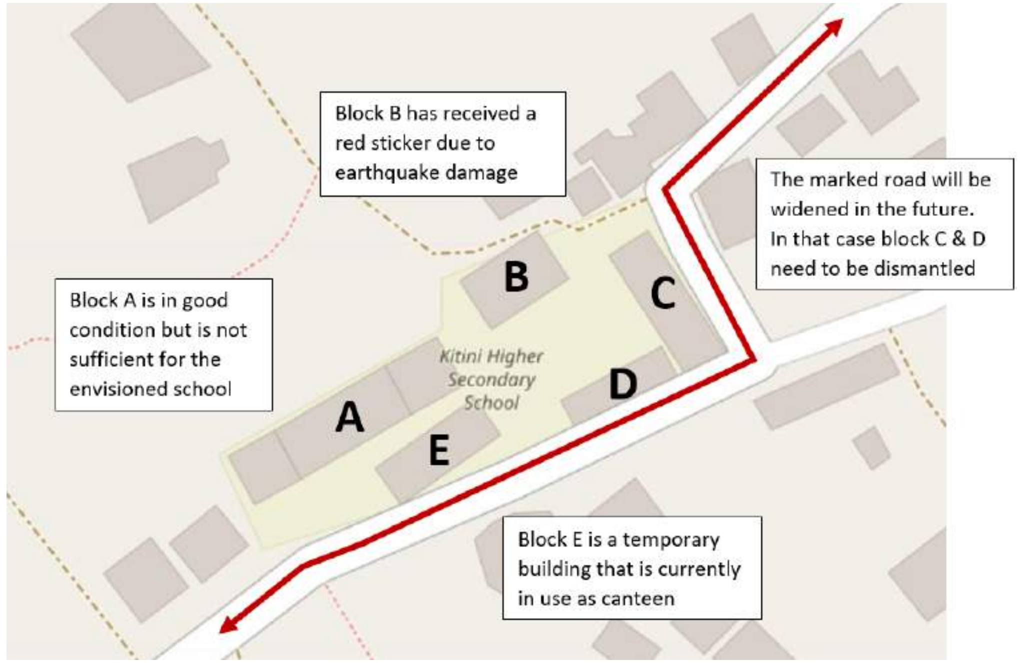
Kitini High Secondary School is a school which covers grade 1 to 12. The existing school buildings are not sufficient for the envisioned model school. I conducted a gap analysis to show the gap between what the school has and what the school needs. The full program with all facilities divided in groups is shown at page 84-85.

Function	Existing m²	Needed m²	gap m²
Classrooms	427	2015	1588
Labs	75	180	105
Offices	107	274	167
Services	78	1765	1687
Sanitary	60	90	30

Computer lab	0	36	36
Language lab	0	36	36
In charge office	0	48-76	48
Meeting room	0	18	18
Accountancy	0	20	20
Management committee room	0	24	24
Counselling room	0	15	15
In charge office	0	12-19	12
Meeting room	0	18	18
Accountancy	0	20	20
Management committee room	0	24	24
Counselling room	0	15	15
Emergency rooms	0	20-30	20
Canteen	0	40	40
Health centre	0	30	30
Conference hall	0	170	170
Museum	0	20	20
Hostel	0	475	475
Special toilets	0	15	15

TOTAL EXISTING	TOTAL NEEDED	TOTAL GAP
747	5380	4633

EXISTING SITUATION



BLOCK A

BLOCK B

BLOCK C

BLOCK D

| Grade 1-2 (ECD)

NUMBER	FUNCTION
6	Classrooms
1	Mini garden
1	Play area
3	Toilets
3	Water taps
1	Sleeping emergency room
1	Library
1	Game area
1	In charge room
1	Teachers room

| Grade 3-6

NUMBER	FUNCTION
8	Classrooms
1	Garden
1	Play corner
3	Toilets + water taps
1	Sleeping emergency room
1	Library (incl. library grade 7-9)
1	In charge room
1	Teachers room

| Grade 7-9

NUMBER	FUNCTION
9	Classrooms
1	Garden
1	Play corner
3	Toilets + water taps
1	Sleeping emergency room
1	In charge room
1	Teachers room
1	Library

| Grade 10-12

NUMBER	FUNCTION
15	Classrooms
1	Garden
1	Play corner
3	Toilets + water taps
1	Sleeping emergency room
1	In charge room
1	Teachers room
1	Library

| Services

NUMBER	FUNCTION
1	Open library with reading area
1	Canteen
1	Counselling room
2	Special toilets
1	Health centre
1	Conference hall
1	Management committee room
1	Accountancy office
1	Computer lab
1	Language lab
1	Physics lab
1	Chemistry lab
1	Biology lab
1	Office area
1	Vice principal office
1	Meeting room
1	Waiting area

| Hostels

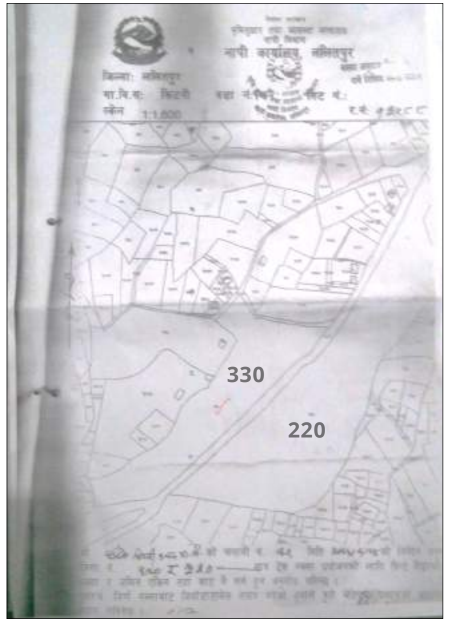
NUMBER	FUNCTION
25	Bedrooms
3	Bathrooms
1	Warden
1	Emergency room
1	Entertainment room

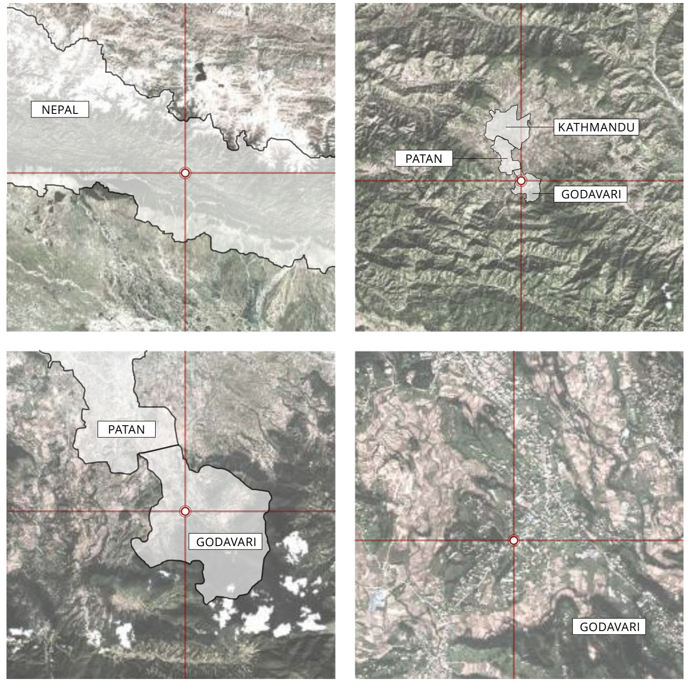
The school provided me with a list of facilities that they envisioned for the new facilities. The school is a higher secondary level school that educates children from grade 1 to 12. Grade 1 and 2, also called ECD, will be in a separate building complex with their own courtyard while grade 3-12 will share the same play and assembly area. Also, a shared service block needs to be built with communal facilities like a library and a canteen.
After a sketch study, I found out that having four sections is the most optimal organization considering the shape of the plot and the facilities that are needed per grade. One section for ECD, one section for grade 3 to 9, a section for shared service facilities and a section for grade 10 to 12.

The school which I will work with is located in Lalitpur, Godavari, Nepal. Lalitpur is one of the districts in Kathmandu Valley and is located south of the Kathmandu metropolitan area.

The community in which is the school is situated is located along the road that connects Patan and Godavari (see infrastructure map on page 89). The school, which is funded by the government, owns land that will be used for the construction of the new educational facilities and two hostels. The location of the new facilities will be approximately 300 metres southwest of the existing school location.

I received the following land register map to work with:

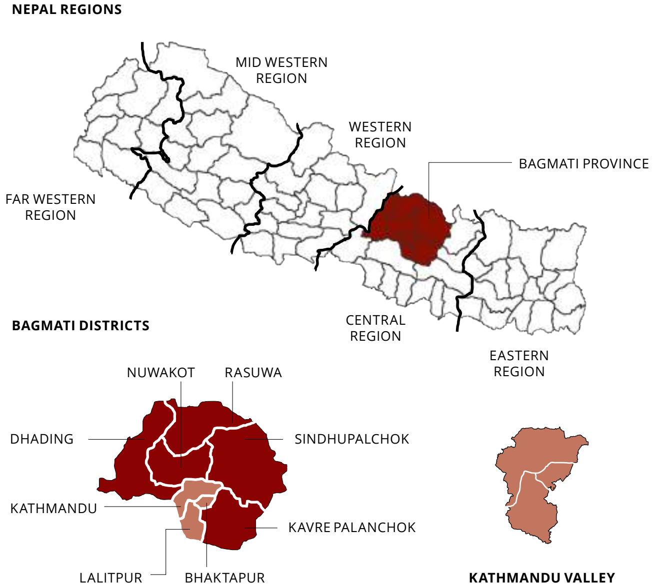




Plot 330 and 220 are available property of the school. The educational buildings are assigned to plot 330 and the hostels to 220. The tentative design phase covers proposals for both plots. I focused only on the educational buildings on plot 330 in the final design phase.

3.3.1 Geography

Kathmandu Valley



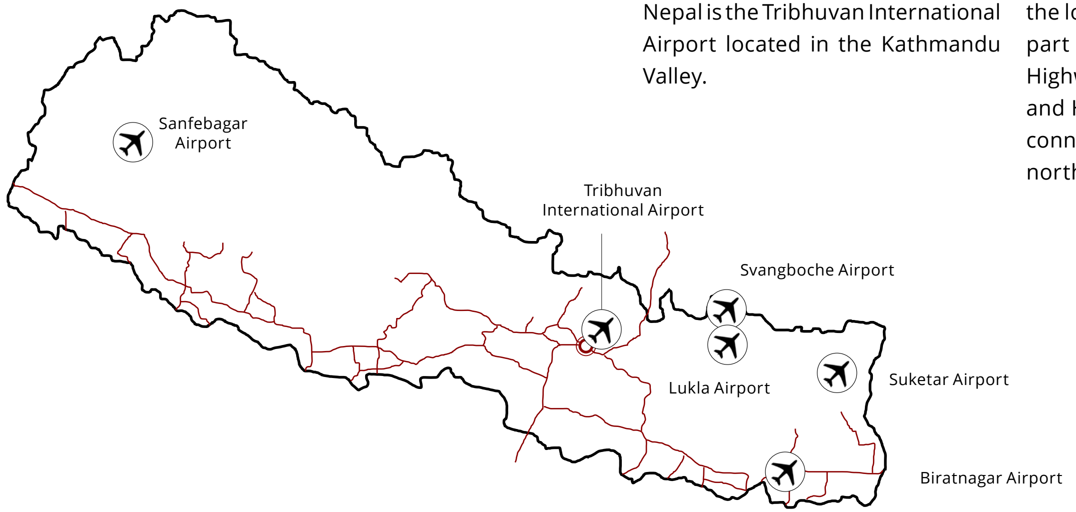
The project location is on the border of the Kathmandu Valley. The Kathmandu Valley has been a main crossroad of ancient civilizations of Asia and hosts many cultural, historical and religious monuments. The capital was Bhaktapur until the 15th century. The valley is the most populated and developed area in Nepal. It is a economic, political, cultural and tourist hub which has a rich culture of street festivals.

The valley has the status of UNESCO World Heritage Site since 1979.

The Kathmandu Valley is shaped like a bowl with the lowest altitude at 1,425 metres above sea level. The valley is surrounded by several mountain ranges. The Bagmati river is the main river running through the valley.

The valley consists of three districts: the Kathmandu District, Lalitpur District and Bhaktapur District. The districts consist of several municipalities.

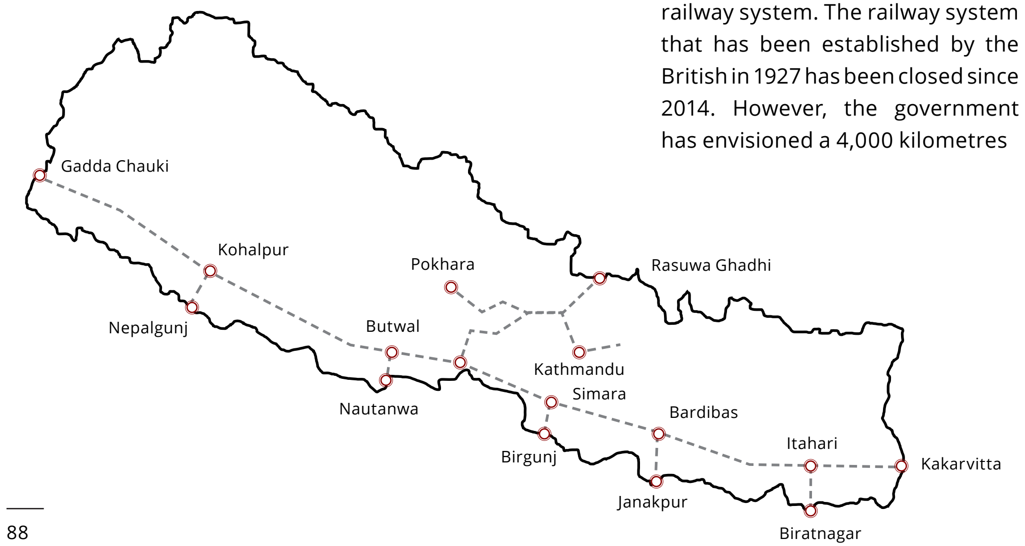
3.3.2 Infrastructure



Main transport infrastructure

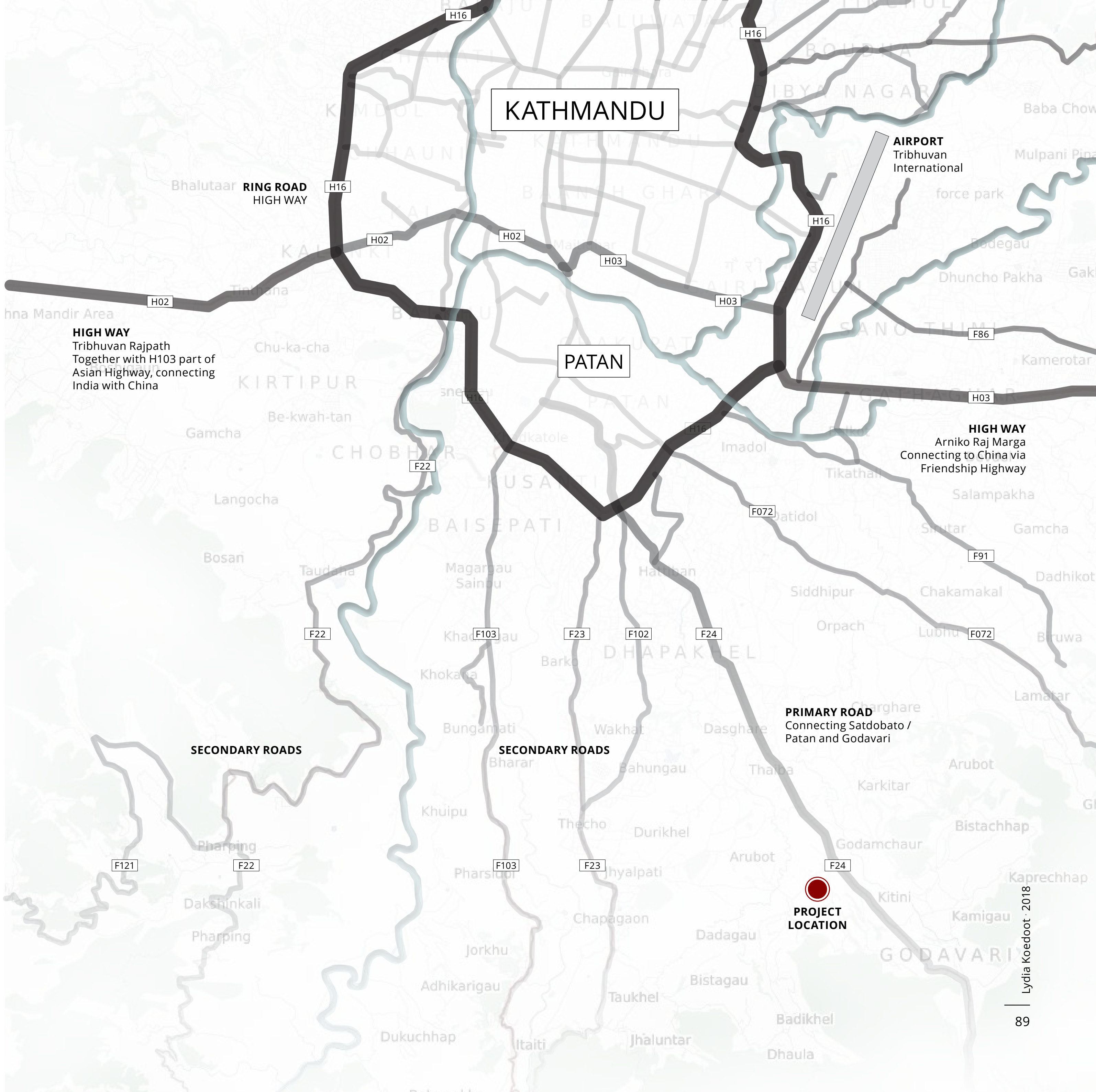
The only international airport of Nepal is the Tribhuvan International Airport located in the Kathmandu Valley.

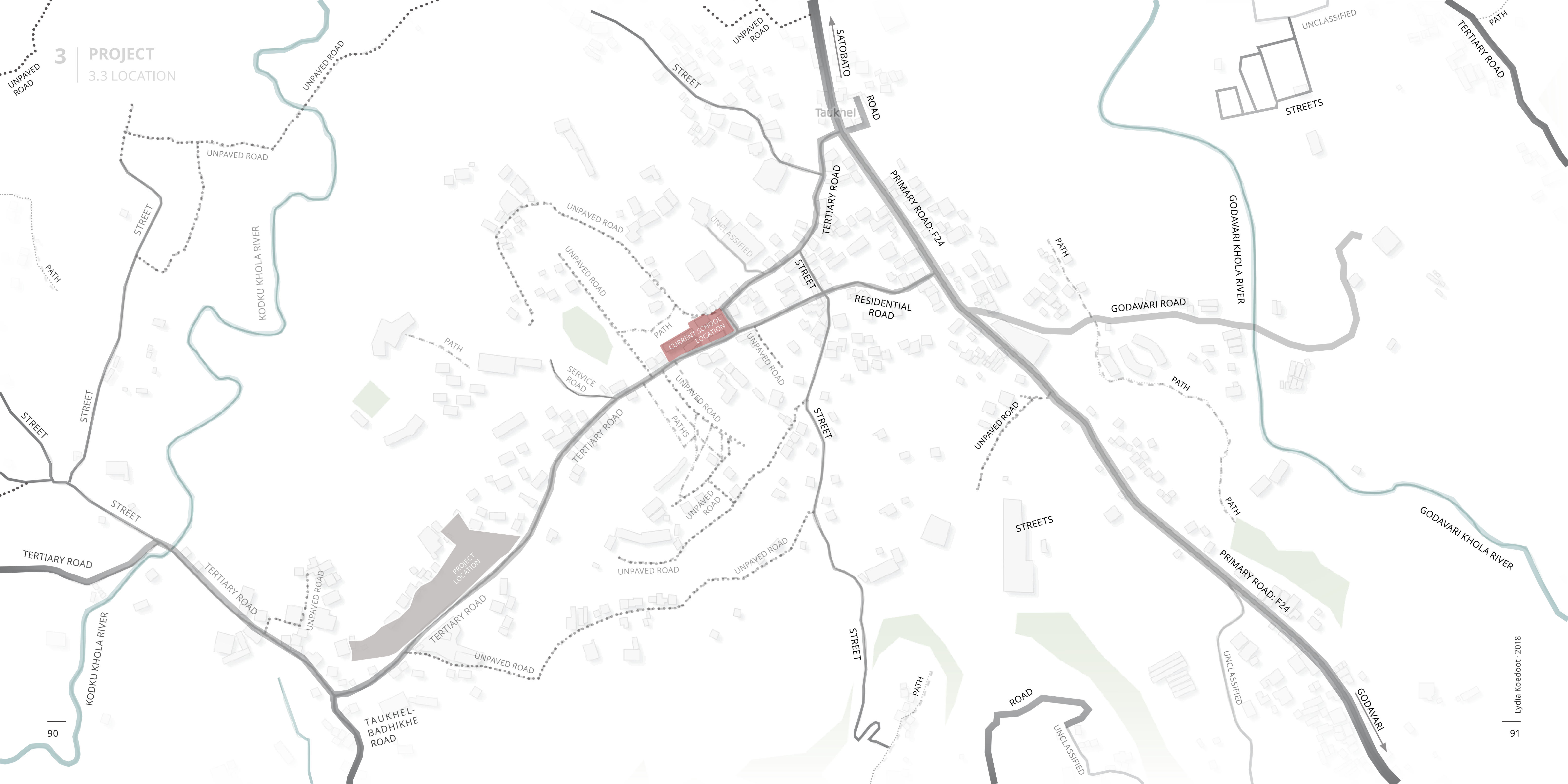
Roads are mainly constructed in the lower flat plains in the southern part of Nepal. Only the Asian Highway, also known as the H102 and H103 in the Kathmandu Valley, connects China and India from north to south through Nepal.



Projected rail way system

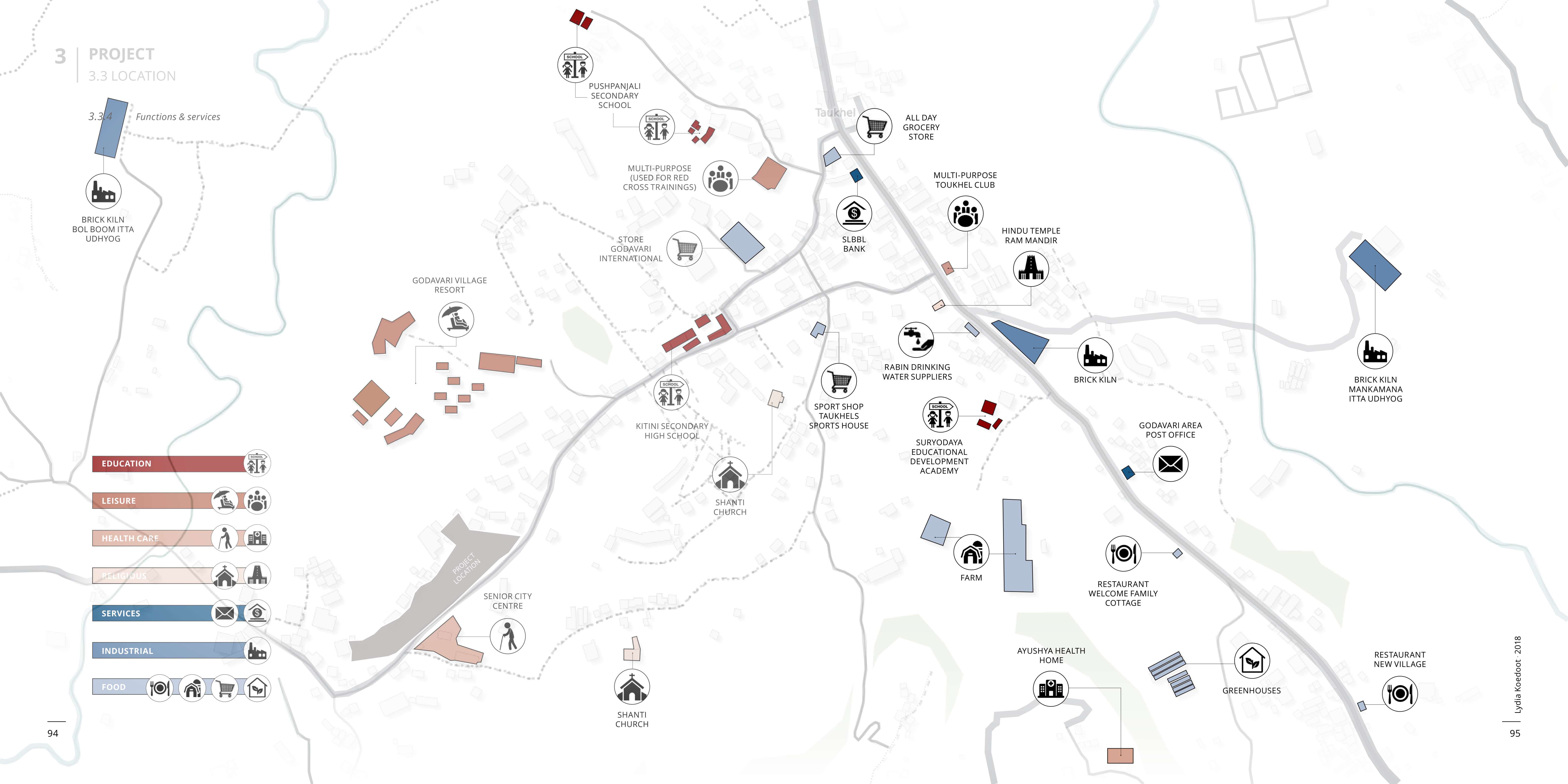
Currently, Nepal has no functioning railway system. The railway system that has been established by the British in 1927 has been closed since 2014. However, the government has envisioned a 4,000 kilometres railway as part of their 20-year railways development plan. This railway system will connect the country east to west and also the northern part of Tibet in China to the Ganga in India.

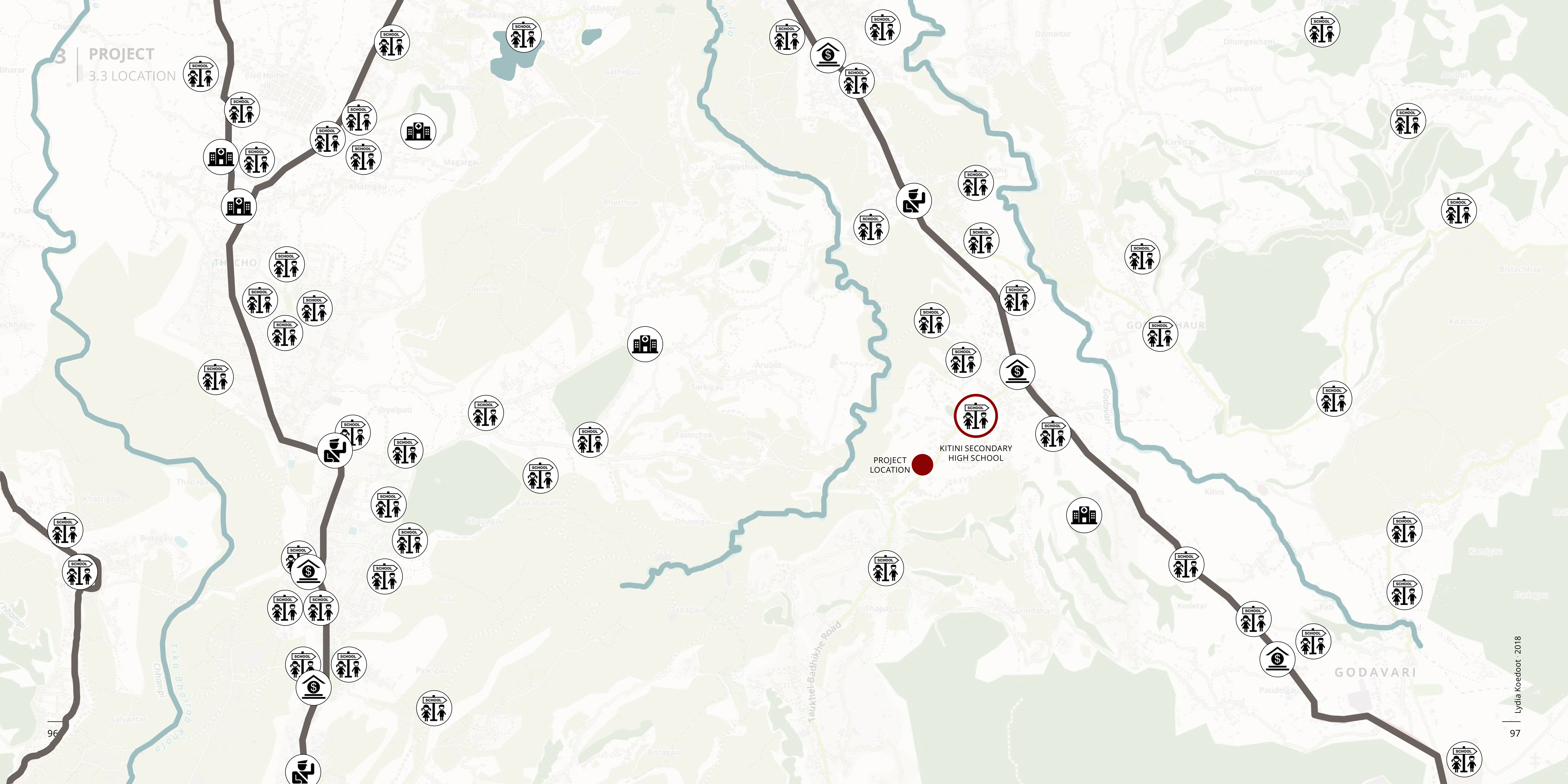



UNPAVED ROAD
UNPAVED ROAD
STREET
UNPAVED ROAD
SATOBATO
ROAD
Taukhel
UNCLASSIFIED
STREETS
PATH
TERTIARY ROAD
PRIMARY ROAD: F24
TERTIARY ROAD
UNPAVED ROAD
UNCLASSIFIED
STREET
UNPAVED ROAD
KODKU KHOLA RIVER
PATH
STREET
GODAVARI KHOLA RIVER
RESIDENTIAL ROAD
GODAVARI ROAD
PATH
CURRENT SCHOOL LOCATION
PATH
SERVICE ROAD
UNPAVED ROAD
UNPAVED ROAD
STREET
STREET
PATH
UNPAVED ROAD
PATHS
TERTIARY ROAD
STREET
STREET
UNPAVED ROAD
STREETS
PATH
GODAVARI KHOLA RIVER
TERTIARY ROAD
UNPAVED ROAD
UNPAVED ROAD
PROJECT LOCATION
TERTIARY ROAD
UNPAVED ROAD
PRIMARY ROAD: F24
TERTIARY ROAD
UNPAVED ROAD
STREET
KODKU KHOLA RIVER
PATH
ROAD
UNCLASSIFIED
UNCLASSIFIED
GODAVARI
TAUKHEL-BADHIKHE ROAD

3.3.3 Elevation

3.3.4 *Functions & services*




PROJECT
LOCATION
KITINI SECONDARY
HIGH SCHOOL
GODAVARI
Taukhel-Badhikhel Road

3.3 CHALLENGES

There will be various challenges within the project and during the process of the project. When it comes to the project itself, there are restrictions that need to be considered. First of all, the budget. Many schools struggle with financial support when it comes to reconstruction. Not only financial sources are scarce, there are also limitations regarding construction materials. Some materials are hard to transport to certain regions. In some cases, there is also a lack of construction skills and knowledge of proper engineering. The aim is to design a proper resilient facility which is affordable, and which makes use of local materials and construction practices.

Also, the specific design location has its challenges. The project site is a narrow long-stretched area which is quite restricting when locating the building blocks. The site is also located on a slope with an approximate height difference of 28 metres from the north down to the southwest corner. A buffer zone of approximately 6 metres from the plot borders should be considered since neighbours might have extended their property on our project site.

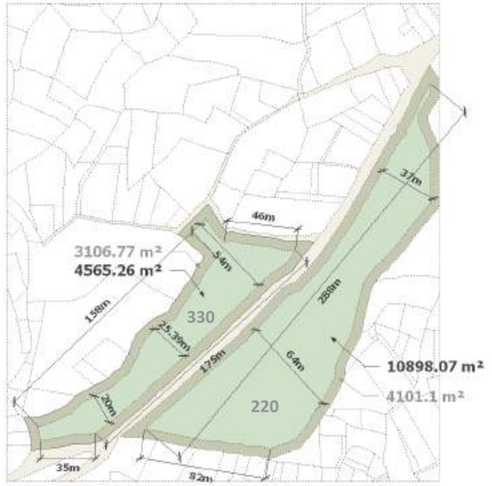
There are not only challenges within the scope of the project, but also during the design process itself. There is a lack of useful material and information online. Also, communication with people in Nepal can be quite challenging due to the language barrier, culture difference and distance. Traveling to Nepal was needed to experience the context myself, connect and work with the local people and develop the first ideas for this project.

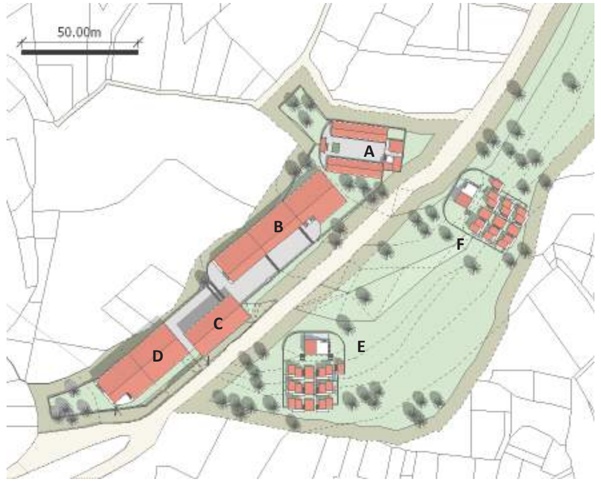
4.1.1 Introduction & site visit

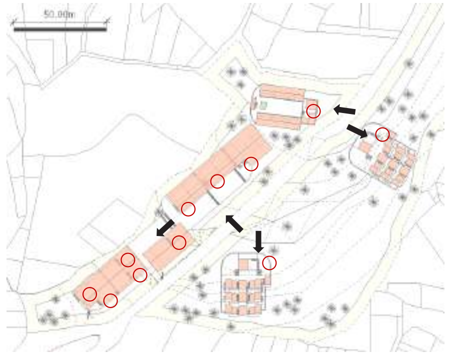
The tentative design phase covers the first half of this design project which is the design proposal that we submitted to the Department of Education in Nepal. The school design in this proposal is developed according to the norms and standards set by the government for model schools. I developed this proposal during my stay in Nepal. I was there from the 10th to the 24th of March and worked with the Proposal Development Committee of Kitini HSS on the model school proposal. I was responsible for developing a design proposal for the new physical structures. We submitted the proposal at the 22nd of March, 2018. My work has been approved before submission by a local engineering firm, B.R. Engineering Consultancy, which also conducted a cost estimation of the proposal.

4 | RESULTS
4.1 PHASE 1: TENTATIVE DESIGN

4.1.2 Urban planning







4.1.3 Architectural design

BLOCK A

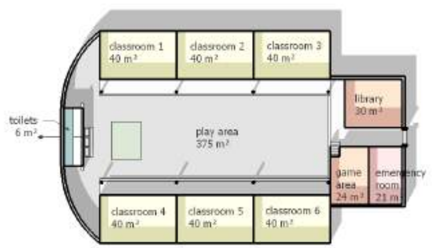
Ground floor: Grade 1-2

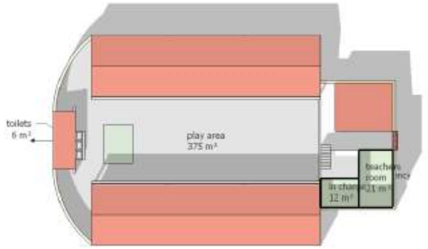
Nr	FUNCTION	PERSONS	M²	L x B	TOTAL M²	COST ESTIMATION (Rs)
6	Classrooms	40-45	40	5 x 8	240	77,47,200.00
1	Mini garden		12	4 x 3	12	-
1	Play area		375	-	375	-
3	Toilets		12	6 x 2	12	3,87,360.00
3	Water taps		3	1 x 3	3	1,05,000.00
1	Sleeping emergency room	3-4	21	3,5 x 6	21	9,03,840.00
1	Library		30	5 x 6	30	9,68,400.00
1	Game area		24	6 x 4	24	10,32,960.00

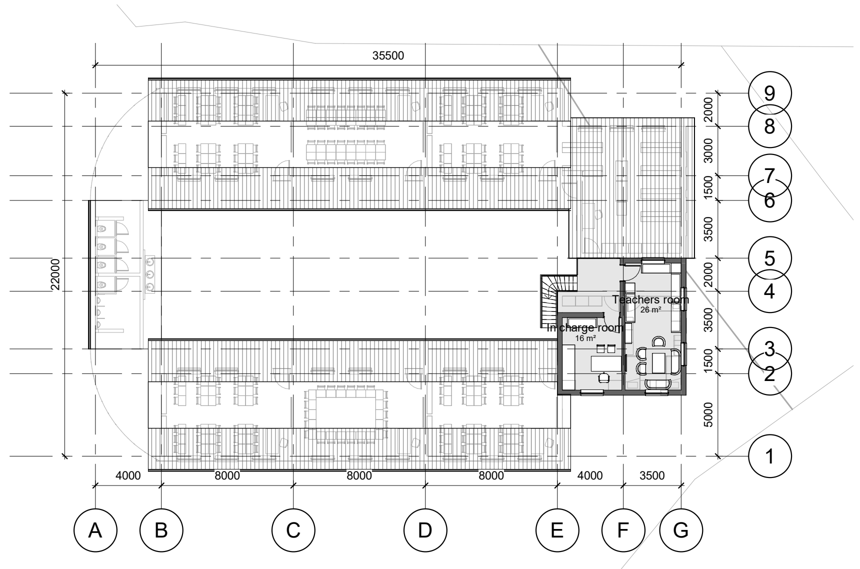
First floor: Grade 1-2

1	In charge room		12	4 x 3	12	3,87,360.00
1	Teachers room		21	3,5 x 6	21	6,77,880.00

BUILDING FOOTPRINT: 702 m²
TOTAL BUILDING COSTS: 1,22,10,000.00 Rs







BLOCK B

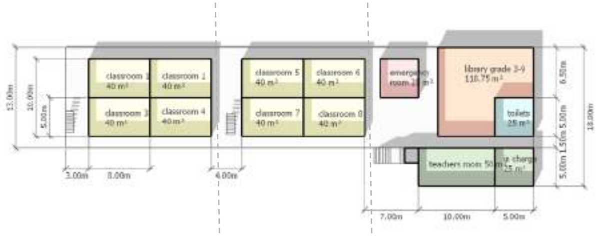
Ground floor: Grade 3-6

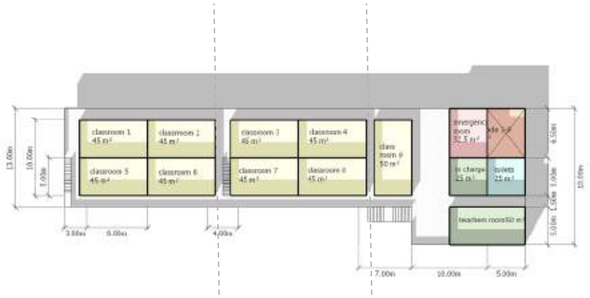
Nr	FUNCTION	PERSONS	M²	L x B	TOTAL M²	COST ESTIMATION (Rs)
8	Classrooms	40-45	40	5 x 8	320	1,37,72,800.00
1	Garden		-	-	-	-
1	Play corner		-	-	-	-
3	Toilets + water taps		25	5 x 5	25	10,76,000.00
1	Sleeping emergency room	3-4	25	5 x 5	25	10,76,000.00
1	Library (incl. library grade 7-9)		118,75	-	118,75	51,11,000.00
1	In charge room		25	5 x 5	25	10,76,000.00
1	Teachers room		50	10 x 5	50	21,52,000.00

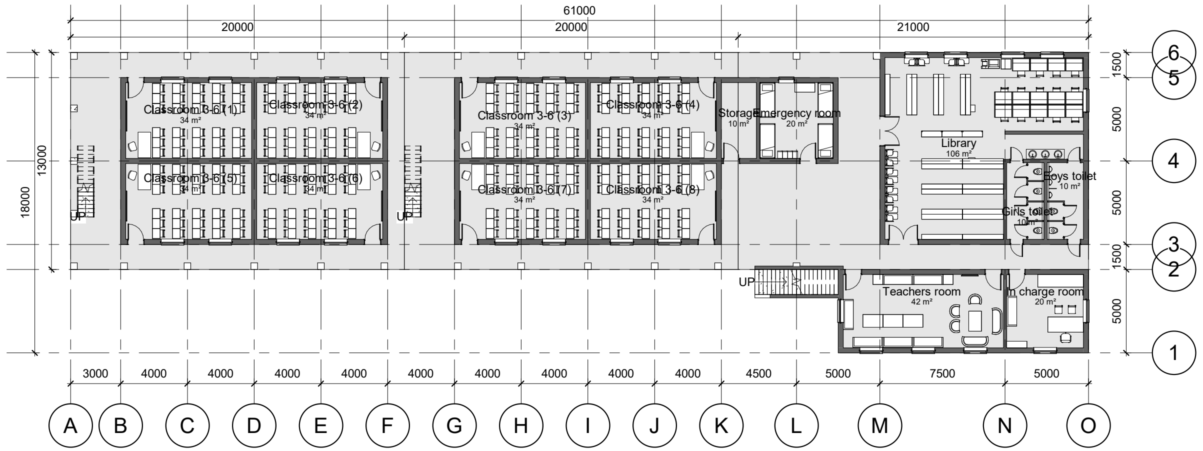
First floor: Grade 7-9

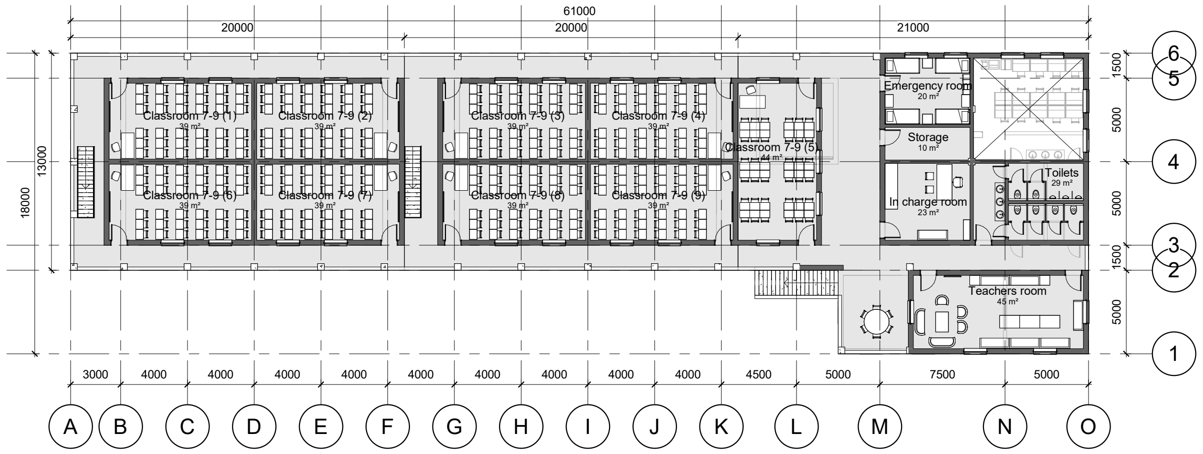
Nr	FUNCTION	PERSONS	M²	L x B	TOTAL M²	COST ESTIMATION (Rs)
9	Classrooms	40-45	45 (50)	5 x 9 (10)	410	1,32,34,800.00
1	Garden		-	-	-	-
1	Play corner		-	-	-	-
3	Toilets + water taps		25	5 x 5	25	8,07,000.00
1	Sleeping emergency room	3-4	32,5	6,5 x 5	32,5	10,49,800.00
1	In charge room		25	5 x 5	25	8,07,000.00
1	Teachers room		50	5 x 10	50	17,14,000.00

BUILDING FOOTPRINT: **879,6 m²**
TOTAL BUILDING COSTS: **4,17,76,400.00 Rs**









BLOCK C

Ground floor

Nr	FUNCTION	PERSONS	M²	L x B	TOTAL M²	COST ESTIMATION (Rs)
1	Open library with reading area		150	10 x 15	150	64,56,000.00
1	Canteen		40,5	9 x 4,5	40,5	17,43,120.00
1	Counselling room		14,63	4,5 x 3,25	14,63	6,29,675.00
2	Special toilets		14,63	4,5 x 3,25	14,63	6,29,675.00
1	Health centre		29,25	4,5 x 6,5	29,25	12,58,920.00

First floor

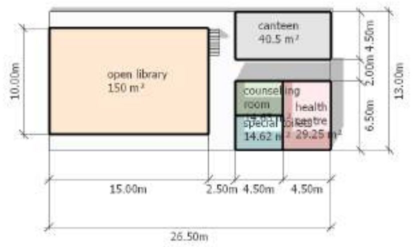
1	Conference hall		171	-	171	73,59,840.00
1	Management committee room		24	4 x 6	24	10,32,960.00
1	Accountancy office		20	5 x 4	20	8,60,800.00
1	Computer lab	30	42,25	6,5 x 6,5	42,25	18,18,440,00
1	Language lab	30	42,25	6,5 x 6,5	42,25	18,18,440,00

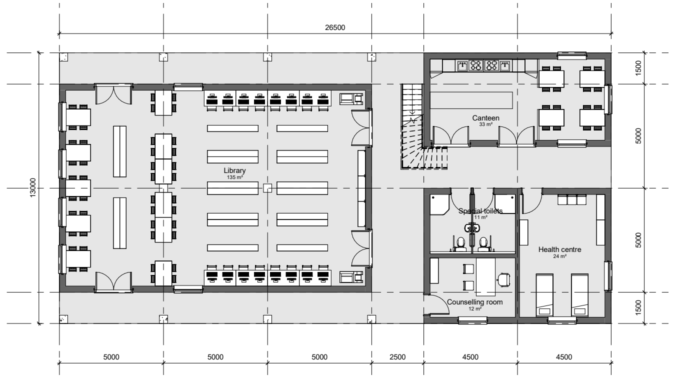
Second floor

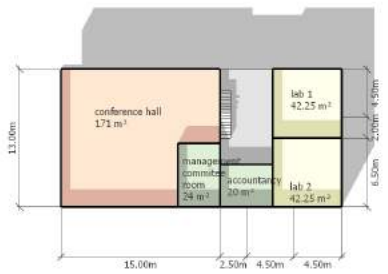
1	Physics lab	30	42,25	6,5 x 6,5	42,25	13,63,830.00
1	Chemistry lab	30	42,25	6,5 x 6,5	42,25	13,63,830.00
1	Biology lab	30	42,25	6,5 x 6,5	42,25	13,63,830.00
1	Office area		25	5 x 5	25	8,07,000.00
1	Vice principal office		40	8 x 5	40	12,91,200.00
1	Meeting room		32,5	5 x 6,5	32,5	10,49,100.00
1	Waiting area		32,5	5 x 6,5	32,5	10,49,100.00

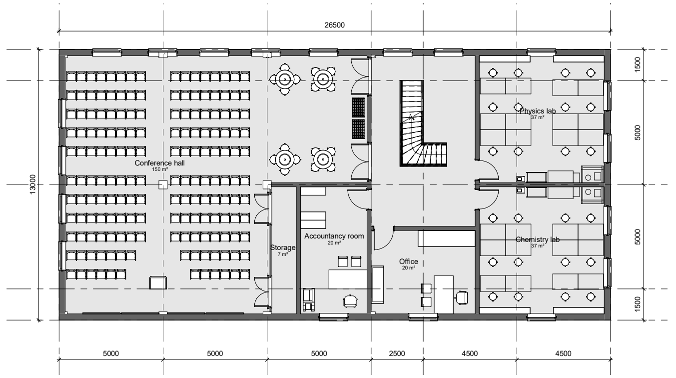
BUILDING FOOTPRINT: **344,5 m²**
TOTAL BUILDING COSTS: **3,21,95,760.00 Rs**

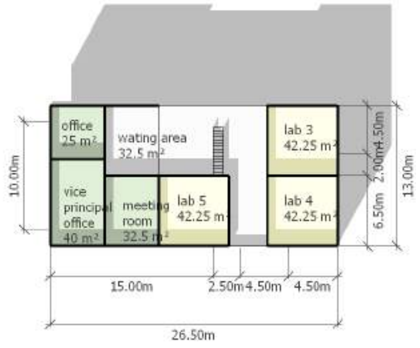
4 RESULTS
4.1 PHASE 1: TENTATIVE DESIGN

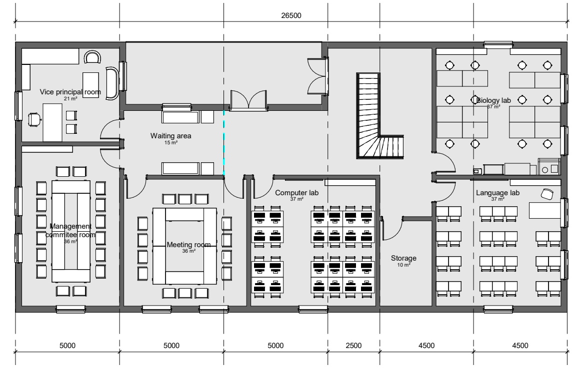












BLOCK D

Ground floor

Nr	FUNCTION	PERSONS	M²	L x B	TOTAL M²	COST ESTIMATION (Rs)
5	Classrooms	60-70	70	7 x 10	350	1,50,64,000.00
1	Garden		-	-	-	-
5	Toilets + water taps		42,5	8,5 x 5	42,5	18,29,200.00
1	Sleeping emergency room	3-4	25	5 x 5	25	10,76,000.00
1	Storage		17,5	3,5 x 5	17,5	7,53,200.00

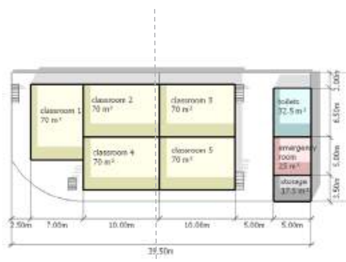
First floor

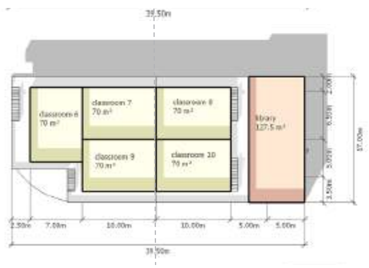
5	Classrooms	60-70	70	7 x 10	350	1,50,64,000.00
1	Library		127,5	7,5 x 17	127,5	54,87,600.00

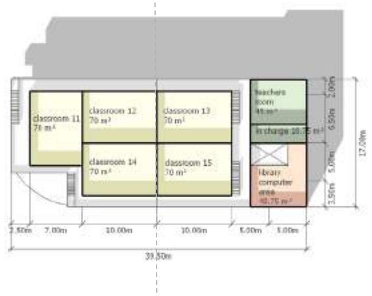
Second floor

5	Classrooms	60-70	70	7 x 10	350	1,12,98,000.00
1	Library computer area		48,75	-	48,75	15,73,675.00
1	In charge room		18,75	7,5 x 2,5	18,75	6,05,250.00
1	Teachers room		45	7,5 x 6	45	14,52,600.00

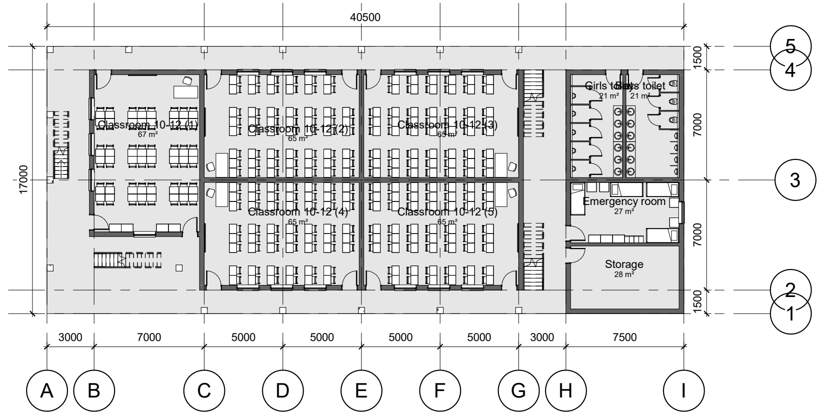
BUILDING FOOTPRINT: **656,4 m²**
TOTAL BUILDING COSTS: **5,42,03,525.00 Rs**

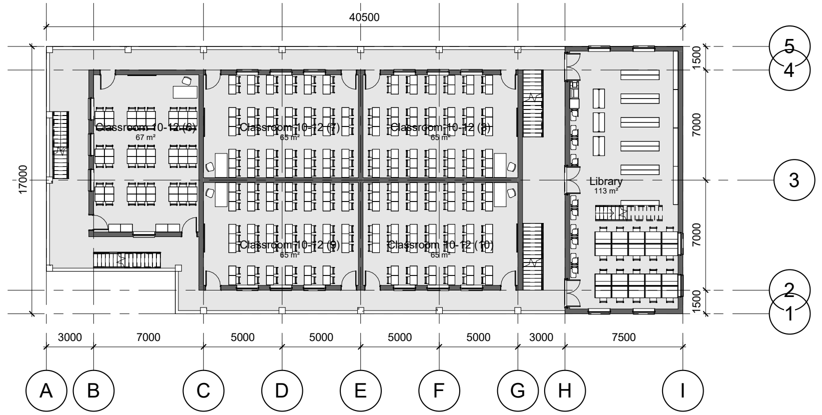


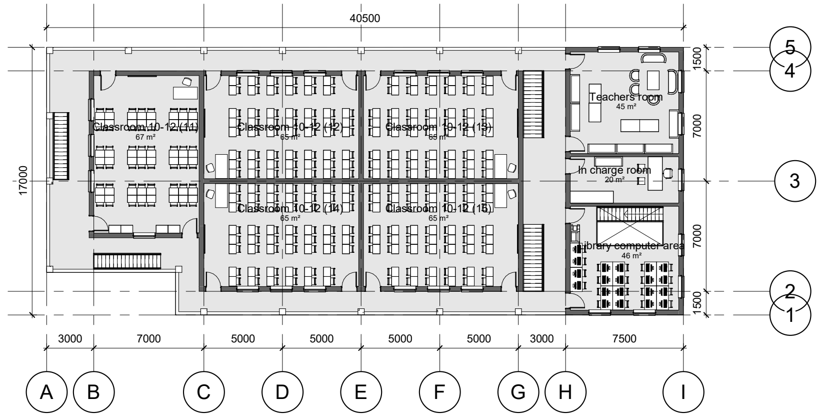




4 RESULTS
4.1 PHASE 1: TENTATIVE DESIGN







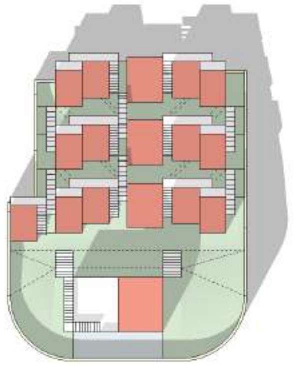
Hostel boys

Nr	FUNCTION	PERSONS	M²	L x B	TOTAL M²	COST ESTIMATION (Rs)
25	Bedrooms	4	12	3 x 4	300	96,84,000.00
3	Bathrooms		20	4 x 5	60	19,36,800.00
1	Warden		30	5 x 6	30	9,68,400.00
1	Emergency room		12	3 x 4	12	3,87,760.00
1	Entertainment room		75	-	75	24,21,000.00

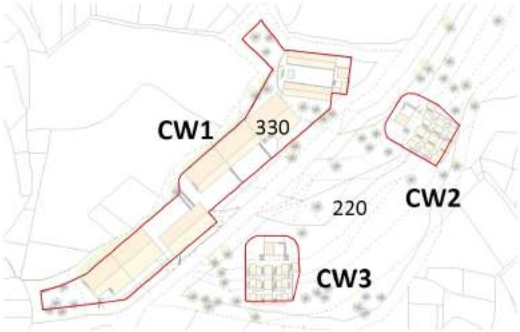
Hostel girls

Nr	FUNCTION	PERSONS	M²	L x B	TOTAL M²	COST ESTIMATION (Rs)
25	Bedrooms	4	12	3 x 4	300	96,84,000.00
3	Bathrooms		20	4 x 5	60	19,36,800.00
1	Warden		30	5 x 6	30	9,68,400.00
1	Emergency room		12	3 x 4	12	3,87,760.00
1	Entertainment room		75	-	75	24,21,000.00

BUILDING FOOTPRINT: **2 x 805 m²**
TOTAL BUILDING COSTS: **2 x 1,53,97,960.00 Rs**



4.1.4 Construction



COMPOUND WALL PLOT 330

Length: 480 m
Width: 30 cm
Height: varying from 2 to 4 m

COMPOUND WALL PLOT 220

Length: 100 m each for each hostel, 200 m in total
Width: 30 cm
Height: varying from 2 m and higher, depending on slope

The following types of construction are suggested for the proposed buildings:

Walls: Confined masonry
Foundation: Concrete reinforced footing

The following construction materials are suggested for the proposed buildings:

Walls: masonry	Bricks on cement with reinforcement (for example interlocking brick with openings for vertical reinforcement) with finishing plaster
Floor:	RCC slab
Doors and windows:	timber
Roof:	RCC slab or sheets on wooden joists or steel trusses (depending on facility)
Staircases:	RCC (for the primary staircase) and steel (for secondary stairways)
Compound wall:	bricks on cement with finishing plaster

ESTIMATED TOTAL COST OF SCHOOL STRUCTURE: 17,11,81,605.00 Rs

4.1.5 Conclusion

The tentative design proposal is rather pragmatic, following the standards without any added qualities. Due to the restricting time schedule, many aspects have been simplified in this phase. This proposal can merely be considered as sketch study of the volumes and dimensions. This phase was completed with the midcrit presentation in the first week of April, once I arrived back in Sweden. Comments and remarks during the midcrit will be processed in the final design phase.

FINAL DESIGN

4 RESULTS
4.2 PHASE 2: FINAL DESIGN

4.2.1 Introduction

After my trip to Nepal and the midcrit presentation, the final phase of the design process started. For the final design phase, improvements are made to tentative model school design. Improvements in the site plan which makes more efficient use of the slope and improvements in the architecture of the buildings which increases the comfort, light conditions and spatial quality. The key aspects that are considered in the final design are:

Design Resiliency

- Resilient building construction
- Resilient building layout
- Resilient building materials
- Emergency meeting points/routes

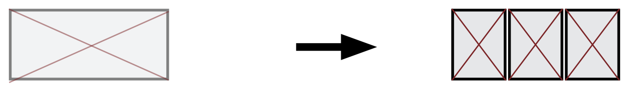
Environmental Sustainability

- Solar power
- Rain harvest
- Natural daylight / ventilation
- Local materials

Architectural and Urban Quality

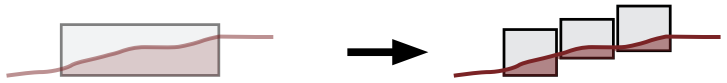
- Natural daylight
- Use of local material
- Use of colour
- Circulation indoor and outdoor space blend on different levels
- Viewpoints on different levels
- Natural vegetation

4.2.2 Concept



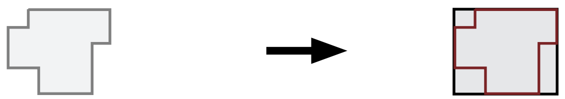
Separation

The length : width ratio may not exceed 1 : 3 due to torsion during an earthquake. Large buildings will be divided into smaller rectangular boxes that can resist lateral seismic forces.



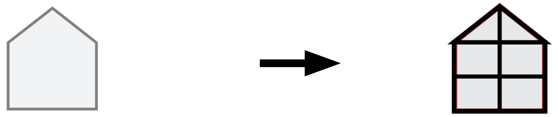
Terracing

A Building that is divided in smaller sections and put on seperate foundations can endure seismic forces better than a large building due to differential ground settlement.



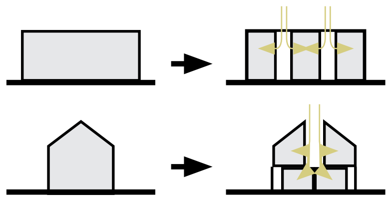
Boxing

Buildings with irregular shapes are less able to endure seismic forces than regular shaped buildings. The construction will therefore be rectangular shaped.



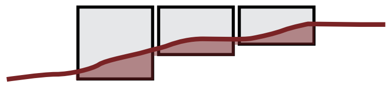
Framing

The construction type that is used for the buildings is confined masonry. A reinforced concrete frame will be constructed and filled with reinforced masonry walls.



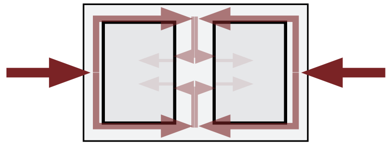
Natural daylight

Larger buildings will be split into sections and seperated for natural daylight to enter and reach lower floors.



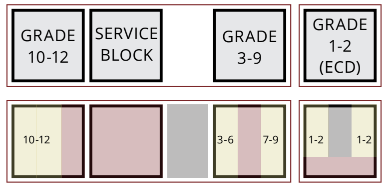
Building height

Higher buildings will be placed lower down the slope while lower buildings will be located at the higher part of the slope.



Blending of in & outdoor spaces

Indoor and outdoor spaces will flow into each other throughout the whole school area.



Space layout

Buildings are divided per grade. Services are located in between.

Classrooms

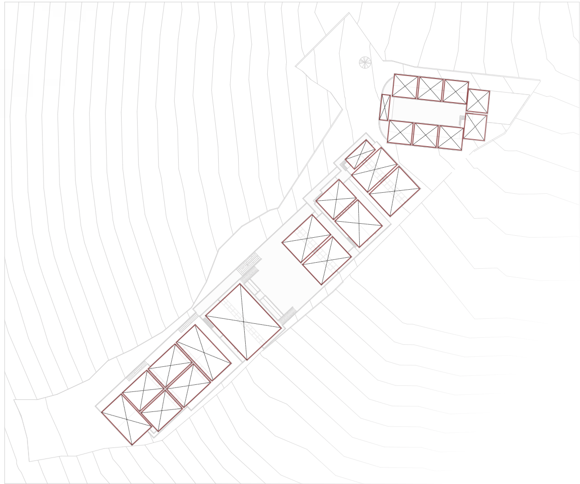
Services

Outdoor space

4.2.3 Masterplan

separation

The length : width ratio may not exceed 1 : 3 due to torsion during an earthquake. Large buildings will therefore be divided into smaller rectangular boxes that can resist lateral seismic forces.

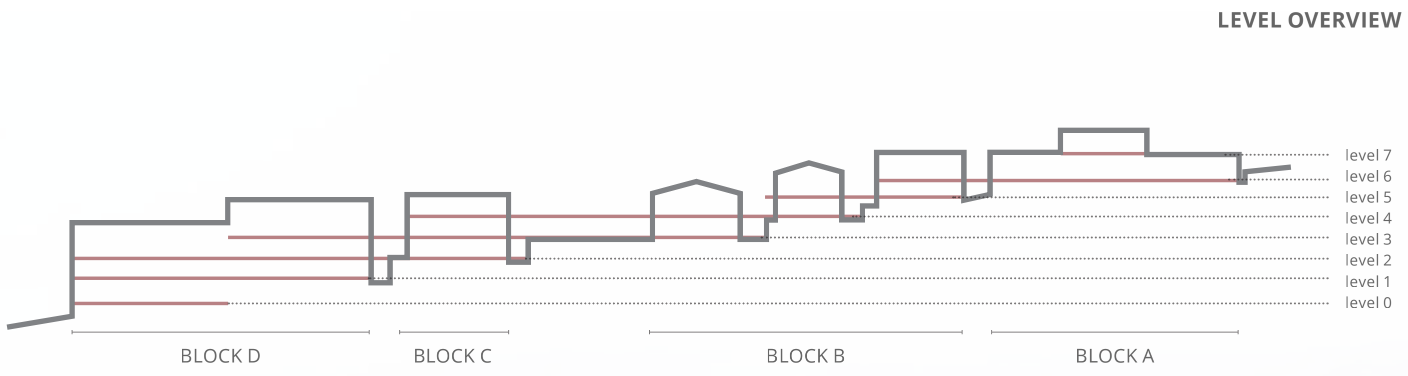


infrastructure

The school has two main entrances. One for ECD's separate facility (1) and another for all other facilities (2). The main circulation routes within the school premises are at the north side. From there all facilities are accesible.

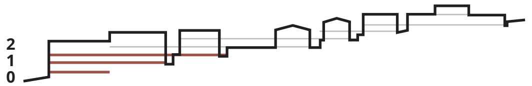
Emergency routes and assembly areas are spread throughout the school area, on open areas within and surrounding the school area.

4.2.4 Section

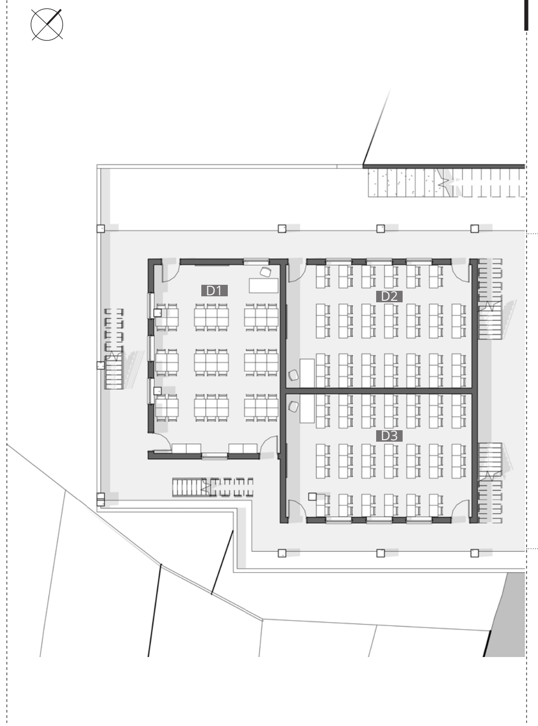

LEVEL OVERVIEW
level 7
level 6
level 5
level 4
level 3
level 2
level 1
level 0
BLOCK D
BLOCK C
BLOCK B
BLOCK A


SECTION LOCATION

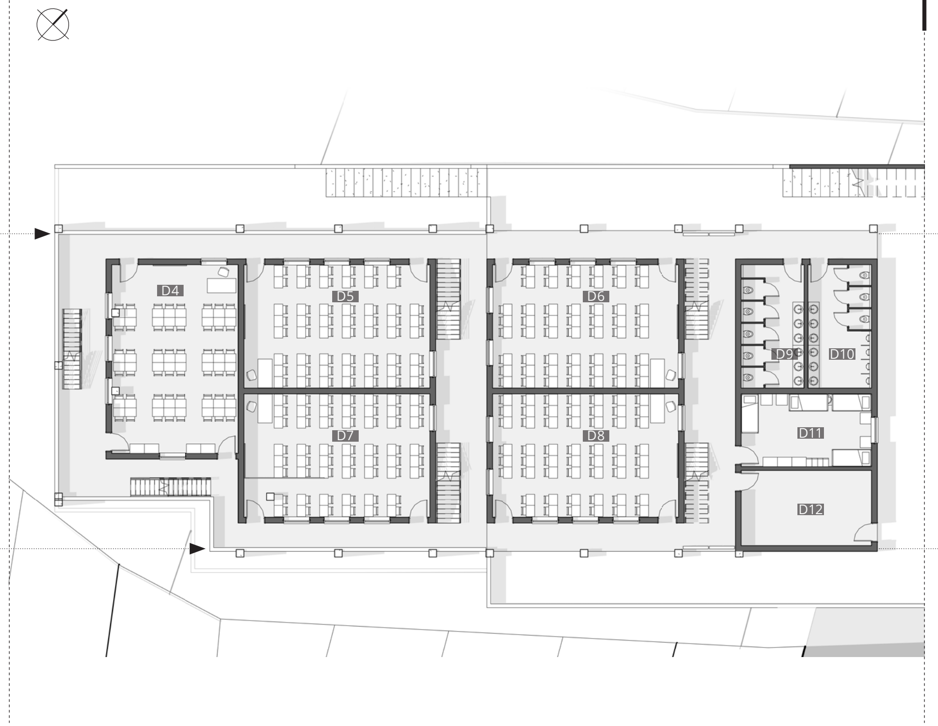
4.2.5 Floorplans



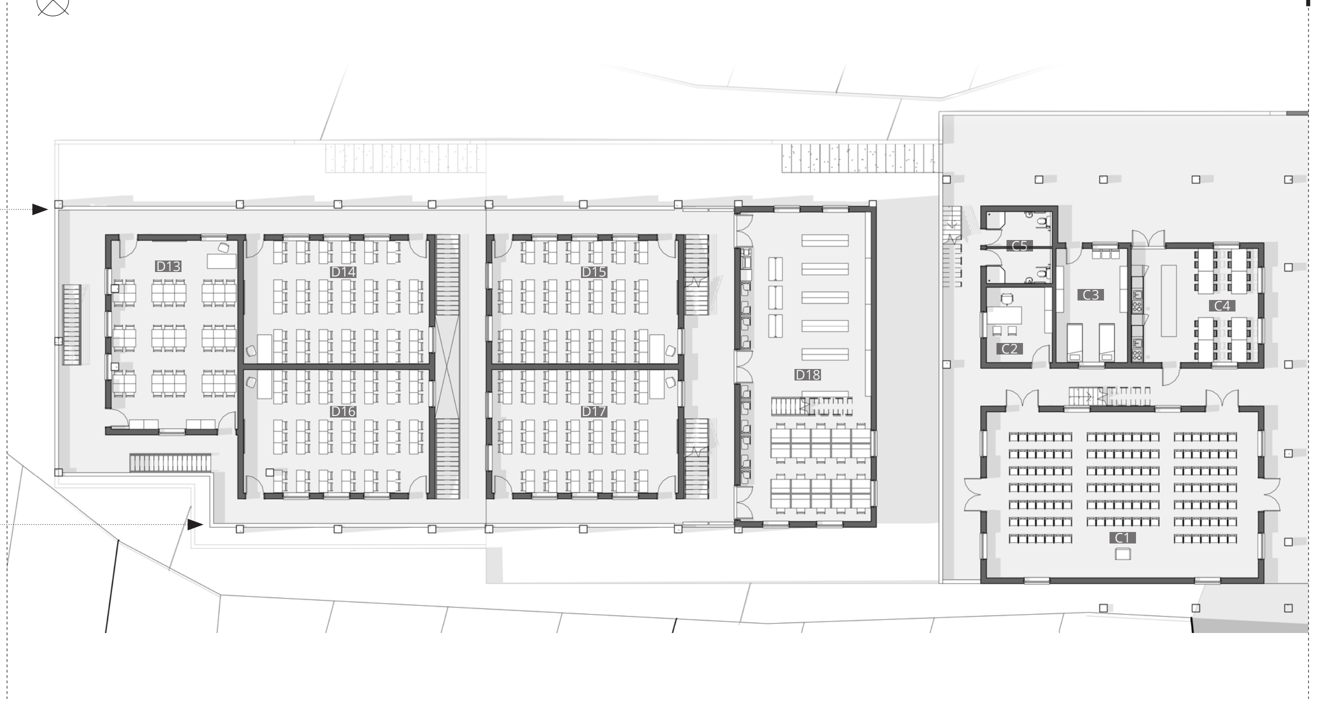
LEVEL 0
Ground floor - BLOCK D



LEVEL 1
First floor - BLOCK D



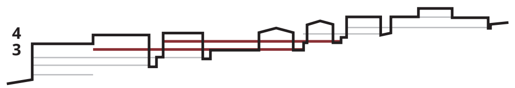
LEVEL 2
Second floor - BLOCK D
Ground floor - BLOCK C



D1	Classroom grade 10-12	67 m²
D2	Classroom grade 10-12	65 m²
D3	Classroom grade 10-12	65 m²

D4	Classroom grade 10-12	67 m²
D5	Classroom grade 10-12	65 m²
D6	Classroom grade 10-12	65 m²
D7	Classroom grade 10-12	65 m²
D8	Classroom grade 10-12	65 m²
D9	Girls toilet	21 m²
D10	Boys toilet	21 m²
D11	Emergency room	27 m²
D12	Storage	28 m²

D13	Classroom grade 10-12	67 m²
D14	Classroom grade 10-12	65 m²
D15	Classroom grade 10-12	65 m²
D16	Classroom grade 10-12	65 m²
D17	Classroom grade 10-12	65 m²
D18	Library	113 m²
C1	Conference hall	127 m²
C2	Counselling room	14 m²
C3	Health centre	23 m²
C4	Canteen	41 m²
C5	Special toilets	12 m²



LEVEL 3
Third floor - BLOCK D
First floor - BLOCK C
Ground floor - BLOCK B

LEVEL 4
Second floor - BLOCK C
First floor - BLOCK B

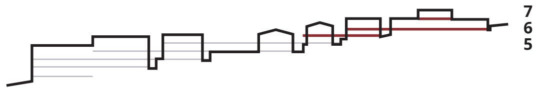
D18	Classroom grade 10-12	65 m^2
D19	Classroom grade 10-12	65 m^2
D20	Teachers room	45 m^2
D21	In charge room	20 m^2
D22	Library computer area	46 m^2

C6	Management committee	34 m^2
C7	Meeting room	34 m^2
C8	Vice principle room	22 m^2
C9	Library	145 m^2

B1	Classroom grade 3-6	34 m^2
B2	Classroom grade 3-6	34 m^2
B3	Classroom grade 3-6	34 m^2
B4	Classroom grade 3-6	34 m^2

C10	Chemistry lab	36 m^2
C11	Biology lab	36 m^2
C12	Accountancy office	14 m^2
C13	Office	14 m^2
C14	Computer lab	40 m^2
C13	Physics lab	36 m^2
C13	Language lab	36 m^2

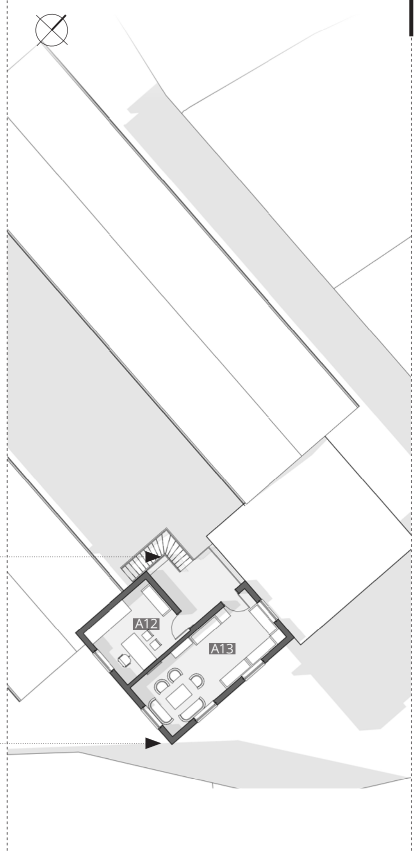
B5	Classroom grade 3-6	34 m^2
B6	Classroom grade 3-6	34 m^2
B7	Classroom grade 3-6	34 m^2
B8	Classroom grade 3-6	34 m^2
B9	Library	121 m^2
B10	Boys toilet	18 m^2
B11	Girls toilet	22 m^2



LEVEL 5
Second floor - BLOCK B

LEVEL 6
Third floor - BLOCK B
Ground floor - BLOCK A

LEVEL 7
First floor - BLOCK A



B12	Teachers room 3-6	35 m²
B13	Teachers room 7-9	35 m²
B14	In charge room 3-6	21 m²
B15	In charge room 7-9	21 m²
B16	Emergency room	19 m²
B17	Emergency room	19 m²
B18	Classroom grade 7-9	44 m²
B19	Classroom grade 7-9	39 m²
B20	Classroom grade 7-9	39 m²
B21	Classroom grade 7-9	39 m²
B22	Classroom grade 7-9	39 m²

B23	Classroom grade 7-9	39 m²
B24	Classroom grade 7-9	39 m²
B25	Classroom grade 7-9	39 m²
B26	Classroom grade 7-9	39 m²

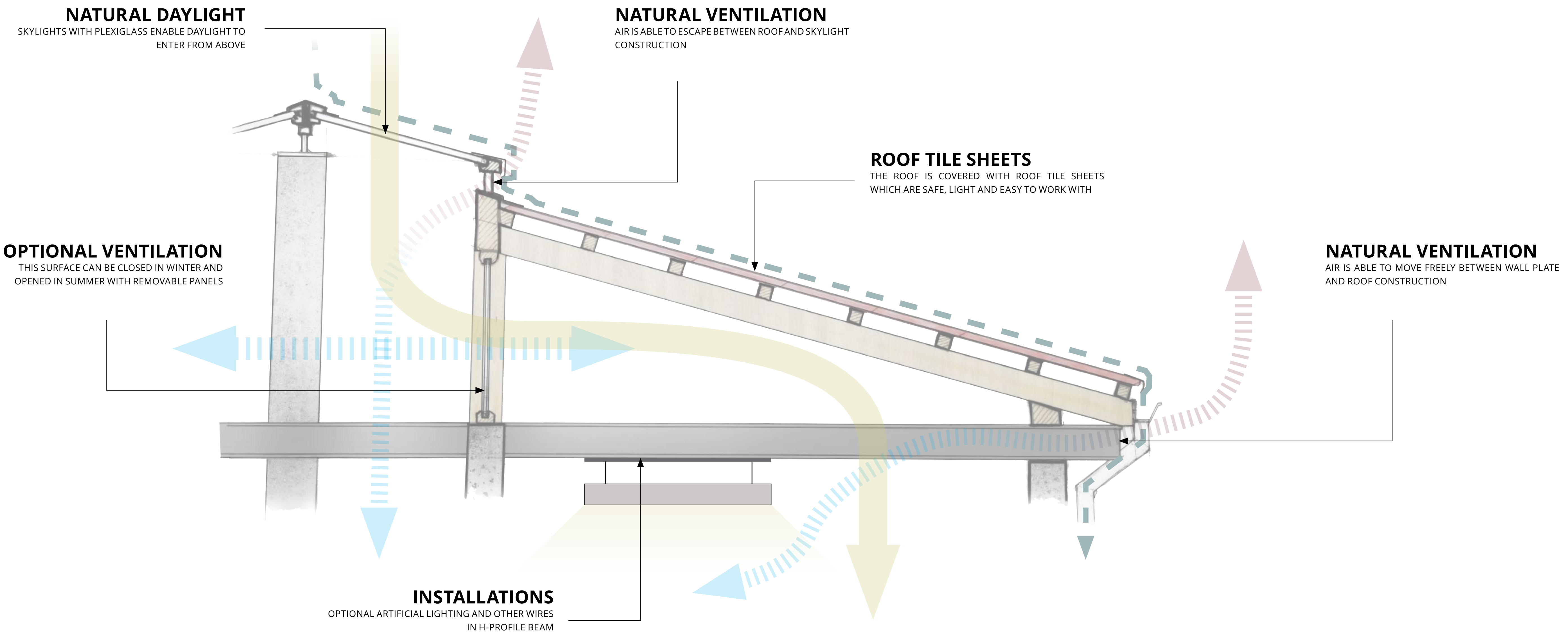
A1	Library	48 m²
A2	Emergency room	19 m²
A3	Game room	21 m²
A4	Classroom grade 1-2	40 m²
A5	Classroom grade 1-2	40 m²
A6	Classroom grade 1-2	40 m²
A7	Boys toilet	9 m²
A8	Girls toilet `	9 m²
A9	Classroom grade 1-2	40 m²
A10	Classroom grade 1-2	40 m²
A11	Classroom grade 1-2	40 m²

A12	In charge room	16 m²
A13	Teachers room	27 m²

4.2.6 Elevations


Kitini
Kitini

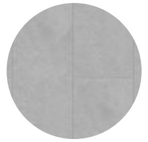
4.2.7 Detail


NATURAL DAYLIGHT
SKYLIGHTS WITH PLEXIGLASS ENABLE DAYLIGHT TO ENTER FROM ABOVE
NATURAL VENTILATION
AIR IS ABLE TO ESCAPE BETWEEN ROOF AND SKYLIGHT CONSTRUCTION
ROOF TILE SHEETS
THE ROOF IS COVERED WITH ROOF TILE SHEETS WHICH ARE SAFE, LIGHT AND EASY TO WORK WITH
OPTIONAL VENTILATION
THIS SURFACE CAN BE CLOSED IN WINTER AND OPENED IN SUMMER WITH REMOVABLE PANELS
NATURAL VENTILATION
AIR IS ABLE TO MOVE FREELY BETWEEN WALL PLATE AND ROOF CONSTRUCTION
INSTALLATIONS
OPTIONAL ARTIFICIAL LIGHTING AND OTHER WIRES IN H-PROFILE BEAM

| *Materials*

LOCAL FABRICATED BRICKS WITH POSSIBILITY FOR REINFORCEMENT

Special fabricated bricks with openings for reinforcement will be used for the walls. Reinforcement will be used both horizontally and vertically. The openings also reduce material use and weight.



IN SITU AND PREFAB REINFORCED CONCRETE

Reinforced concrete will be used for the loadbearing construction frame consisting of columns, beams and floor slabs.

CONCRETE TILES

Concrete tiles will be used for the outdoor spaces like the play/assembly area and the walking paths.

SYNTHETIC ROOF TILES

Synthetic roof tiles are safer in case of an disaster. Synthetic roof tiles are connected in sheets and are connected by screws to the roof construction.

YELLOW PLASTER

Service facilities, like libraries and offices in all blocks, will be indicated by a finishing layer of yellow plaster.

PLEXIGLASS

Plexiglass will be used for all windows and skylights. Choosing plexiglass over glass saves money and makes the building safer since it will not shatter during earthquakes.

WHITE PLASTER

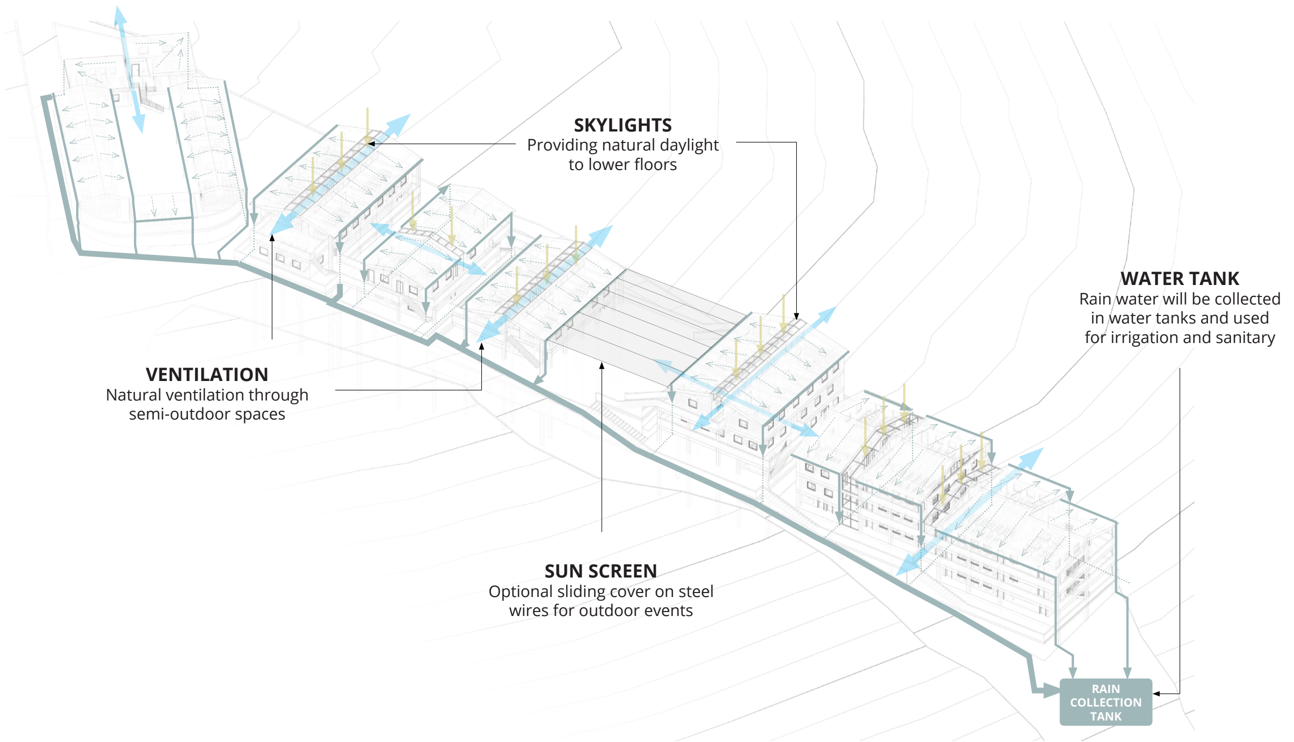
Classrooms blocks are indicated by a finishing layer of white plaster.

WOOD

Wood will be used for the door and window frames. Also most furniture will be made of wood. The wood will be made fire-resistant.

4 | RESULTS
4.2 PHASE 2: FINAL DESIGN

| *Climate*




GRADE 7-9


KITINI
HIGH
SECONDARY
SCHOOL


LIBRARY
READ


"Education is the most powerful weapon which you can use to change the world."
Nelson Mandela

5 CONCLUSION

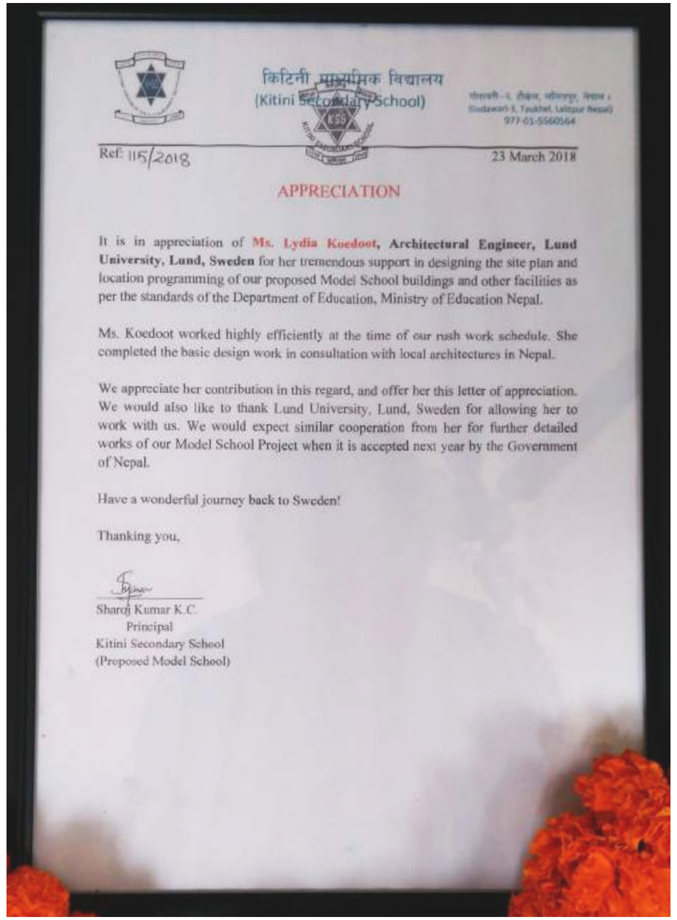
The background research has helped me to gain a better understanding of earthquakes and their effect on the built environment. The research provided me with a design toolbox for seismic design which has been very useful during later phases of the project.

Travelling to Nepal has been an amazing experience. This project would not have been possible without the site visit. Designing and working in Nepal is different from working in a Swedish or Dutch context in so many ways. Working with the school committee on the model school proposal has helped me to develop myself and my skills. I learned it is important as an architect/engineer to be in close contact with the local people, the users, and be on site when desiging social architecture.

Developing a design proposal in a couple of days has been intense but rewarding. Working within a tight schedule helped me to simplify and frame the project to the most important aspects. I applied the guidelines and regulations that I found during the research to the tentative design. The school was very satisfied with the results and we submitted the proposal report to the Department of Education.

However, the tentative design proposal is rather pragmatic, following the standards and guidelines. The final design focuses on disaster resiliency and environmental sustainability while providing a comfortable and pleasant learning environment. The use of colour, light and indoor and outdoor spaces with various atmospheres on different levels has improved the architectural quality which is visible in the final design of the project.

I will be involved in the process of Kitini model school in the future. I will be following the progress on distant the coming months and I am planning to visit Nepal again in a later phase of the project. The exact details and steps that need to be taken in the future and how I can contribute during the process is not determined yet, but I am open and willing to contribute at any time and in any way possible in the development of Kitini High Secondary School towards a leading model school.


किटिनी माध्यमिक विद्यालय
(Kitini Secondary School)

Godawari-3, Taukhel, Lalitpur Nepal
977-01-5560564

Ref: 115/2018

23 March 2018

APPRECIATION

It is in appreciation of **Ms. Lydia Koedoot, Architectural Engineer, Lund University, Lund, Sweden** for her tremendous support in designing the site plan and location programming of our proposed Model School buildings and other facilities as per the standards of the Department of Education, Ministry of Education Nepal.

Ms. Koedoot worked highly efficiently at the time of our rush work schedule. She completed the basic design work in consultation with local architectures in Nepal.

We appreciate her contribution in this regard, and offer her this letter of appreciation. We would also like to thank Lund University, Lund, Sweden for allowing her to work with us. We would expect similar cooperation from her for further detailed works of our Model School Project when it is accepted next year by the Government of Nepal.

Have a wonderful journey back to Sweden!

Thanking you,

Sharoj Kumar K.C.
Principal
Kitini Secondary School
(Proposed Model School)

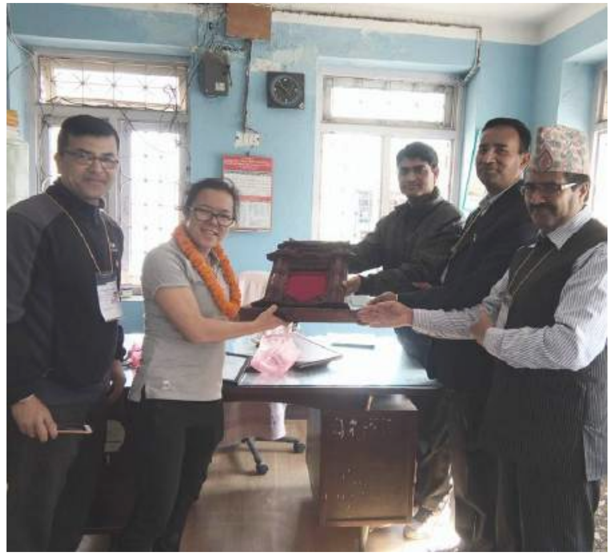


Photo: Lydia Koedoot 2018

7 | ACKNOWLEDGEMENTS

I would like to thank Lund University for the opportunity to pursue my master's degree in architecture and all the facilities they have provided me to do so. I am in particular grateful to my supervisor, Maria Rasmussen, for guiding me with suggestions that have significantly improved my final results. I also want to thank Christer Malmström, my examiner, for his contributing feedback during the project.

I would like to express my very great appreciation to Kitini High Secondary School. I thank the school director, Sharoj Kumar K.C. for the opportunity to work with the school and his support during my stay in Nepal.
I am in particular grateful to Dinesh Thapa, teacher at Kitini HSS, for his indispensable support before, during and after my visit to Nepal with practical and work-related matters. My work for this project would not have been possible without him. It has been a great and valuable experience to work with him and the school.

I would like to thank Lisa Lyons, U.S. Director of ETC (Educate The Children) in Nepal. I was able to get in touch with Kitini High Secondary School and travel to Nepal thanks to her. Also, her colleague Laxmi Bhakta Basukala, Education Director at ETC, has been involved in the communication process whom I also like to thank.

I would also like to thank all the other people that I met in Nepal. Arjun Koirala, Rup Narayan Chaulagain, staff and students at Kitini High Secondary school and Dinesh' family. They all contributed in their own way by supporting me during my stay in Nepal and making this trip unforgettable.

I am very grateful to all my family members in The Netherlands. They have been a great support by motivating and encouraging me in all my pursuits to follow my dreams. I am particularly grateful to my parents who have supported me emotionally and financially throughout my entire studies.

I would also like to thank all my friends in Lund who have helped, supported and prayed for me during my thesis work.

Above all, I thank God Almighty for giving me the knowledge, strength, opportunity and the ability to follow the path He has prepared for me.

"For I can do everything through Christ, who gives me strength" – Philippians 4:13

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LYDIA KOEDOOT

SPRING 2018

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