Vernacular Construction Techniques of the Kangra Region of Himachal Pradesh, India

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Abstract

Architecture of a specific place is always an outcome of geography, availability of materials and resources, climate, socio-economic conditions, and, most importantly, culture. Considering the harsh conditions, indigenous architecture forms the spine of its social and cultural setup. In indigenous architecture, inhabitants do the construction primarily by hand and sometimes with the help of other inhabitants from the village. Knowledge of construction is empirically passed down from generation to generation, mainly through oral narratives or years of apprenticeship.

A notable indigenous architecture exists in India's Kangra region of Himachal Pradesh. This research examines the indigenous architecture of this region. Residential structures are notable for their considerable energy consumption and production of substantial emissions and waste. The potential for energy conservation in the housing sector is significant and warrants evaluation through building's entire life cycle. Life Cycle Assessment (LCA) has been employed to examine the primary energy utilization and corresponding environmental consequences associated with various stages of residential building development, including product manufacturing and construction processes.

In this investigation, two distinct house types were analyzed to determine their total embodied energy: a traditional vernacular house constructed using dry stone and a modern contemporary house. The embodied energy calculation incorporated the conveyance of unprocessed materials to the manufacturing facility and the delivery of end products to the consumer. After comparing, it became evident that the total energy usage of the traditional house was just 2% of the energy consumption of the modern house making it a more environmentally friendly option.

Keywords: Embodied Energy, Himachal Pradesh, Vernacular Architecture, Life Cycle Assessment, Indigenous architecture

1 Introduction

From the historical records kept in Himachal Pradesh, it can be observed that vegetation in areas like Kangra is comparatively weak. This means there is a lack of high-quality wood, such as deodar only found in higher altitudes, which can be utilized as structural members in the construction of houses. Due to the abundant supply of river stones and the dearth of wood, people have been forced to abandon their conventional building methods, such as *Kath-kunni* (cator-and-cribbage). Instead, they have adopted this dry-stone masonry version. This form of buildings has no common local name; instead, it is referred to as "*patthar ke makan*" (houses of stone). The intricate use of interlocked joints without nails is the hallmark of indigenous construction. With changing times, as a society, knowledge, construction and values continuously transform, while newly introduced modern materials such as cement, concrete, and plaster of paris etc are replacing the old.

Residential structures are a crucial contributor to environmental and energy problems since they account for a sizable amount of land use and house the most significant number of people. The building industry consumes about 39% of all primary energy, 38% of carbon emissions, and 40% of unprocessed materials annually in the US and Canada. (Ooteghem and Xu, 2012). Due to these effects, the sector has embraced ways for more effective, ecologically friendly designs and building methods. (Ganjidoost and Alkass, 2012). Sustainability aims to place an increased emphasis on environmental concerns. Therefore, a building's environmental evaluation is crucial for reaching sustainability objectives. The building industry frequently uses the Life-Cycle Assessment (LCA) method to examine and quantify the environmental effects of a structure throughout its entire life cycle, including the procurement of unprocessed materials, construction, usage and end of life (Asif, Muneer and Kelley, 2007). Many LCA studies have been done in the construction industry, with many of them concentrating on residential constructions.

The embodied energy of two distinct construction types—traditional construction and vernacular construction—is explicitly examined in this study. To achieve better understanding of the full life-cycle effects of residential buildings in Himachal Pradesh, this study compares two distinct house styles from the same region: vernacular construction and contemporary construction. The aim of this study is to assess and analyze, using LCA ideas, the primary energy use related to these two types of residential buildings. It considers the embodied energy of structures exclusively in the Himachal Pradesh province of Kangra. The following supporting objectives must be fulfilled to reach this primary goal.

- Documentation of architectural aspects of houses of different construction types.
- Estimation of quantities associated with the construction of the selected houses.
- Performing a building energy simulation to identify the buildings' operational energy.

A wide range of stakeholders, and researchers, including planners, engineers, developers and politicians are anticipated to find value in the study's findings.

2 Literature Review

A life cycle perspective is recommended for evaluating resource consumption, energy use, and environmental impacts of the building sector (Bekker, 1982). This comprehensive approach encompasses the whole life span of a structure, from its erection and usage to its decommissioning and disposal (Bekker, 1982). By considering these aspects throughout the lifecycle of a structure, opportunities for enhancing energy efficiency and reducing the environmental footprint of the sector can be identified (Bekker, 1982). Numerous studies have focused on the embodied energy of various structure types, particularly during the construction phase. Suzuki, Oka and Okada (1995) point out that steel-reinforced concrete buildings exhibit the highest embodied energy at 8-10 GJ/m2, followed by lightweight steel buildings at 4.5 GJ/m2, and wooden buildings at 3 gigajoule per sq. m. Debnath, Singh and Singh (1995) show that steel, cement, and brick are the main contributors to the embodied energy of a single-story residential building with load bearing construction, constituting 9%, 33%, and 41% of the full embodied energy, respectively. Adalberth (1997a, 2000) examining 7 residential buildings in Sweden has discovered that the construction phase represented 14-15% of the entire life cycle energy usage, while building operations accounted for 84-85% and transportation, erection, and demolition for 1%. Chen, Burnett, and Chau, (2001) have analyzed 25 Australian homes finding that in-situ construction energy constituted around seven percent of the total preliminary embodied energy, with operating energy being four times greater than the construction energy. Transportation and equipment used during the on-site construction phase accounted for sixty nine percent and twenty eight percent, respectively, of the total in-situ construction energy usage. The construction phase contributed 20% to the entire life cycle energy usage.

According to the LCA of a partially-detached house in Scotland, reinforced concrete accounted for sixty five percent of the entire embodied energy usage in the construction (Asif, Muneer and Kelley, 2007). An analysis of a 55 m^2 house in Indonesia found that embodied energy constituted 9 to 14% of life cycle energy, with the building envelope serving as a significant source of embodied energy (Utama and Gheewala, 2008). Another study discovered a 50% decrease in embodied energy when contrasting a low-energy house with a traditional concrete structure (Shukla, Tiwari and Sodha 2009; Devi & Palaniappan, 2019). A study examining houses in Spain and Colombia have revealed that elements like usage patterns, climate variations, technology-related factors and cultural as well as socio-economic differences played a role in affecting energy usage and emissions over the course of life cycle of a structure (Ortiz-Rodrguez, Castells & Sonnemann, 2010). According to research, building operation, in-situ construction, and material manufacturing contributed, respectively, to thirteen percent, one percent, and eighty six percent of the entire life cycle energy (Kua and Wong, 2012).

There are hardly any studies comparing the embodied energy of contemporary structures with residential buildings constructed using traditional methods. It is true also for the Kangra region of Himachal Pradesh.

3 Research Methodology

This research compares two distinct buildings located in Kangra village, Himachal Pradesh, to analyze their embodied energy based on the materials used and construction techniques employed. One of the buildings is a vernacular residential structure constructed in 1930 using traditional materials. It consists of two rooms, a storage area and a verandah, covering a floor area of 85.5m2. The second building is a contemporary structure made from modern materials like reinforced concrete (RCC) for the roof, concrete for the floor and clay bricks for the walls. This building features five rooms and a veranda. The contemporary structure has windows with a 20% window-to-wall ratio and single-pane, clear glass having SHGC of 0.86, fitted in wooden frames. Conversely, the traditional building features a sloping slate roof, a mud floor, and slate walls with mud plaster, as well as windows with a 20% window-to-wall ratio fitted with wooden panels in wooden frames.

The aim of this research is to calculate the demand in terms of energy for the production of both buildings from a primary energy perception. It is assumed that the energy utilized for any renovations of the structures will be relatively minor and is incorporated in the embodied energy calculation for the structures. The coefficients of embodied energy for the materials used for construction is derived from a literature review. To achieve the objectives, several case studies are conducted. Following steps are employed.

- A physical survey of the study area is carried out to identify contextual issues and settings. This survey aims to comprehend the typology, architectural style, construction techniques and materials used in the case study of Kangra region's vernacular architecture, specifically dry-stone construction houses.
- A document survey is conducted to investigate the context and the rationale behind the construction techniques practiced in the region.
- Analysis and inferences drawn from the case studies are categorized into two aspects: architectural aspects and life cycle energy aspects. This classification helps in understanding the implications of the building techniques and materials on the embodied energy of the buildings and offers insights into potential improvements for energy efficiency and sustainability.

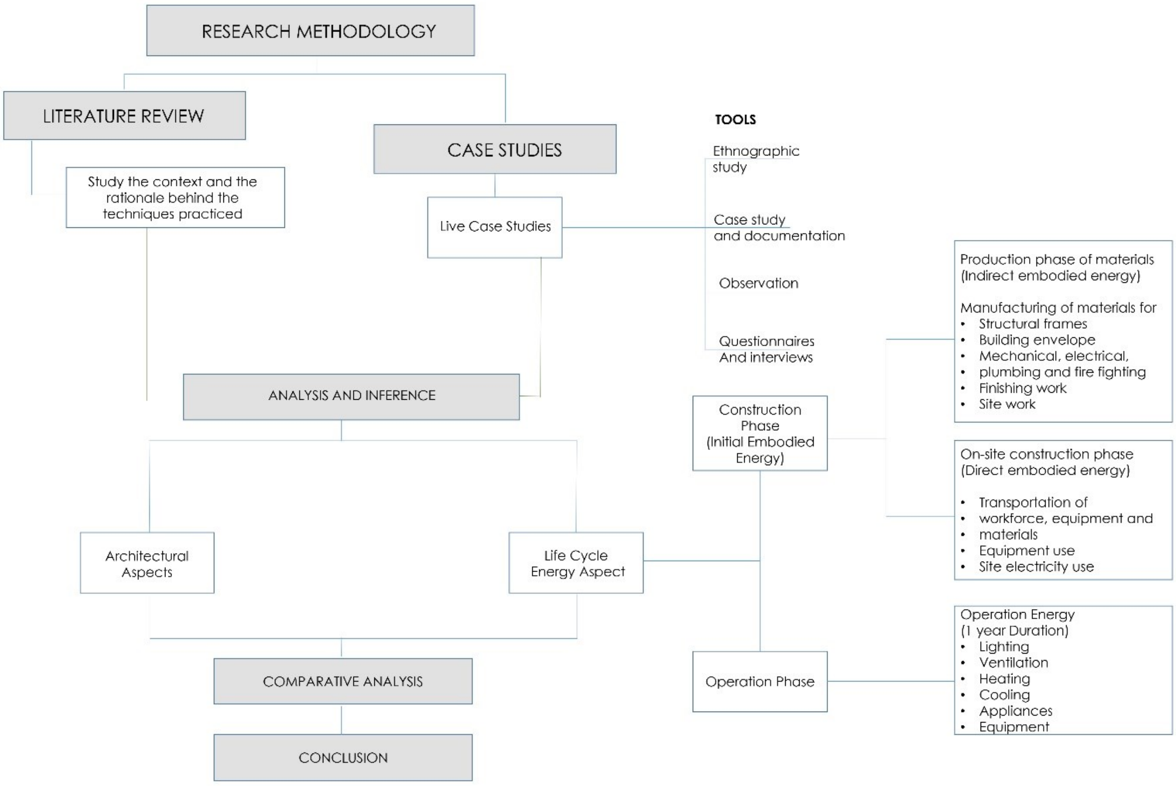

Fig. 1: Life Cycle Energy Aspect- For the calculation of total Embodied Energy, only Embodied Energy Initial (i.e., manufacturing) and Embodied Energy on-site is considered, and no recurrent and end-life embodied energy is considered.
Source: Author

4 Introduction to the site: Kangra (Himachal Pradesh)

The Kangra district is situated between the latitudes of 31° 21' and 32° 59' N and longitudes of 75° 47' and 77° 45' E, aligned on the southern edge of the Himalayan Mountain range (Uniyal, Sharma and Jamwal, 2011). The Shiwalik and Dhauladhar ranges traverse the district from the Southeast to the Northwest, resulting in an elevation that varies between five hundred and five thousand meters above the mean sea level. The topography of Kangra, a region in the mountains of the Himachal Pradesh, India, is characterized by high, undulating landforms with elevations ranging from 500 to 5,000 meters above the mean sea level. Deep valleys nestled amid mountain ranges of varying heights characterise the mountainous landscape. To better comprehend and categorize the Kangra's diverse terrain, the region is divided into three altitude-based zones: low hills and valleys, mid hills, and high hills (Uniyal, Sharma, and Jamwal, 2011). Low hills and valleys, accounting for 49% of the district reach elevations up to 900 meters above the mean sea level. Mid hills, constituting 16% of the district, range from 900 to 1,500 meters, while high hills, spanning 35% of the district's area, extend from 1,500 to 5,000 meters above the mean sea level. Each of these zones possesses distinct characteristics, providing a variety of ecological environments that support diverse plant and animal species. Understanding Kangra's altitude-based zoning can inform land-use planning, management decisions and conservation efforts for the region's diverse ecosystems. Kangra's climate varies with altitude, resulting in mild conditions in the high hills, sub-humid conditions in the middle hills and a sub-tropical climate in the low hills and valleys. The region experiences an average annual rainfall of approximately 205 cm, with the southern areas receiving 100 cm and the northern areas up to 250 cm. Approximately 80% of the precipitation occurs from June to September.

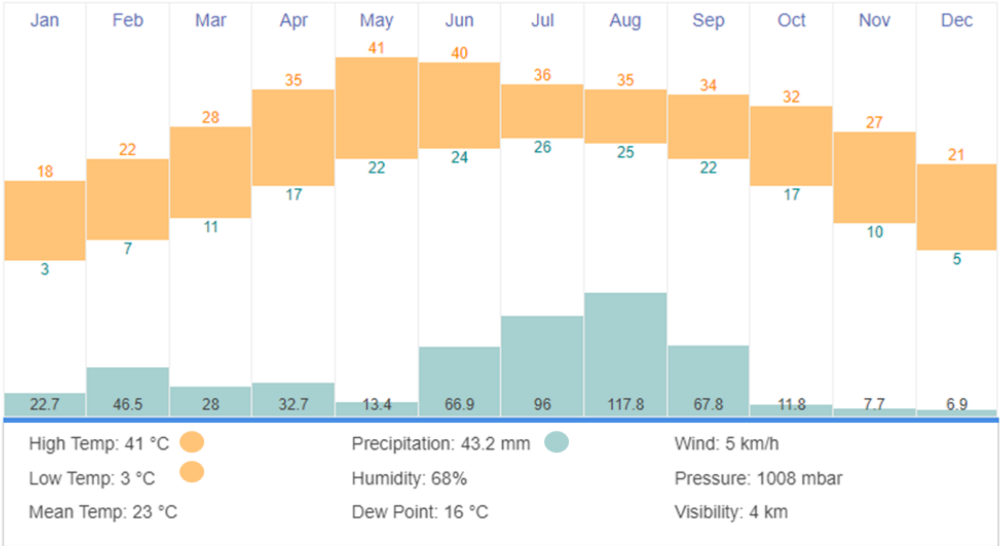

Fig. 2: Annual Rainfall in Kangra and the Himachal Pradesh
Source: https://www.timeanddate.com/weather/@1268083/climate

The forest cover in Kangra spans over 284.18 thousand hectares, accounting for more than 49% of the total geographical area. However, only 143.3 thousand hectares, or one-fourth of the total geographical area are currently utilized as forest resources. Four primary forest divisions exist in the Kangra district: Nurpur, Palampur, Dehra, and Dharamsala. Additionally, two more forest blocks fall under the Una Forest Division (Ramprasad, Joglekar, and Fleischman, 2020). These forests are further classified into seven broad categories, reflecting the diverse range of forest types and plant species in Himachal Pradesh, India. Dry alpine forests in the Baijnath region's Bara Bhangal and Chhota Bhangal feature xerophytic vegetation, including Lonicera, Juniper, Cotoneaster, and Artemesia. Moist chain scrub forests, situated above the tree line and below the snow line are dominated by Viburnum, Lonicera, and Salix. Sub-alpine forests, found up to 3,500 meters in elevation are characterized by Kharsu and Betula utilis trees. Himalayan moist temperate forests situated above 1,500 meters in elevation in the Kangra region are home to the valuable Cedrus deodara species. Wet temperate forests in Kangra, Dharamsala, and Palampur feature Kail, Deodar, and Chil trees and include bamboo groves on the western slopes. The sub-tropical pine forests found at the mean sea levels between 1,000 and 2,200 meters in the Dehra, Nurpur, and Kangra areas are dominated by Himalayan chil trees. Finally, the sub-tropical broad-leaved hill forests found below 1,000 meters in the sub-tropical areas of Kangra, such as Indora, Pragpur, and Dehra are characterized by albizia, Khair, kachnar, tun, bamboo, and beul trees. Overall, the forests of Himachal Pradesh are diverse and support a wide range of plant and animal species.

5 Slate as a Building Material

Slate is a type of metamorphic rock that is finely grated and imitative from sedimentary rock shale, made from clay or volcanic ash through the rigorous process of regional metamorphism. Among the category of metamorphic rocks, it is the best-grained foliated. Moreover, in this case, foliation corresponds to planes in the direction perpendicular to metamorphic compression, not the original sedimentary layering (Lee and Kim, 2021; Bogdanowitsch, Sousa and Siegesmund, 2022). The most protuberant roofing material used in the Himachal Pradesh is slate. These come mainly from Thatri, Kareti, Khaniara, Narwana, and Bhagsunath. Nevertheless, this process of mining slates goes back to the 1880s. Earlier, these quarries were handled and controlled by the local contractors with mining privileges, but lately the administration has taken over these, making this a lot more systematic (Encyclopaedia, 2013;Kant and Kumari, 2021).

Fig. 3: Stone Quarry at Khanyara, Kangra
Source: Author (2022)

6 Dry Stone Construction in Himachal Pradesh

The Kangra region is well known for its dry-stone construction as slates are abundant here. However, the Kinnaur region also carries out this construction style as the excellent quality of stone is quarried there. This whole process is carried out without the use of any mortar. Stones of different sizes are kept over each other and compacted after regular intervals, they are used through the stone. One key point to notice here is that the interlocking of stones is done to achieve a more robust bond instead of throwing the smaller stones in the gaps. Mud plastering of interior surfaces is preferred. Structural walls of stone masonry are made for lateral and gravity loads, which efficiently distribute the load uniformly in orthogonal directions (Kant and Kumari, 2021).

Fig. 4: Dry Stone Construction House
Source: Author (2022)

7 Case Studies

The study adopts a case study approach for the research as this will deliver a thorough description of the cases and their users in the right context. The detailed study will help in structuring a systematic analysis process enabling achieving the research objectives.

7.1 Case Study 1: The Vernacular House of Kangra- VH1

The residential vernacular house is 92 years old (build in 1930), belongs to Ram Karan Rana and is located in the Khaniyara village (Fig. 5) on the outskirts of district Kangra with adjoining residential buildings made of dry stones. The built-up area is 106 sq.m on the ground floor and is used for residing purposes whereas the upper floor is used as a storage area accessed by a stone staircase. The typical rectangular plan of dimensions 12.5m X 8.5m is divided into 4 areas, as a veranda, a storage area and 2 rooms (Fig. 6 and 7).

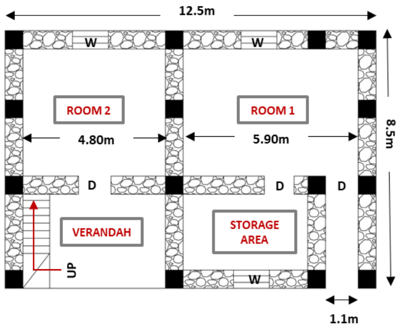

Fig. 5: Isometric View of the House
Source: Kant and Kumari, 2021

Fig. 6: Ground Floor Plan of the House
Source: Author,2022

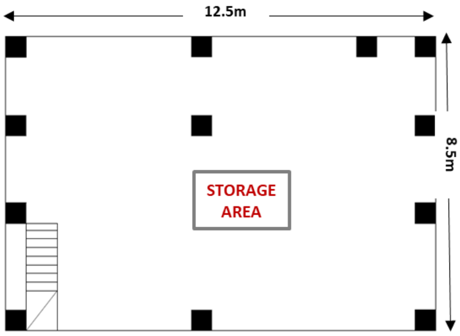

Fig. 7: First Floor Plan of the House
Source: Author,2022

7.1.1 Inferences: Architectural Aspects

Siting: These buildings are typically located on hilly or sloping areas. Although there are no shared walls between them and the next buildings, there may be as little as 30 cm or 3 metres between them (typical street width). In almost all cases, the available land is contoured. As a result, a flat base platform is created using one of the two methods, depending on the slope of the site. A dry-stone gravity retaining wall is built across the steeply sloping terrain to produce usable flat land before the dwelling is built.

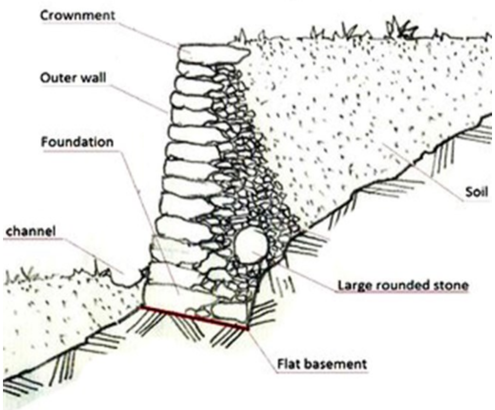

Fig. 8: Dry Stone Gravity wall system
Source: Bragança dos Santos, 2018

On a site with a relatively gentle slope, the cut and fill technique is employed, allowing for a smaller usable space (utilized for storage) on the bottom level and a larger usable area on the top level.

Configuration of the Building: The houses often have a front veranda and a rectangular shaped plan. A two-story house is typical. Ventilation is frequently provided through large apertures in the walls. Because a single brick wall is substantially thinner than a dry-stone wall, small niches are left in the wall, and bricks are placed there to create spaces inside the wall. Horizontal walls are built using wooden planks or RC slabs within the niche that has been created.

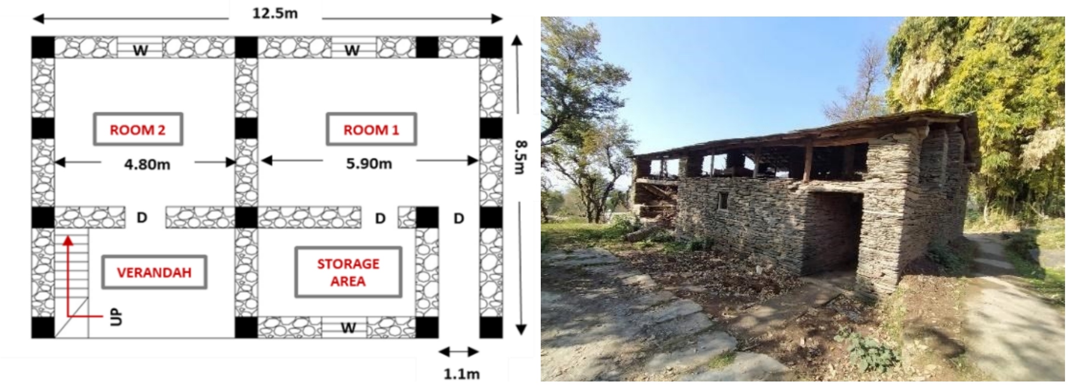

Fig. 9: Typical Rectangular Floor Plan with openings in walls for ventilation
Source: Kant and Kumari, 2021

Modifications to Building: The buildings in question are frequently built in accordance with the original blueprints, with no significant adjustments to older buildings. In some situations, the structure is built with RCC columns, slabs and stone walls.

Fig. 10: Stone wall with RCC columns, slabs and concrete band
Source: Author, 2022

Gravity & Lateral Load-Resisting System: Stone masonry walls serve as a vertical load-bearing system. The most frequent roof style is a slanted wooden roof with slate stone. The gravity force is transferred to the 450-600 mm thick walls constructed of undressed slate stones without mortar by the floors and roof. In some circumstances, RC columns support beams with larger spans (Encyclopedia, 2013; Singh and Sharma, 2019; Kant and Kumari, 2021). In contrast, these supportive RCC columns are non-engineered parts of the structure, and the mason's judgment determines their proportions and reinforcing detailing. The high axial stresses and bearing capacity of the RCC columns are known to the masons; hence, they commonly utilise very thin columns (with cross-sections of 200-250 mm). These columns, like the dry-stone walls are equally vulnerable to earthquake loads because of their slenderness, lack of reinforcement and poor joint details.

Fig. 11: 600mm Stone Column (left) and RC Column to support larger span (Right)
Source: Author,2022

Walls consisting of stone masonry make up the system for resisting lateral loads. The same dry-stone walls, which may be up to 600 mm thick and are composed of undressed river stones without cement supply all of the building's lateral load resistance (Singh and Sharma, 2019). The standard dimensions of these structures are lengths of 8 to 15 meters and widths of 5 to 8 meters. There are two to three levels in each structure, with a standard story height of 2.5 meters. The walls of these structures often have a density of more than 20%, which means that the proportion of the floor area to the total area of the walls facing both directions is high. With rafters, GI sheets, or wood shingles for cladding, roofs are frequently tilted. Stone slates are also utilized for roof cladding, depending on local availability.

The lack of cross-bracing and ties on sloping roofs makes them vulnerable to damage during an earthquake. Due to the dry-stone construction of walls, the connection of walls to the roof is often not seen. Some structures have flat RC roofs, which, because to their in-plane stiffness and favourable bearing on the walls are supposed to slightly enhance a building's seismic behaviour. Without any mortar, the foundations are made of hand-packed stones of various shapes and sizes. For loose soil, the foundation depth up to the ground level is 900 mm; for hard strata, it is 200 mm. The foundation typically has the same width as the wall described earlier (i.e., 450 to 600 mm). The plinth is approximately 300 mm above the ground level. Sometimes backfill is supported by dry stone retaining walls, or a flat platform for the construction is made.

7.1.2 Inferences: Life Cycle Energy Analysis (LCEA) Aspect

In LCEA, the energy embodied in a structure and the energy used to operate it are calculated throughout the anticipated lifespan of the structure (Fay, Treloar and Iyer-Raniga, 2000).

Embodied Energy Analysis Method: The energy required to collect, transport, and refine raw materials, manufacture component parts and assemble the product is included in the energy contained in the product (Fay, Treloar and Iyer-Raniga, 2000).

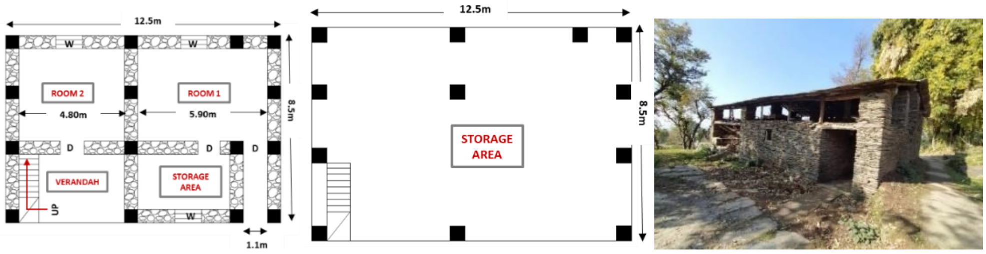

Fig. 12: Ground Floor Plan (1), First Floor Plan (2) (Source: Author,2022) and Perspective View (3) Source: Kant and Kumari, 2021

Table 1: Bills of Quantities of Vernacular House
Source: Author

Building Components	Building Material	Unit	Quantity
Foundation	Slate Stone	m^3	28.30
	Mud	m^3	9.42
Walls	Slate Stone	m^3	78.50
Floor	Slate Stone	m^3	6.03
Roof	Slate Stone	m^3	8.10
Wood Work	Timber	m^3	10.21

The energy intensity (GJ/unit) of timber is 7.2 GJ/unit (Reddy and Jagadish, 2003).

Table 2: Embodied Energy Calculation for House
Source: Author

Building Components	Building Material	Unit	Quantity	Energy Intensity(GJ/unit)	Embodied Energy (GJ)
Foundation	Slate Stone	m^3	28.30	_	_
	Mud	m^3	9.42	_	_
Walls	Slate Stone	m^3	78.50	_	_
Floor	Slate Stone	m^3	6.03	_	_
Roof	Slate Stone	m^3	8.10	_	_
Wood Work	Timber	m^3	10.21	7.2	73.4994
Total					73.4994

In India, natural construction stones have been used to construct several structures. The hard-natural stone is often chopped into workable sizes to produce slate blocks. The sizing activities of slate stone is done by manual labor. Detonators are occasionally used to break apart large, extremely hard stones into smaller pieces for easier handling during manual processing. Consequently, very little thermal energy is used to produce desired size stones. (Reddy and Jagadish, 2003)

Operational Energy Analysis Method: The study of operational energy is based on the consumption of electricity for the residence. The value of operational energy of the residence calculated in the design builder is 12.63 kWh/m^2 (0.045468 GJ).

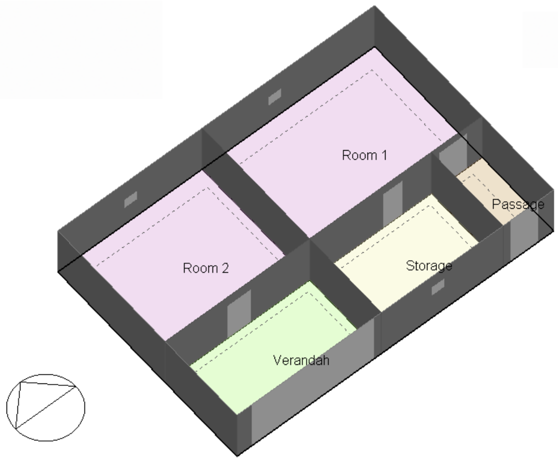

Fig. 13: Isometric Plan of Vernacular House from Design Builder V4.0
Source: Author

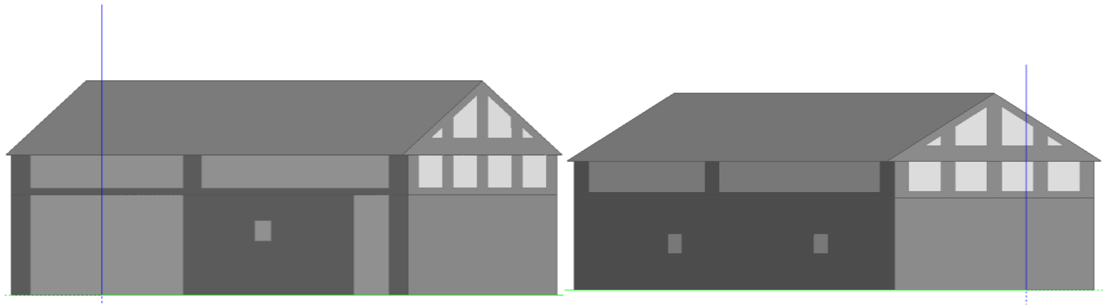

Fig. 14: Front (Left) and Rear (Rear) Elevation of Building from Design Builder V4.0
Source: Author

Life cycle Energy Analysis of the Vernacular House: Life-cycle energy (LCE) is a measure of the energy required to operate a building, as well as the initial and ongoing embodied energy throughout the course of its anticipated lifetime. To calculate the LCE, the most adopted equation is used: LCE = Initial Embodied Energy of Building + (Annual Recurrent Embodied Energy + Annual Operational Energy) x Building lifespan (Fay, Treloar and Iyer-Raniga 2000, Reddy and Jagadish 2003, Utama and Gheewala 2008;Devi & Palaniappan (2019). According to this equation, the total LCE of the vernacular house is 73.535 GJ. This includes the primary embodied energy of the structure, as well as the yearly recurring embodied energy and yearly operative energy required to maintain and operate the structure over its lifespan. The LCE is an important consideration in the design and building of a structure, as it helps to identify opportunities for reducing energy consumption and improving overall sustainability.

7.2 Case Study 2: Contemporary House

The contemporary residential house is about seven years old (build in 2015), belongs to Dile Ram Thakur and is located in the Khaniyara village (Fig. 15) on the outskirts of district Kangra. The adjoining residential buildings are also made of modern materials. The built-up area is 106 sq.m on the ground floor and are used for residential purposes whereas the upper floor is used as a storage area accessed by a concrete staircase. The typical rectangular plan is 12.5m X 8.5m and is divided into six areas, as a veranda and 5 rooms.

Fig. 15: Front View of Contemporary House
Source: Author

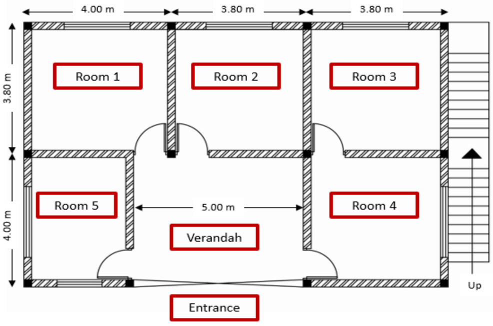

Fig. 16: Ground Floor Plan
Source: Author

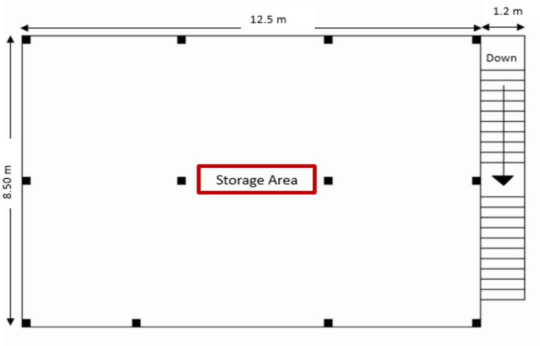

Fig. 17: First Floor Plan
Source: Author

7.2.1 Inferences: Architectural Aspects

The modern house incorporates numerous remarkable architectural elements, beginning with its foundation. A step foundation, positioned within a 1.5-meter-deep trench establishes a robust and stable base for the entire structure. A concrete plinth beam, with a height of 0.3 meters offers support for the walls and aids in distributing the building's load. The flooring consists of 12mm ceramic tiles, which are both long-lasting and simple to maintain. Positioned at 0.9 meters in height, the RCC sill functions as a foundation for window placement. The windows and doors have timber frames, and a foldable steel gate is installed at the entrance for enhanced security. An RCC lintel slab is situated above the doors and windows, contributing to structural support and assisting in load distribution for the structure above. The ceiling is completed with a reinforced bar and concrete ceiling slab, which is coated with POP (plaster of Paris) on the interior side. This results in a smooth, seamless finish that enhances the overall aesthetics of the home. In summary, these architectural components collectively create a sturdy, stable and visually pleasing modern house.

7.2.2 Inferences: Life Cycle Energy Analysis (LCEA) Aspect

In LCEA, the energy embodied in a structure and the energy used to operate it are calculated throughout the anticipated lifespan of the structure (Fay, Treloar and Iyer-Raniga, 2000).

Embodied Energy Analysis Method: The energy required to collect, transport and refine the raw materials, manufacture of component parts and assembly of the product is included in the energy contained in the product (Fay, Treloar and Iyer-Raniga, 2000)

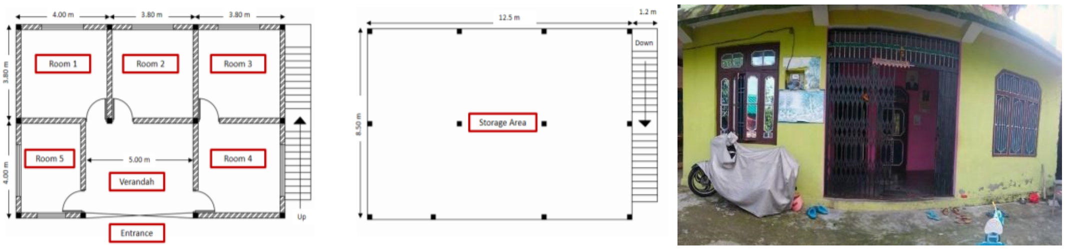

Fig. 18: Ground Floor Plan (1), First Floor Plan (2) and Front View of House (3)
Source: Author

Table 3: Bills of Quantities of the Contemporary House
Source: Author

Building Components	Building Material	Unit	Quantity
Foundation	PCC (1:3:6)	m^3	3.27
	Concrete (1:1.5:3)	m^3	7.35
	Sand	m^3	5.50
	Reinforcement	kg	239.70
Grade Beam	Concrete (1:1.5:3)	m^3	2.86
	Reinforcement	kg	291.70
	Brick Work	m^3	3.73
Column	Concrete (1:1.5:3)	m^3	2.06
	Reinforcement	kg	1.99
Roof Slab and Beam	Concrete (1:1.5:3)	m^3	10.03
	Reinforcement	kg	396.30
Staircase	Concrete (1:1.5:3)	m^3	0.71
	Reinforcement	kg	42.22
	Brick Work	m^3	10.90
Masonry	Brickwork	m^3	47.29
Plastering	Mortar	m^2	267.00
Painting	Paint	m^2	267.00
Flooring	PCC (1:3:6)	m^3	9.92
Wood Work	Timber	m^2	16.20

Table 4: Embodied Energy Calculation for House
Source: Author

Building Components	Building Material	Unit	Quantity	Energy Intensity (GJ /unit) (Reddy and Jagadish, 2003)	Embodied Energy (GJ)
Foundation	PCC (1:3:6)	m³	3.27	6.85	22.40
	Concrete (1:1.5:3)Sand	m³	7.35	8.27	60.78
	Sand	m³	5.50	0.15	0.83
	Reinforcement	kg	239.70	0.04	8.41
Grade Beam	Concrete (1:1.5:3)	m³	2.86	8.275	23.67
	Reinforcement	kg	291.70	0.0351	10.24
	Brick Work	m	3.73	1.2	4.48
Column	Concrete (1:1.5:3)	m³	2.06	8.275	17.05
	Reinforcement	kg	1.99	0.0351	0.07
Roof Slab and Beam	Concrete (1:1.5:3)	m³	10.03	8.275	83.00
	Reinforcement	kg	396.3	0.0351	13.91
Staircase	Concrete (1:1.5:3)	m³	0.71	8.275	5.88
	Reinforcement	kg	42.22	0.0351	1.48
	Brick Work	m³	10.9	1.2	13.08
Masonry	Brickwork	m³	47.29	1.2	56.75
Plastering	Mortar	m²	267	7.45	1989.15
Painting	Paint	m²	267	5.65	1508.55
Flooring	PCC (1:3:6)	m³	9.92	6.85	67.95
Wood Work	Timber	m²	16.2	10	162.00
Total					**4049.71**

Operational Energy Analysis Method: The study of the operational energy is based upon the consumption of electricity for the residence. The value of operational energy is calculated by the Design Builder is 45.29 kWh/m^2 (0.16 GJ).

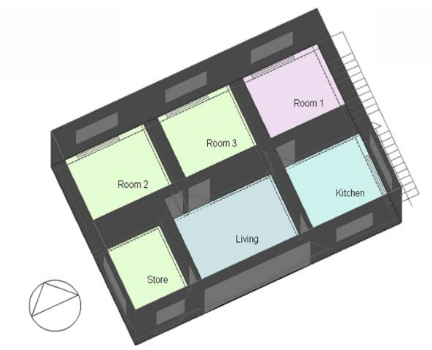

Fig. 19: Isometric Plan of Contemporary from House from Design Builder V4.0
Source: Author

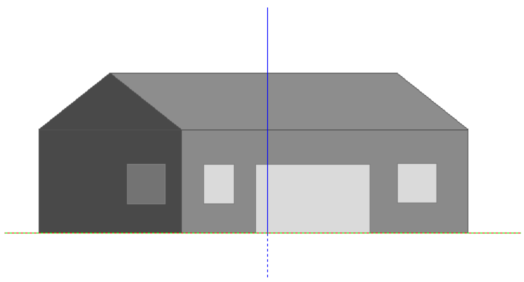

Fig. 20: Front Elevation of Building from Design Builder V4.0
Source: Author

LCEA of the Contemporary House:

The operating energy of the building as well as the initial and ongoing embodied energy throughout the course of its anticipated lifetime comprises life-cycle energy. To calculate the LCE, the most adopted equation is used: LCE = Initial Embodied Energy of Building + (Annual Recurrent Embodied Energy + Annual Operational Energy) x Building lifespan (Fay, Treloar and Iyer-Raniga 2000, Reddy and Jagadish 2003, Utama and Gheewala 2008; Devi & Palaniappan, 2019). Thus, the total Life Cycle Energy of the contemporary house is 4049.87 GJ. The contemporary house has a moderately high LCE compared to the other types of buildings, which may be due to its size, materials, and other factors. However, there are various strategies that can be implemented to reduce the LCE of a building, such as using energy-efficient appliances and systems and incorporating renewable energy sources.

8 Comparative Analysis (LCEA Aspect)

A comparison between the results of vernacular and contemporary houses is presented in Table 7. The floor space of each house is restricted to 107 m2. Vernacular houses in the Kangra region exhibit significantly lower embodied energy than modern houses within the same area. The embodied energy in both cases ranges from 73 to 4050 GJ. This vast difference in embodied energy can be attributed to the materials utilized. The material palette for vernacular houses consists of slate stone, mud and timber. Slate, a naturally occurring material, is readily available in the region, and minimal thermal energy is required to produce the desired size stones, resulting in low embodied energy. In contrast, the material palette for contemporary houses includes cement, fine aggregate or sand, brick, coarse aggregate, reinforcement bars, lime, timber, PVC and copper wire. Construction materials used in contemporary houses involve high thermal energy consumption. The operational energy of the building per year varies between 0.04 and 0.16 GJ. The difference of 0.12 GJ in the operational energy of houses with the same area is due to the materials used. The combination of mud and slate in vernacular houses creates natural insulation, maintaining a comfortable internal temperature during both summer and winter. In contemporary houses constructed with modern materials, mechanical ventilation is required to achieve and maintain the desired ambient temperature, which is naturally attained in vernacular houses due to the distinct thermal properties of traditional and contemporary materials.

Table 5: Comparison of Energy use for the Vernacular and the Contemporary houses
Source: Author

Type of Construction	Location	Floor Area	Type of House	Embodied Energy (GJ)	Operational Energy (GJ)	Life Cycle Energy (GJ)
Vernacular	Kangra, HP	107 m^2	Residential	73.50	0.045	73.54
Contemporary	Kangra, HP	107 m^2	Residential	4049.71	0.16	4049.87

9 Discussion and the Conclusion

This study concludes that the dry-stone construction is an outcome of all the indigenous techniques of the mountains. Although it is greatly affected by the availability of materials, there have been drastic changes over time. A few key features of this construction style are thick walls and the placement of slates on the roof without any braces. However, in recent times, people have started opting for newer construction techniques for many reasons, like providing safety from seismic activity, covering less space on the ground, and having more lay-people available for building them. With such continuous changes in lifestyles, people are opting for new styles and materials, resulting in the changes that this construction style might not survive for long. Even though it is clear how the vernacular construction style is comparatively better in terms of budget, operational energy and embodied energy and is a more sustainable architectural practice with cultural linkages.

However, people are more inclined towards modern constructions. This is inevitable. Thus, with this study, attempts are made to document and investigate the traditional techniques, which may soon disappear. These findings underscore the importance of reconsidering traditional construction techniques and materials in the pursuit of more sustainable and energy-efficient housing solutions. By integrating vernacular design principles and locally available materials, it may be possible to minimize the environmental impact of residential construction while maintaining thermal comfort and overall liveability. Future research should focus on identifying and refining strategies to combine the benefits of both vernacular and modern materials and construction techniques for optimal sustainable development of houses.

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