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Vernacular Construction and Sustainability in Response to Post Earthquake Reconstruction in Nepal

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The primary objective of this thesis was to promote the efficiency and sustainability of the traditional constructional practises in the hilly region of Nepal. Natural construction materials that are abundantly available were prioritised for economic and sustainable construction practices. Possible interventions in locally available materials and technologies were presented in this paper to provide an ultimate housing solution.

The models of houses proposed by the government of Nepal were presented, and a life cycle assessment of the buildings were calculated using one click LCA. Vernacular construction practices using regional building material incorporated with earthquake resistant construction techniques were studied for sustainable, economical and speedy reconstruction of post-earthquake dwellings.

This thesis can be used as a starting guide for the people affected by a natural catastrophe, such as an earthquake, to construct affordable and sustainable house with good building performance, and resilient to earthquake, so that possible damage in the future can be minimized.

This paper helps as an example for the people to construct affordable houses who have lost their homes. Furthermore, the thesis can be used if there is another catastrophe.

Keywords	sustainable construction, earthquake, affordable housing, vernacular materials, local skills and technology, life cycle assessment

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1 Introduction

In a disaster-prone country like Nepal, the uses of traditional construction techniques often using locally available resources and technologies which have been practiced for years, often helps in reducing the vulnerability of the buildings. Traditional vernacular architecture that has been practiced for centuries was developed without creating a negative impact on the health and environment. Vernacular buildings are unique buildings that are designed and constructed on the basis of local needs and availability of construction materials, reflecting local traditions of a particular community. Vernacular architecture evolves over time, reflecting the characteristics of the local environment, climate, culture, natural materials, technology, and the experience of centuries of community build. It helps to keep the balance between environment and sustainable society. [1.]

In the rapidly growing world economies, modern engineering tools and technology are used in every corner of the globe. Hence, the replacement of traditional architecture by current engineering solutions causes the disappearance of traditional skills, knowledge, and technologies. Nowadays, the traditional form of architecture and technology is decreasing and being displaced by modern artificial design, materials, and imported technology. If this continues, not only our ancient technologies will be lost but also many environmental problems are caused which directly impact on both present and future generations. There is a linkage between housing and disaster which is amplified in developing country like Nepal where housing is considered as the most valuable assets. [2.]

Various studies show that vernacular construction has accountable performance in terms of survivals and low damage intensity recorded during the past disasters [3]. Earthquakes are fatal natural disasters which claim an enormous loss of life and property also in Nepal. It is necessary to study local responses and resilience techniques from the local level to national level.

2 Background

The final year project aims at designing the affordable houses to the victims of the 2015 earthquake of Nepal, while keeping the cost of the construction reasonable and improving the performance of the buildings. Using vernacular technologies and architecture, local materials, non-engineered locally available building technology and study about the Nepalese housing with the inclusion of earthquake-resilient reinforcement solution. This thesis introduces local construction practices together with some improved earthquake-resistant technologies. After the 2015 Gorkha earthquake Nepal is in the era of reconstruction where people are seeking for alternative techniques and materials which could be both safer and healthier as well as strong enough to endure a disaster like an earthquake. This final year project focused on strengthening the local economy through the process of reconstruction which is beneficial to a poor and marginalized community, ensuring a sustainable and environmental friendly habitat.

The number of concrete building in Nepal makes it look like the people see concrete building as a sign of higher social states. However concrete building often seen to suffer poor indoor environment. Therefore, people are attracted to building a concrete house rather than a traditional building of rock, mud and wood. This thesis, reviews various studies carried out by both private sector and the government of Nepal focusing on traditional building technologies in the hilly areas of Nepal up to 2000 m where vehicular land transport and logistic poses a great challenge where people are most affected and in need of immediate rehabilitation after the earthquake.

The thesis is based on the literature study and the various data available on the internet. The final year study performs a lifecycle assessment on two of the ten houses de-signed by the Depart of Urban Development and building Construction (DUDBC) for the victims of 2015 earthquake in Nepal. The scope of the study is to analyse the life cycle assessment of the house. [3.] The studied house can be built with the local construction materials in the hilly region of Nepal.

3 Gorkha Earthquake

Nepal faced massive destruction during two devastating earthquakes on the 25th of April and the 12th of may 2015 known as the Gorkha earthquake due to the name of the area. The first earthquake was of the magnitude of 7.8 and it hit at 11:56 am Nepalese time. The epicentre of the earthquake was Gorkha, 82 km North West of the capital city Kathmandu. The earthquakes killed 8,790 people and injured 22,300 people. It is estimated that at least 498,852 private houses and 2,656 government buildings were area. The destroyed and another 256,697 private houses and 3,622 government buildings were partially damaged. In addition, 19,000 classrooms and also 2,313 cultural heritage buildings were destroyed, and 16,910 were partially damaged. The earthquakes destroyed houses that were mostly built of mud-brick and mudstone occupied by the rural poor. [4.]

Rural areas in the central and western regions were particularly devastated and further isolated due to road damage and obstructions caused by landslide right after the earthquake. As the loss caused by this calamity was enormous, a smart, effective way for the recovery is needed. An equal participation of the public and government is carried out in the design and construction of houses that are earth-quake resistance economical and sustainable [3]. This results in the construction of new houses with better energy performance by using passive techniques and materials for example use of local insulating materials, increased wall thickness, Jhingati (a clay tile) roof, and orientation of the house for better performance in rural areas, where there is no access to modern heating technology.

3.1 Government Aid to Victims

Financial aid of NPR 300,000 (3,000$) was announced by the Government of Nepal for the reconstruction and repair of the affected houses. The victims received the aid in three instalments. Out of 765,618 eligible houses, only 603,990 houses have been provided the first instalment of the aid granted by the government while 62,552 houses and 3,776 schools have received their second and third instalments, respectively. This is because the reconstructed buildings could not fulfil the criteria that have been standardized by the government. [5.]

The Government of Nepal has developed various design catalogues for the reconstruction of houses. They are suitable for the rural scenarios of Nepal, but even the cheapest prototype among the catalogues cannot be constructed by the government's financial aid. In total, there are fifty-one earthquake-resilient design that are proposed in the volumes I and II of the catalogues with stone and brick as main building materials. [2.] The availability of construction materials, funding, and experienced manpower plays a crucial role in the implementation of the build back better houses programme which aims to replace houses lost during the 2015 earthquake. The completion of the shelters can be helped with construction management which enhances an efficient expenditure of funds on locally available technologies and materials. [6.] It seems to be necessary to train the locally available manpower in the easy techniques of construction so that the hurdle due to lack of manpower does not cause trouble. Furthermore, the local technicians were updated about the design, planning, and construction of the affected buildings. They also encouraged for equal participation. [3.]

3.2 Sustainable Shelters after Earthquake

A sustainable shelter is a better concept a complete house for rapid rehabilitation of people right after an earthquake. There is a difference between a shelter and a house: a shelter is a temporary structure constructed in emergency conditions while a house is a permanent structure where people live their lives. The term sustainable shelter means a safe house which also accommodates for a social and economic growth of people. Right after the 2015 earthquake, the government and various NGOs and INGOs help to build temporary shelter. [7.] As the reconstruction process in Nepal continues government are promoting green resource. The government is focusing on efficient and sustainable reconstruction, recovering the environment that was destroyed during earthquake. Restoration of life, and livelihood-supporting ecosystem as well as promoting resource efficiency for the notion of build back better programme started after earthquake [5]. There is a need for the of study construction and project management for an easy and fast execution of the recovery program so that the people who suffer get help [3]. Sustainability can be attained by empowering local manpower and local materials available.

4 Geographical Diversity and Climate

Nepal is a beautiful landlocked country located between China and India with an area of 147181 km^2. It can be divided into three physiographic regions on the basis of geographical diversity: the Himalayan region, the hilly region, and the Terai region. Nepal rises from an elevation of 60 m from sea level to 8,848 m in the Himalayas. There are very different climatic conditions from subtropical to freezing. The Himalayan region covers 16% of the total land area and the hilly region and Terai region cover 68% and 17 %, respectively. Be-cause of the geographical diversity and differences in religious beliefs, socio-economic traditions, and cultural patterns, there is a variety of expression in architecture. The different geographic regions have their own expression in housing and in terms of living. The Terai region, Himalayan region, and hilly region have their own lifestyles and culture, which they have inherited through centuries, adapting according to the climate, and availability of local resources and materials. [8.]

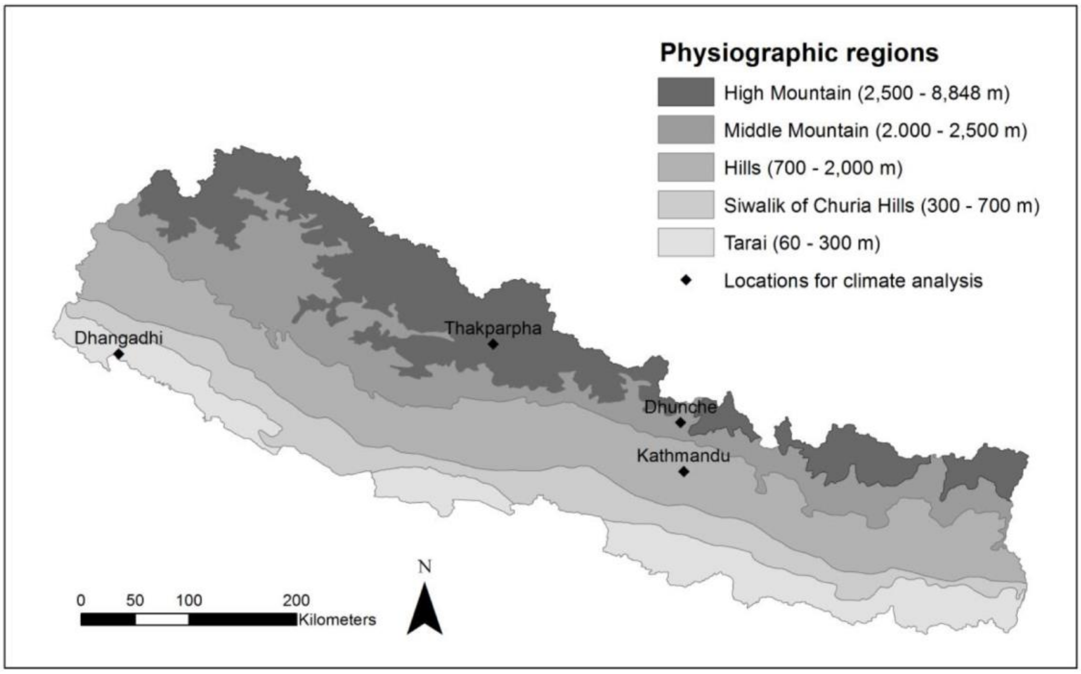

Figure 1. Physiographic regions of Nepal [9].

Table 1 lists the available construction materials in the different regions of Nepal. The Terai region is rich in fertile soil; its mud and sand can be used for construction. It is also rich in wood as there are dense forests of mainly sal tree. Furthermore, thatch for roofing is widely available in the Terai. [9.]

Table 1. Construction materials in the different geographic regions [8; 9]

Availability of traditional building materials	Terai Region	Hilly Region	The Himalayan region
Geomorphic unit	Northern edge of Gangetic Plain	Churia Hills or Siwalik	High mountain
Width (km)	20-50	10-50	10-35
Altitudes (m)	60-1000	1000-2000	2000 above
Main rock type	Alluvium: Coarse, gravel in the north becoming finer southwards	Sand-Stone, mudstone, shale, conglomerate	Schist, phyllite, gneiss, quartzite
Soil type	Rich fertile alluvial soil, gravelly and sandy soil	gravelly and Sandy soil	Fertile residual soil
Typical vegetation	Fertile agricultural land, dense Sal forest	Sal forest	Along middle slope: hill forest
Available traditional building materials	Abundant: wood, thatch, daub, other biogenic materials, mud, sand, gravel	Abundant: stones, slate, timber, thatch, clay for brick making, sand, gravel	Along middle slope: hill forest

The hilly region is rich in various types of stones, like granite, schist, slate, gneiss and limestone, which can be used in building construction. Timber is also available abundantly due to the presence of dense forests of sal trees. Vegetation also produces roofing materials like thatch for building construction. [9.]

The Himalayan region, characterized by cold climate only offers a small quantity of timber because very little land is found on the snow covered mountains are found. However, stones and rocks are available some mud can also be seen. [10.]

5 Building Architecture in Nepal

Nepal is a country with diversity, both geographically and culturally. People living in different geographic regions have a unique style and variation in building techniques, adopted over centuries. With the variation in the natural topography, environment and ethnicity, the rural architecture of Nepal is different in the various geographic regions. Nepal can be divided into three vernacular architectural regions according to the natural environment and construction material: the Terai, hilly region and high mountain region. [11.]

In the Terai region traditional buildings have light wattle and daub walls with exterior walls made of bamboo strips with gaps in between and tied up by a frame made of timber. Roofing is done with thatch. Openings are very few in number except from the low windows below the roof, which help to maintain indoor comfort by allowing air circulation in and out of the building. Usually, compacted earth is used in floors although clay tiles and stones are also seen. The people who live in the Terai region are mostly Tharu. Houses are arranged in clusters around a courtyard with one side open. This allows for easy natural airflow. The houses are mostly single-storied with internal medium height partitions for rooms so that the airflow is maintained inside the house. [12.]

In the hilly region, the buildings are south oriented in order to inlet solar gain, To prevent overheating in the summer, a shading roof and openings are provided in the houses. Houses are arranged in a courtyard system so that passive heating and cooling is done in the winter and summer, respectively. Materials used for construction are locally available, mud and brick walls, clay tiles for roofing and timber for openings. Vertically staggered allocation of spaces assures warm winters because ground floors are used as buffer spaces and upper floors as living spaces. [13.]

In the Himalayan region, denser building settlement is prioritized since the main target is to maintain warmth and prevent heat loss. No or very few windows are seen in the houses. Roofs, walls and partitions are made from materials with high thermal mass with longer lag. Flat roofs with inverted pots or timber on top are sometimes seen to preserve the heat gain by the sun. [13.]

6 Vernacular Architecture

Traditional architecture is the result of a long practice of using local materials and technology in construction. Due to the absence of modern mechanical technology, people started building according to the site. Basically, todays traditional buildings are the result of adopting passive solar methods. It is found that such buildings perform better in terms of thermal comfort, and also are energy efficient [9]. Nepalese vernacular architecture is diverse not only in geography but also culturally abided by the people living here. In addition, the availability of local material and the differences of climate from one geographical region to another enhance their uniqueness.

The energy performance of a building in this region depends upon the orientation, planning, and the layout of the building, and upon the construction materials. The construction cost of the building also depends upon the site on which it is to be built, and the cost of construction also comes along with the understanding of material availability, transportation ease, and the skills available. [14.]

Vernacular housing construction materials in different regions are unique and have traditional technologies of construction, invented by the local peoples with their own resources and knowledge. Throughout the world, vernacular housing construction is common and the rational and resilient features are nowadays more recognized in terms of sustainability. The abundance of materials for construction in the hilly region of Nepal includes stone, burnt brick, mud, cow dung, wood, and clay which are the traditional building materials of Nepalese architecture. [15.]

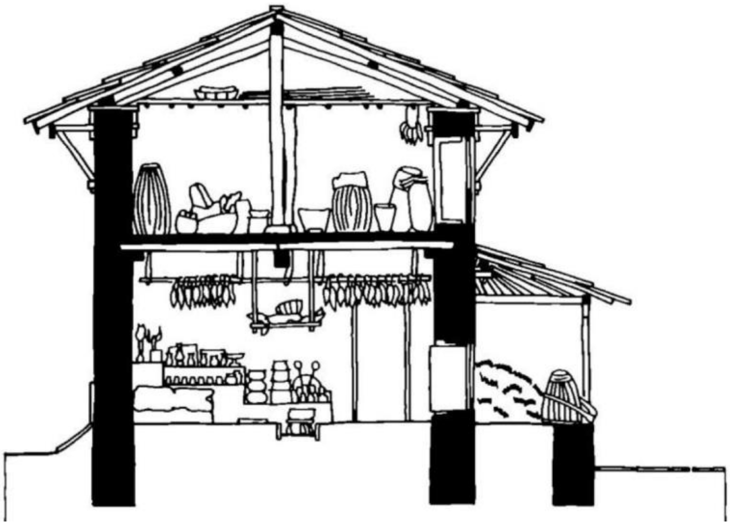

Figure 2. Typical vernacular house in the hilly region of Nepal [16].

Figure 2 shows an ideal home in the hills of Nepal with a thick wall, a kitchen on the ground floor, storage in the attic, and an upper story bedroom. There is a spacious and cozy veranda which is used as storage of hay and food for livestock. The design is well suited for the common need of the people. [16.]

7 Climate and Building

When designing a building, it is always essential to analyse the climate of the site. A building and the climate are interconnected with each other. It is because the comfort required by the users can be maintained if the building is designed to interact with the climate of the site in a healthy way. Primarily, indoor comfort is gained through thermal comfort, which is again governed by a few very important natural parameters like air temperature, radiant temperature, air speed, and humidity. However, personal factors like clothing may also affect the indoor comfort. The heat gains and heat loss mediums like solar gain, appliances used indoors, occupants, ventilators, furniture and plants, create a certain level of heat inside a building. These heat gains and losses are maintained by their major natural phenomena: convention, convection, and radiation. [9.]

Medium-sized openings are required in order to maintain air circulation inside a passive solar house. The temperate climate of the hilly region demands double-banked rooms with the thermal mass of longer lag. The variations in many geographical factors like altitude, orientation, wind, and its direction in the hills of Nepal widely affect the indoor climatic conditions. For the climate of the hilly region, mechanical heating would be good because sometimes it gets too cold in the winter season but using mechanical heating cost expensive and the cold climate does not last long so construction of passive solar house is recommended instead of using mechanical heating. [17.]

As recommended by "Passive solar design tools, and strategies for Nepal, the temperate climate of the hills require a north-south orientated building, medium-size windows .Furthermore shading devices should be adopted to maintain the indoor climate. For warmness in temperate climate, the longer facade of a building should face south, and shading devices should be used to avoid sunlight during summer. Air movement is necessary, and the rooms should be arranged in a single banking order so that natural ventilation can be achieved. [18.] Likewise, cool, temperate climates demand thermal mass for longer time-lag. Natural ventilation is required to prevent the building from overheating in the summer.

An economic and sustainable design of a traditional passive solar building not only covers the external parameters, and the composition of a building but also the way it is constructed and the technologies it embraces. The design also focuses on what kind of a space is required for the occupant and what kind of comfort they need. The interior space should perform well to achieve the desired comfort level for the user. Thus, if buildings are studied with the climatic parameter and solutions are given earlier in the design phase for higher performance, extra cost for the desirable space heating and cooling becomes nullified and the building is economical in the long run.

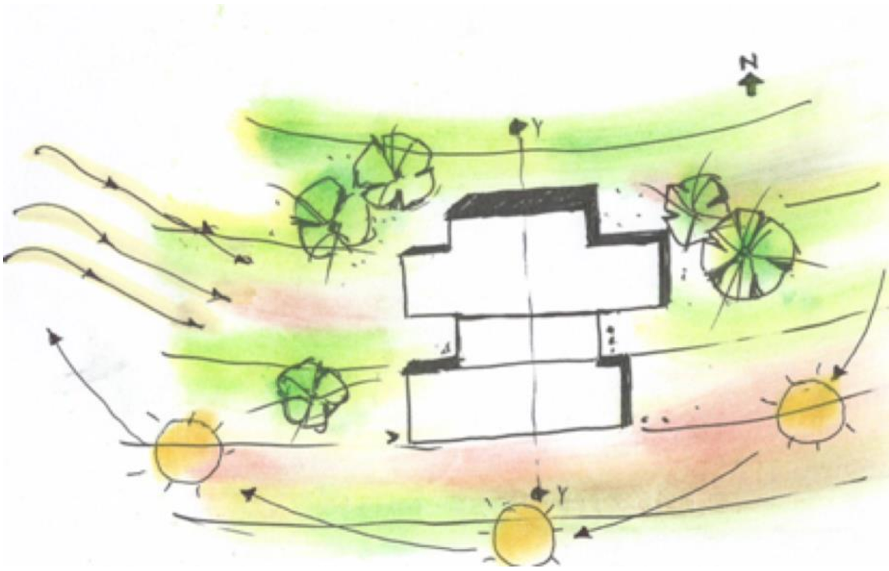

Figure 3. Building plan view for gaining optimum solar heat in hilly region

Figure 3 represents the design of a traditional passive solar building. It is rectangular with the inner courtyard spaces open to one side so that building can breathe the air coming from the outside. The orientation of the building should be north-south with the longer side facing south to gain solar heat. [13.]

Figure 4. Altitude difference at hilly region.

Figure 4 shows the altitude difference and human settlement in the hilly areas of Nepal. Houses are built on hill terraces along the slope. The houses are built on the sunny slopes of the hills to allow maximum sunlight for all kind of household activities during sunny winter days.

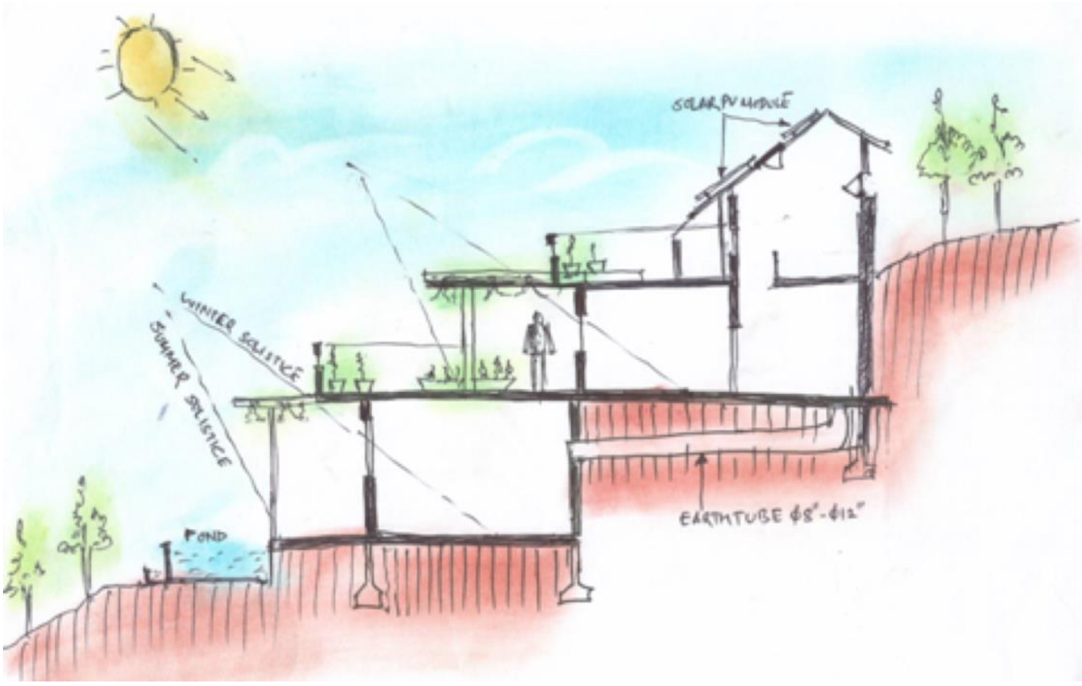

Figure 5. Building in elevated land of hilly region

Figure 5 shows that the design of an effective building in the hilly region requires solar energy utilization to the maximum. Thus, the main focus is to gain solar heat in the winter and avoid it in the summer. It can be done with the efficient use of shading. Human comfort can be gained with the use of passive solar tools like sunspaces, solar PV cells, and also with water bodies, greenery, and vegetation. Providing an earth air tunnel is useful for the heating and cooling of the indoor air without much expenditure on electricity as shown in the figure 5.

8 Earthquake Resistant Traditional Building

The design of earthquake-resistant buildings in an economical and sustainable way demands smart and easy solutions for this, cheaper alternative technologies which can be carried out with the utilization of local manpower, skills, and materials. For a building to be earthquake resistive, one must follow the national building code in the design and construction. DUDBC has published a catalogue for construction and spreads the knowledge of seismic vibrations, the damage that could happen, and preventive measures. DUDBC has divided building materials into four categories: stone and mud mortar masonry, brick and mud mortar masonry, stone and cement mortar masonry, and brick and cement mortar masonry. The National Building Code of Nepal has revised the design catalogue, and make compulsory inclusion of plan, elevation, sections, technical details, and 3D view of the design in order to get a construction permit. Earth-quakes are unpredictable. The most efficient preventive action is to build according to earthquake resistance principles. Most local people are unaware about earthquake resistance construction. Thus, they just lay the brick and stone on mud mortar, but to improve their houses and to become an earthquake sound structure, small changes which can be carried out easily and understandable to the local people are efficient. The materials collected needs to be laid into building components with smart construction techniques. Some of the amendments that can be done for building an earthquake sound house are discussed below. These include wall binds, tying the floor at corner and tying the floors with walls.

Wall binding as shown in figure 6 increases building integrity and prevents a built structure from falling in case of an earthquake. Similarly, when making the roof of a shelter, the tying of gables prevents the fall of the gable walling materials during an earthquake. [4.]

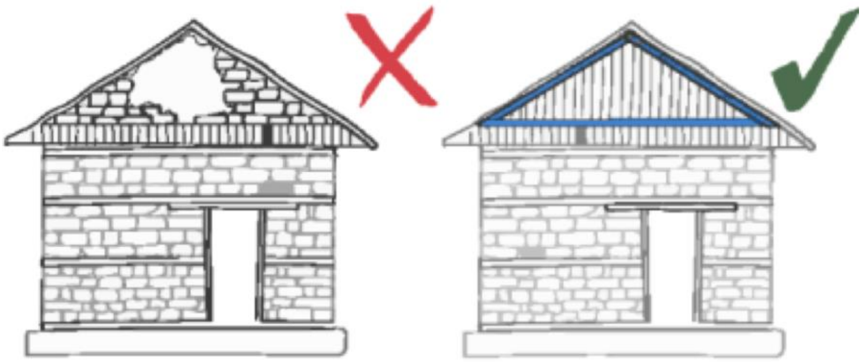

Figure 6. Binding a wall with horizontal bands and tying gables up [4].

Figure 7 shows the tying of walls at the corners with tie stones. This enhances the building's resistance to earthquakes. The tying is done by arranging longer walling stones in a staggered manner at the corners so that the bond between the walls becomes stronger.

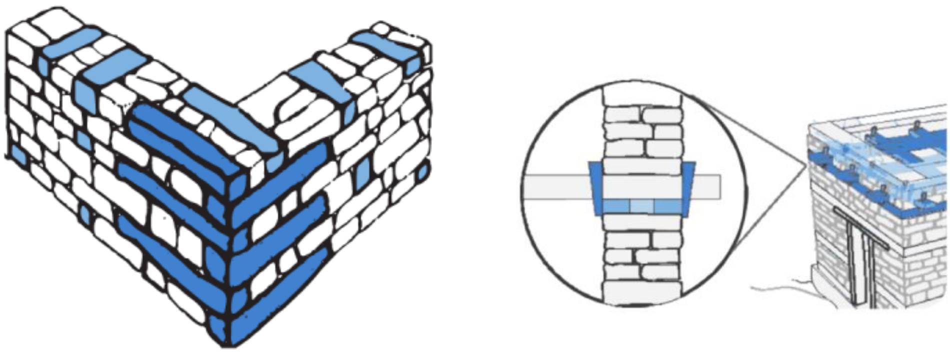

Figure 7. Tying up of walls and floors [4].

Figure 7 shows the wall and the floor tied up in the corner of the building which helps the houses to withstand the lateral movement during an earthquake. To achieve the optimum strength of the building during an earthquake, walls and floors should be tied up at the corner that strengthens the stability of a house during an earthquake. Applying this simple construction technique, the building will act as single integrated unit which enables the forces of an earthquake to be transferred from one section to another without major failure. [19.]

9 Government Proposed Buildings

The Nepalese government has done excellent work to rehabilitate the victims of the 2015 earthquakes. It has changed the laws and made the people aware of how they can make their buildings stronger and more earthquake resistant. The people get free engineering counselling and help in the technical aspect of constructions. Besides simple corrections in the traditional way of construction, the government of Nepal has also proposed various building designs that are earthquake resistant, easier to build and economical due to their design and used materials. The construction materials are locally available and with a few days of training the local mason can build. [5.] The two models which the government has proposed, which especially suit the climate of the hilly region of Nepal, where the temperature is moderate along the year are discussed bellow.

9.1 Compressed Stabilized Earth Block Masonry

A compressed earth block masonry house is built with compressed stabilised earth blocks (CSE) in mud mortar with a stabilized roof. The building has a strip foundation of compressed earth block masonry with the of width 400 mm and a depth of 400 mm. The masonry wall is constructed with 300*200*100mm cement stabilized earth blocks in mud mortar. All the construction materials are found locally. [20.]

Figure 8. Compressed stabilized earth block masonry building [20].

The Figure 8 shows the front elevation of a CSE building consisting of the main door and three windows on the front side. Wooden doors and windows with glass and aluminium frame are used in the construction. Glass windows help to gain maximum sunlight in the day, which also reduces the energy consumption. Shading is provided over the porch which can be used as common space. A building constructed in this design is a reflection of traditional architecture of the hilly region of Nepal. A corrugated galvanised iron (CGI) sheet is used as roofing material. [20]

9.2 Compressed Stabilized Earth Block

A CSE block also called an earth brick, is a reliable and earth-quake resistance material suitable for an earthquake-prone country like Nepal. This brick house technology is proven and used for decades in earthquake-affected areas for example India and Pakistan. This technique assures high-quality earthquake resistance construction at a low cost. The behaviour and properties of a CSE block are similar to those of fired bricks.

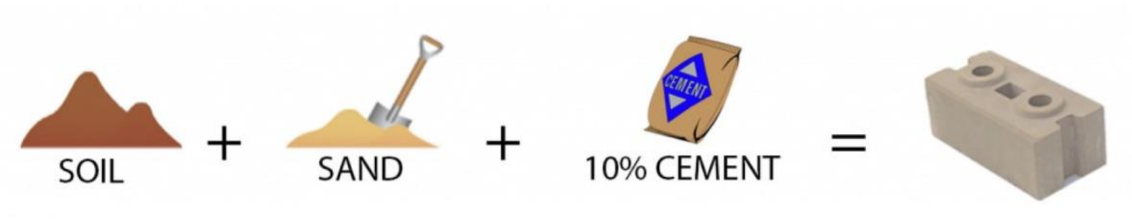

Figure 9. CSE brick block [21].

Figure 9 shows the component mix when making CSE block. CSE block consists of soil, sand and 10 percent of cement. The mixture is compressed in a machine to produce high density compacted blocks, and cured for three weeks which sets the adhesive and stabilizes the brick and results in a compacted brick with high density. [21.]

9.3 Life Cycle Impact Assessment of CSE Block Masonry Building

In this final year project, the life cycle assessment was done using one-click LCA. The obtained results from the calculations are summarized in table 2. The results represent the total life cycle impact of the buildings during 50 years of service life. The calculations show that the total embodied carbon of the studied sample building is 296 kg CO2 /m^2.

Table 2. Impact of the CSE building in environment

Impact category	Unit	Results
Global warming potential (greenhouse gases)	kgCO2 eq.	9.18
Acidification potential	kgSO2 eq.	5.09
Eutrophication potential	kgPO4-eq	2.1
Ozone depletion potential	kgCFC11eq	3.32
Formation of ozone of lower atmosphere	kgC2H4eq	1.67
Primary energy	MJ	1.04

Table 2 shows the calculated result of the life cycle assessment of CSE buildings. The results show the total environmental impact of the house during the construction to demolition phase and throughout the service life of the CSE block building.

9.4 Embodied Energy of CSE Block Masonry Building

Embodied energy is the total energy required to produce any service. The process of accessing embodied energy in building life cycle includes measuring or estimating the total energy consumed in the lifecycle of the building. This energy may come from for example electricity, oil or natural gas, and also consists of the feature which may not be easy to quantify like water use. [22.] Table 3 below shows the embodied energy and impact of the building materials on the environment throughout the life cycle of CSE block house.

Table 3. Lifecycle assessment result of CSE block house

		Global warming kg CO2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethen	Primary energy MJ
A1-A3	Construction materials	1.88E4	5.53E1	8.31E0	1.27E-3	6.82E0	1.93E5
A4	Transportation to site	1.81E2	4.92E-1	1.13E-1	6.78E-6	-8.81E-2	2.99E3
A5	Construction and installation process	2.28E2	8.73 E-1	6.68E-1	1.68E-5	2.91E2	2.62E3
B1-B5	Maintenance and material replacement	7.45E3	1.8E1	3.32E0	5.72E-4	2.62E0	6.34E4
B6	Energy use	6.2E4	4.14E2	1.46E2	1.15E-3	6.33E0	7.2E5
B7	Water use	2.53E3	1.77E1	5.06E1	2.55E-4	7.41E-1	4.56E4
C1-C4	Deconstruction	6.67E2	2.72E0	6.02E1	4.48E-5	2.1E-1	1.09E4
D	External impacts (not included in totals)	-2.63E3	-6.91E0	-2.03E0	-7-39E-5	8.3E-1	-3.56E4
	Total	9.18E4	5.09E2	2.1E2	3.32E-3	1.67E1	1.04E6

From table 3, it is seen that the construction materials and the energy use in the building cause more carbon emissions than other factors of the LCA studied. Since all materials are locally made and available close to the construction site, transportation of the construction materials has less impact on the assessment. Without any building technology installed in the building, there is more impact from the energy. Maintenance and material replacement does not have an impact as it can be said that using these materials is economical in the long run of the building both in terms of cost and environmental impact.

The calculation results presented in figure 10 below illustrate the share of embodied carbon for various building elements and materials for bamboo and stone masonry building. Among the materials important for embodied carbon are brick (54 percent), steel structure (21 percent) and doors and windows (14 and 9 percent, respectively).

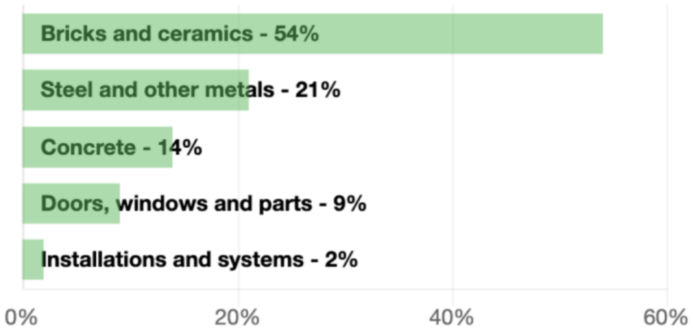

Figure 10. GWP contribution of construction materials used

Figure 10 shows that the primary building materials like bricks and ceramics contribute most to global warming. Although the model building does not have any modern building services systems like ventilation and heating systems, energy usage during the service life accounts for a major share of the embodied carbon. The building material has less impact on global warming due to its natural resources. Building materials sourced locally for construction reduces the carbon emissions and costs related to transportation.

9.5 Global Warming Impact of CSE Building

The global warming potential of various stages during the service life of the CSE block house was obtained from the life cycle assessment calculation. The various stages in the service life used in the LCA are indicated with the colour code next to the pie chart in figure 11. A1-A3 represent construction materials, B1-B5 stand for maintenance and materials replacement, B6 is the energy use, B7 the water use and C1-C4 are the construction and demolition. The phases A1 to A2 produce 20%, the phases B1 to B5 8%, the phases B6 67%, the phase B7 3% and the phase C1 to C4 produce 1% of the global warming impact of a CSE building throughout its service life.

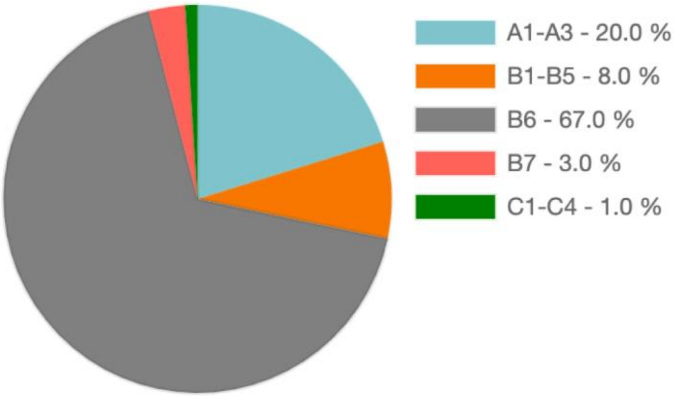

Figure 11. CSE Building's net impact on global warming

Figure 11 shows the net impact on global warming of the different materials and components used in the construction. Primary energy (B6) has the biggest effect on global warming, about 67%, followed by construction materials (A1-A3) with 20%. Maintenance and replacement (B1-B5) and water use (B7) in the building throughout its service life cause 8% and 3% of the total impact, respectively. The deconstruction of the building does not play a vital role in global warming, it has a negligible effect.

10 Bamboo and Stone Masonry Hybrid Structure

Bamboo and stone masonry hybrid building proposed in the design catalogue is a traditional building, integrated with earthquake resistant construction techniques. Due to the versatility, high strength, and availability of bamboo and stone, they have been widely used in construction in Nepal. Seasoned and well-treated bamboo is used mostly in non-load bearing structures, whereas natural stone masonry wall with mud mortar is common in the ground floor of a house. This design is a perfect example of strengthening the traditional construction method of stone masonry with bamboo as vertical reinforcement. This construction technique is resistant to earthquakes and sustainable both economically and environmentally. [20.]

Figure 12. Front and side elevation of bamboo and stone masonry hybrid structure. [20].

Figure 12 shows the front and side elevation of the bamboo and stone masonry hybrid structural buildings. The building has a masonry wall of stone with mud mortar in the ground floor and bamboo wall in the first floor. [20]

10.1 Life Cycle Assessment of Bamboo and Stone Masonry Hybrid Structure

The life cycle assessment of a bamboo and stone masonry hybrid structure done for the thesis was calculated in one click LCA. The environmental impacts are calculated for of 50 year service life. The results thus obtained are presented in table 4 below.

Table 4. LCA assessment results according to impact category

Impact category	Unit	Results
Global warming potential (greenhouse gases)	kgCO_2 eq	7.92
Acidification potential	kgSO_2 eq	5.24
Eutrophication potential	kgPO_4-eq	2,28
Ozone depletion potential	kgCFC_{11}eq	2.51
Formation of ozone of lower atmosphere	kgC_2H_4eq	1.16
Primary energy	MJ	1.01

Table 4 shows the results obtained from the LCA calculation of the bamboo and stone masonry building. The result quantifies the environmental impact of the building during its construction, operation, and demolition phases. The global warming potential of greenhouse gases measured in kg CO_2 equivalent can be attributed to the transportation of materials and equipment to the construction site. The purposed building has an impact of 1.01 MJ from primary energy to the environment annually. However, it has to be noted that the primary factor for supplied energy is most likely lower in the project scenarios than in the data input. The primary factor for diesel can be assumed to be the same as the one used by the LCA tool. In the absence of project-specific data, generic data were used in the final year project.

10.2 Embodied Energy

The value of the embodied energy of individual materials at different stages has been summarized in table 5. Construction materials have a significant role in carbon emissions. Energy usage in the buildings was found to have the highest embodied energy with 85% of the total embodied energy.

Table 5. Lifecycle assessment result

		Global warming kg CO2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Etheee	Primary energy MJ
A1-A3	Construction materials	5.35E3	4E1	7.68E0	4.99E-4	3.27E0	1.11E5
A4	Transportation to site	8.46E1	3.83E-1	8.34E-2	1.66E-5	5.23E-3	2.42E3
A5	Construction and installation process	2.32E3	7.98E0	4.92E0	3.25E-4	2.94E-1	4.14E4
B1-B5	Maintenance and material replacement	9.42E2	6.8E0	1.61E0	1.43E-4	3.14E-1	2.31E4
B6	Energy use	6.72E4	4.49E2	1.58E2	1.24E-3	6.86E0	7.85E5
B7	Water use	2.77E3	1.94E1	5.55E1	2.79E-4	8.12E-2	5E4
C1-C4	Deconstruction	6.11E2	7.71E-1	1.81E-1	1.64E-6	6.08E-2	2.1E3
D	External impacts (not included in totals)	-2.97E3	-4.81E0	-1.16E0	--4.17E-5	-6.49E-1	-4-98E4
	Total	7.92E4	5.24E2	2.28E2	2.51E-3	1.16E1	1.01E6

Table 5 above presents the 50-year total life cycle assessment for a bamboo and stone masonry house model. From this assessment result, it can be seen that a considerable amount of carbon emissions came from construction materials and primary energy supplied to the house as shown below in figure 13.

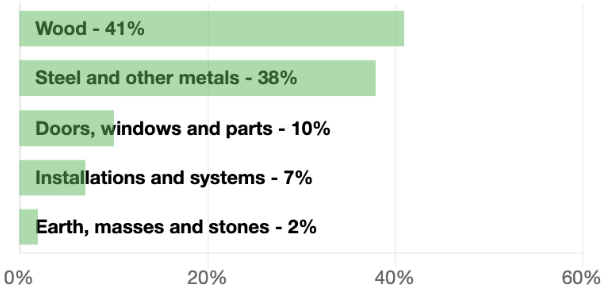

Figure 13. Share of GWP of building materials.

As shown in figure 13, a large share of the embodied GWP comes from the wooden products, attributing to 41 percent of net GWP of the construction materials used, followed by steel and metals with 38 % of the net GWP. GWP related to earth materials was the lowest among all the materials used in the building.

10.3 Global Warming Potential

The global warming potential of the various stages during the service life of the bamboo and stone masonry hybrid structure was obtained from the calculation. The outcome of the calculations is shown in figure 14 below. The various stages in the service life of building are indicated with the colour code next to the pie chart in the figure.

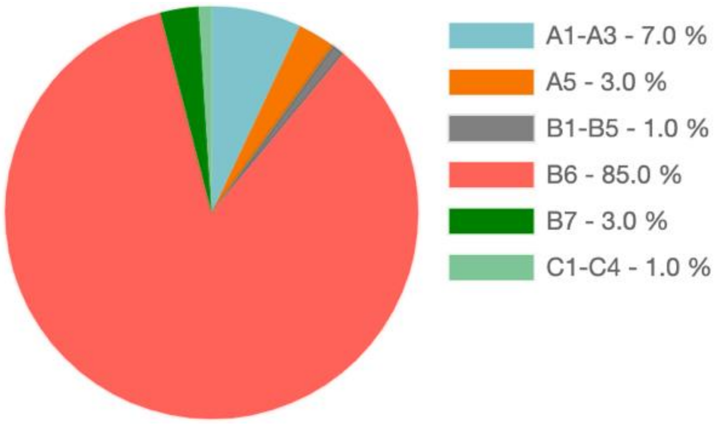

Figure 14. Global warming potential at different stages of building's lifecycle

Figure 14 shows a pie chart that reflects the bamboo and stone masonry building's potential life cycle impact. Constructions like the bamboo and stone masonry hybrid structures have little impact on global warming. Only seven percent of the total global warming impact is produced by construction materials, most of it comes from primary energy supplied. The installation of the construction materials (A5) and water use (B7) contribute three percent of the global warming impact of the building. Maintenance and installation (B1-B5), and deconstruction(C1-C5) have very little impact on the global warming, only one percent. As the building consumes a significant amount of energy, reducing the energy consumption can reduce the building's GWP. A reduction in energy consumption can be achieved with a climate responsive design and by using energy efficient technology.

11 Building Elements and Scope Included in LCA

Table 6 below shows the components of the building and the range of the LCA that are included in the calculation of lifecycle impact assessment of the buildings.

Table 6. Building components assessed in LCA

Element	Comments
SUPERSTRUCTURE	
Upper floors	yes
Roof	yes
Stairs	yes
External Walls	yes
Windows	yes
Internal Walls and Partitions	yes
Internal Doors	yes
INTERNAL FINISHES	
Wall Finishes	Yes
Floor Finishes	No
BUILDING FITTINGS & FURNISHINGS	Not applicable in the buildings
Fixed fittings and equipment	No
SERVICES	No, not applicable in the buildings
Heat Source	No, not applicable in the buildings
Space Heating and Air Treatment	No, system is not required
Ventilation Systems	No , ventilation system was not installed
EXTERNAL WORKS	no

To complete the life cycle assessment, various building elements such as the floor, roof, stairs and wall finishes were included to calculate the LCA of the building in section 10.

Building services technology like heating or ventilation are not taken into account as they were not installed in the studied buildings. The installation of the building elements and operational water and energy use of the buildings throughout their service life are taken into account in the assessment.

Table 7. Scope included for LCA assessment of CSE block house and stone bamboo hybrid masonry building

Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage				Benefits and loads beyond the system boundary		
Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A 1	A 2	A 3	A 4	A 5	B 1	B 2	B 3	B 4	B 5	B 6	B 7	C 1	C 2	C 3	C 4	D	D	D
x			x	x						x	x					x		

Table 7 shows the scope of the lifecycle assessment at the various stages of construction. At production stage, the supply of raw materials required for the construction is included, and the transportation of the materials to the sites is taken into account. A tentative distance to the construction sites in kilometres is provided in the one click LCA application. The installation of the materials at the construction stage is also taken into account in order to calculate the life cycle impact. In the use stage the most contributing factors are the energy and the water used by both building throughout its service life are taken into account. The reuses of the leftover materials after construction are also included in the calculation of lifecycle impact assessment.

12 Conclusion

The final year project aimed at studying the sustainability of the vernacular construction in the hilly region of Nepal. The study also calculated the carbon emissions and other environmental impact of the building with one click LCA software. The result obtained from the calculation shows that a building constructed with vernacular materials has a lower impact on CO_2 emissions and global warming. The available materials for building construction in the hilly region of Nepal include stone, brick, mud, cow dung, wood, and clay. A building constructed with these materials has low carbon emissions, energy efficient, economical and has low environmental impact.

Simple improvements in construction techniques are recommended to give a structure stability against earthquakes and weather effects. Locally available construction materials used for housing decrease the cost of the building as the extra costs for transporting materials from a distant place are nullified. Passive solar techniques used for construction result in climate responsive design solutions and, at the same time, lower the cost of heating and cooling and, finally, decrease the building operation costs greatly in the long run, which enhances sustainability. Construction materials used in building not only cut the costs of building construction but also preserve the uniqueness and identity of a place. Traditional ways of constructing buildings comprise natural materials and techniques which ultimately make the building perform well, maintain the thermal comfort inside the building without consuming much energy and preserve the unique vernacular architecture of a region. These designs should be incorporated in modern construction to make it more earthquake resistive.

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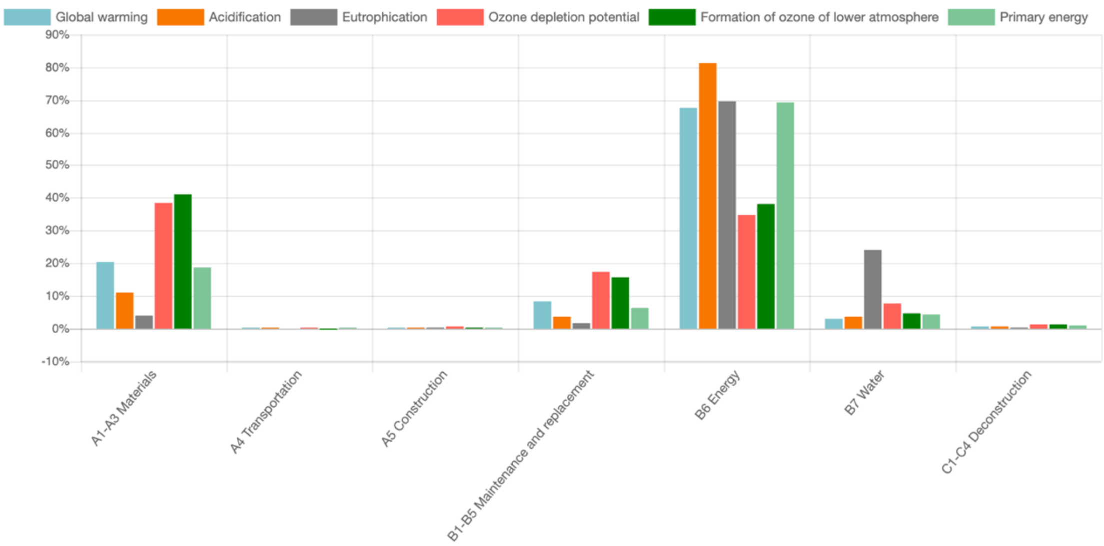
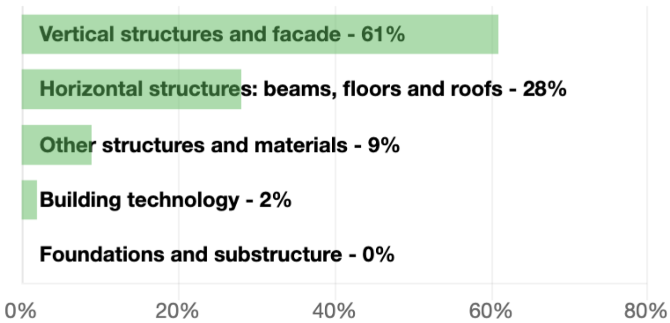
Life cycle Assessment CSE building

Result distribution by lifecycle stage of CSE buildings



Most contributing building element in GWP of CSE building



Construction materials assessed in the LCA of CSE building.

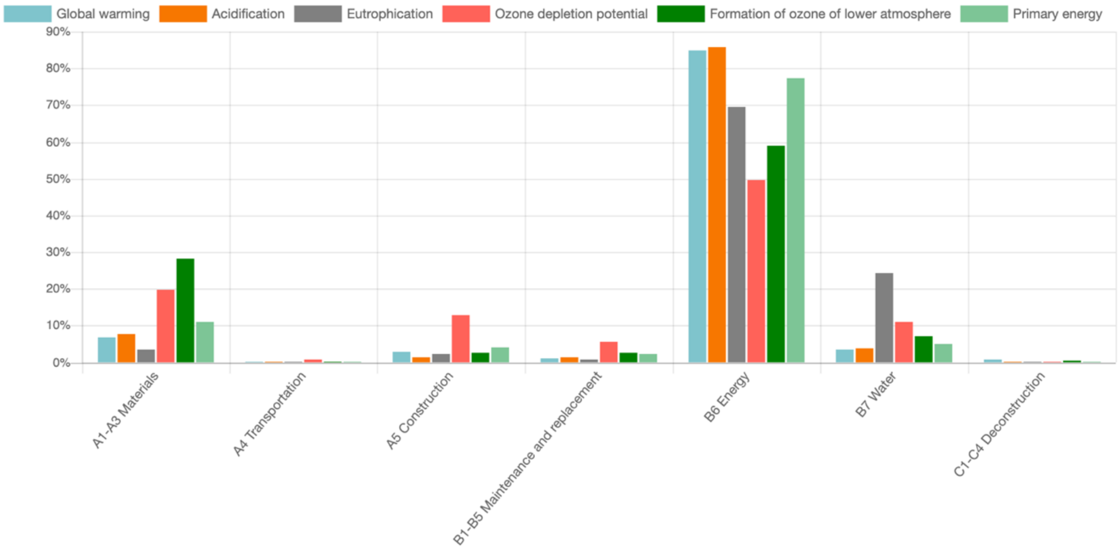
Life-cycle assessment, EN-15978: Construction Materials

Show numbers | Hide headings | Close

Construction	Resource	User input	Global warming kg CO2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Primary energy MJ	Comments
› Building materials > Foundations and substructure > Foundation, sub-surface, basement and retaining walls									
		Section share	0,13 %	0,12 %	0,11 %	0,08 %	0,07 %	0,11 %	
› Building materials > Vertical structures and facade > External walls and facade									
		Section share	36,42 %	22,64 %	20,63 %	34,86 %	34,45 %	21,23 %	
› Building materials > Vertical structures and facade > Columns and load-bearing vertical structures									
		Section share	7,53 %	6,78 %	6,32 %	4,63 %	3,95 %	6,47 %	
› Building materials > Vertical structures and facade > Internal walls and non-bearing structures									
		Section share	17,25 %	10,72 %	9,77 %	16,51 %	16,31 %	10,05 %	
› Building materials > Horizontal structures: beams, floors and roofs > Floor slabs, ceilings, roofing decks, beams and roof									
		Section share	27,63 %	32,82 %	31,42 %	22,54 %	29,96 %	35,59 %	
› Building materials > Other structures and materials > Windows and doors									
		Section share	8,85 %	22,25 %	20,45 %	14,79 %	14,39 %	22,87 %	
› Building materials > Other structures and materials > Finishings and coverings									
		Section share	0,09 %	0,36 %	0,07 %	0 %	0,19 %	0,18 %	
› Building materials > Building technology > Building systems and installations									
		Section share	2,1 %	4,3 %	11,23 %	6,61 %	0,69 %	3,49 %	

Life cycle Assessment Bamboo and stone masonry building

Result distribution of lifecycle stage of Bamboo and stone masonry buildings



Construction materials assessed in the LCA of bamboo and stone masonry building.

Life-cycle assessment, EN-15978: Construction Materials

Show numbers Hide headings Close

Construction	Resource	User input	Global warming kg CO2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Primary energy MJ	Comments
› Building materials > Foundations and substructure > Foundation, sub-surface, basement and retaining walls									
		Section share	0,29 %	0,1 %	0,08 %	0,13 %	0,09 %	0,12 %	
› Building materials > Vertical structures and facade > External walls and facade									
		Section share	31,55 %	49,34 %	30,77 %	22,1 %	38,37 %	23,22 %	
› Building materials > Vertical structures and facade > Columns and load-bearing vertical structures									
		Section share	7,27 %	3,88 %	24,06 %	11,55 %	10,1 %	10,45 %	
› Building materials > Vertical structures and facade > Internal walls and non-bearing structures									
		Section share	3,01 %	4,73 %	2,46 %	2,16 %	4,52 %	1,97 %	
› Building materials > Horizontal structures: beams, floors and roofs > Floor slabs, ceilings, roofing decks, beams and roof									
		Section share	1,4 %	0,84 %	0,9 %	1,48 %	1,27 %	3,22 %	
› Building materials > Other structures and materials > Windows and doors									
		Section share	10,22 %	11,07 %	8,74 %	11,8 %	8,16 %	14,72 %	
› Building materials > Other structures and materials > Finishings and coverings									
		Section share	38,87 %	24,08 %	20,84 %	33,91 %	36,06 %	40,22 %	
› Building materials > Building technology > Building systems and installations									
		Section share	7,39 %	5,95 %	12,15 %	16,86 %	1,43 %	6,07 %	