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Vernacular Architecture in Nepal: A Review on Planning and Building Materials

Samikshya Kandel[1,*], Luna Thapa[1], Kedar Chhetri[1], Pragati Baniya[1]

[1] Lecturer, Pokhara Engineering College, PU, Pokhara

**Corresponding email: samikshyaa.kandel2@gmail.com*

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Abstract

Vernacular architecture, deeply rooted in local traditions, stands as a pivotal force in shaping sustainable and climate-responsive building practices. This study aimed to assess the planning, building materials, thermal comfort, and design recommendations presented in seven research articles, focusing on three distinct geographic regions of Nepal. The results emphasized the significance of vertical planning, simple layouts, and the use of local materials, along with the implementation of passive design strategies for thermal comfort. The findings revealed a research gap, pointing to insufficient literature on the topic, particularly in non-hilly regions. The review concludes by emphasizing the practical value of the study for both practitioners and researchers, providing a comprehensive understanding of vernacular architecture in terms of materials and design strategies, and its relevance to contemporary climate responsive design. Additionally, the paper identifies future research directions to further enhance knowledge in this field.

Keywords: *Architecture, Building, Design, Materials, Planning, Thermal Comfort, Vernacular architecture*

1. Introduction

Vernacular architecture, defined as the indigenous response to climate, culture, and available resources, has evolved over generations to meet the needs of specific geographic locations. The current shifts in vernacular architecture, influenced by modernist trends and global solutions to homelessness, present not a threat but an evolutionary aspect, showcasing adaptability and changing practices within this architectural tradition. (Srivastava & Das, 2023) . Furthermore, vernacular architecture, as a dynamic cultural heritage, has evolved over centuries, embodying resource optimization, social organization, and climate responsiveness (Bodach et al., 2014; Upadhyay et al., 2006) rooted in distinctive cultural values, it seamlessly integrates indigenous technology, ensuring social acceptance and sustainability by uniquely addressing local communities' environmental needs (Bhatta et al., n.d.; Shrestha, 1981).

Nepal, spanning diverse climates from sub-tropical to frigid due to its vast altitude range, showcases traditional houses aligned with local climates and cultures across its 147,181 square kilometers (Rijal & Yoshida, 2002). However, challenges, such as winter discomfort due to the absence of glass in windows and doors and indoor pollution from open-hearth stoves without chimneys, underscore the necessity for refined adaptations in vernacular architecture. The gradual integration

of modern materials like corrugated iron further complicates the indoor environment, reflecting the ongoing evolution of vernacular architecture to address these complexities. Despite its rich cultural and ecological significance, vernacular architecture in Nepal faces a threat from modernization influenced by cultural globalization, poverty, and inadequate national policies (Tiwari et al., n.d.). The shift towards 'modern' housing in rural Nepal, driven by global trends and a lack of emphasis on local materials, not only endangers its unique character but also raises concerns about sustainability, thus impacting the country's tourism industry.

Geographical diversity: Nepal, renowned for its diverse landscapes, spans approximately 800 km east–west and 200 km north–south, showcasing a dynamic topography from the lush Terai plains to the majestic Himalayas. The distinctive features of each region, including altitude and temperature, as highlighted below:

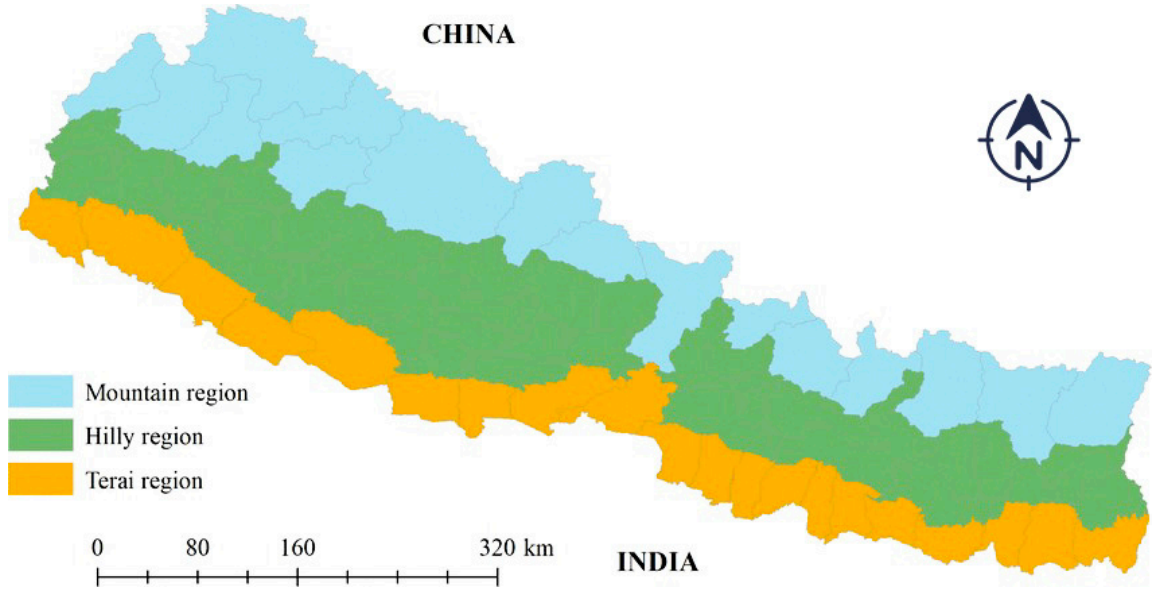

Figure 1: Geographic map of Nepal showing different climatic region (Joshi et al., 2018)

Nepal features three distinct climatic zones: the Terai region, situated at altitudes between 60 to 300 meters above sea level, characterized by a subtropical climate with temperatures fluctuating between 15°C to 40°C; the Hilly region, spanning altitudes from 300 to 2,000 meters, experiencing a temperate climate with temperatures ranging from 0°C to 30°C; and the Himalayan region, reaching altitudes from 2,000 meters to peaks exceeding 8,848 meters, characterized by alpine conditions with temperatures ranging from sub-zero to 20°C. These diverse climatic zones contribute to the rich ecological and topographical diversity of the country.

Vernacular architecture in Nepal

Vernacular architecture, a valuable gift from our forebears, evolved over centuries without causing significant environmental or health issues.(Lamsal et al., n.d.) It is found that traditional residential buildings are a minimum of one-to-two-degree cooler in summer and warmer in winter compared to contemporary residential buildings of Kathmandu Valley (Bajracharya, n.d.)Nepal has diverse vernacular architecture tailored to its climate. In the Terai region, homes have thatched roofs for warmth. The Hilly region features pitched roofs and wood structures for moderate temperatures. In the Himalayan region,

sturdy stone structures with steep-sloped roofs handle severe winters and heavy snow.

Terai Region: Nepal's Terai region showcases a vernacular architecture that skillfully intertwines cultural wisdom with environmental adaptation. Utilizing locally sourced bamboo and thatch, construction prioritizes sustainability. Architectural planning incorporates raised platforms and courtyards to foster community engagement. Noteworthy are the earthquake-resistant, low-profile structures, showcasing a thoughtful response to seismic activity.(Bodach et al., 2014) Orientation is meticulously designed to maximize natural light and thermal comfort, and the intricate woodwork not only serves functional purposes but also holds cultural and spiritual significance. The strategic provision of open spaces exemplifies the region's vernacular approach, integrating innovation to address its unique challenges.

Hill Region: The vernacular architecture in Nepal's hill region epitomizes a harmonious integration of cultural heritage and environmental responsiveness. Crafted primarily with locally sourced stone and timber, these dwellings showcase efficient spatial planning. Distinctive pitched roofs contribute to weather resilience, and the architecture demonstrates a nuanced understanding of the challenging topography. Emphasizing optimal sunlight exposure, wind protection, and thermal comfort through thick walls and strategic openings, the design seamlessly blends tradition with innovation. (Rijal^ & Yoshida^, 2002).Symbolic decorations on these structures convey profound cultural values, while communal spaces play a crucial role in fostering community bonds.

Mountain Region: In Nepal's mountainous region, traditional architecture reflects a strong mix of geography and culture. Buildings, mainly made of local materials like stone and wood, harmonize with the rugged landscape. The steep roofs and careful positioning show a commitment to tradition and the environment. Cultural values are woven into the design, emphasizing sacred spaces and community-oriented layouts. Prioritizing comfort, the architecture uses well-placed small openings and interconnected houses(Rijal, 2021).Innovations, including earthquake-resistant designs, highlight adaptability and a blend of local values and resilient design principles.

2. Materials and Methods

In conducting this review paper, a meticulous selection process was undertaken, focusing on seven journals that specifically addressed the characteristics of vernacular architecture in various climatic zones of Nepal. The initial step involved utilizing prominent search engines, including Google Scholar to identify relevant literature. The keywords employed in the search included "vernacular architecture in Nepal," "climate-responsive design," and "thermal comfort." These keywords were chosen to narrow down the search and target papers that specifically addressed the intersection of vernacular architecture and climatic considerations in Nepal.

The inclusion criteria were carefully defined, with a focus on selecting papers that investigated the details of vernacular architectural planning and thermal comfort within the Nepalese context. This ensured that the chosen papers contributed directly to the understanding of how traditional architecture responds to local climatic conditions.

Additionally, to enhance the local perspective and authenticity of the findings, an important criterion was applied during the selection process. Priority was given to papers authored by at least one Nepalese contributor. This criterion aimed to incorporate insights from scholars with a deeper understanding of the local cultural and environmental nuances, thereby enriching the overall review with a relevant perspective. The combination of these methodological steps ensured a focused and comprehensive exploration of vernacular architecture in Nepal within the selected climatic zones. The details of the paper are given below:

Table 1: The details of a review paper

Author name	Title	Geographic Regions	Keywords
(Datta Bhatta et al., n.d.)	Vernacular Architecture: Exploring the Architectural Characteristics and Changes in Traditional Settlements of Rana Tharu from Far Western Nepal	Terai Region	Vernacular Architecture, Settlements, Rana Tharu, Far Western Nepal
(Pokharel et al., 2020)	A field investigation on indoor thermal environment and its associated energy use in three climatic regions in Nepal	Mountain Region Hilly Region Terai Region	Nepal Thermal environment Energy use Firewood use Climatic region Comfort standard
(Upadhyay et al., 2006)	Climate Responsive Building Design in the Kathmandu Valley	Hilly Region	Climate; comfort; vernacular architecture; energy efficiency; design guidelines
(Bodach et al., 2014)	Climate-responsive building design strategies of vernacular architecture in Nepal	Mountain Region Hilly Region Terai Region	Vernacular architecture design responsive building design, Developing country, Traditional building techniques.
(Shrestha, 1981)	Nepal's Traditional Settlement: Pattern and Architecture	Hilly Region	
(Rijal, 2009)	Changes and improvements to traditional vernacular houses in a mountain area of Nepal	Hilly Region	Nepal, Vernacular architecture, Changes, Improvements, Thatched roof, Slate roof, Corrugated iron roof, Stoves
(Fuller et al., 2009)	Improving comfort levels in a traditional high-altitude Nepali house	Mountain Region	Nepal Traditional Housing Comfort Simulation Energy conservation

After the selection of papers, papers are identified based on the inclusion of three different climatic zones of Nepal; Mountain, Hill, and Terai. Once the papers were identified based on their regional focus, they were organized into respective groups for in-depth analysis. The characteristics of vernacular architecture and thermal comfort unique to each region were systematically summarized. The planning and materials utilized in these regions were tabulated and explained to separate distinct design strategies. The methodology described involves the development of a comprehensive research matrix to systematically analyze and compare existing design approaches and recommended strategies for vernacular architecture in different geographical regions of Nepal. This matrix serves as a structured framework to organize and evaluate data collected from seven different research papers, allowing for a meticulous examination of vernacular architecture and thermal comfort across three geographical regions.

Identification of Parameters

The first step involves identifying key parameters that are relevant to understanding vernacular architecture and thermal comfort in different geographical regions. These parameters may include: the location, settlement pattern, number of stories, building form, orientation, internal space arrangement, semi-open spaces, building materials/thickness/size.

Data Collection from Research Papers

The next step involves systematically collecting data related to these parameters from the seven research papers selected for analysis. Each paper provides insights into vernacular architecture and thermal comfort in specific geographic regions of Nepal.

Development of the Research Matrix

Using the identified parameters, a comprehensive research matrix is developed. The matrix consists of rows and columns, with each row representing a specific parameter and each column representing a geographic region of Nepal (e.g., Terai, Hill, Mountain). The data collected from each research paper is then inputted into the corresponding cells of the matrix. For example, information about building materials used in the Terai region would be entered into the respective cell under the "Building Materials" parameter and the "Terai" column.

Analysis and Comparison

Once the research matrix is filled with data from all seven papers, analysis and comparison is conducted along the three geographical regions. By examining the patterns and variations across different parameters and geographic regions, insights into existing design approaches and recommended strategies for each region are collected.

By employing this methodology, the study ensures a rigorous and systematic examination of vernacular architecture and thermal comfort across Nepal's diverse geographical zones, facilitating a comprehensive understanding of traditional building practices and design strategies.

3. Results and Discussions

Vernacular architecture in Nepal's diverse geographical regions, about the Hilly, Himalayan, and Terai zones, reflects a rich indigenous building tradition shaped by local climates, topography, and cultural practices. The tabular analysis of planning and building materials in vernacular architecture, as discussed in various papers, is organized based on geographical zones. Each table entry represents a single case study selected from multiple cases discussed in the paper within each specific zone.

Table 2 : Planning and building materials in the Mountain region of Nepal

Geographical Zone:		**Author Name**		
a. Mountain		(Pokharel et al., 2020)	Bodach et al., 2014)	(Fuller et al., 2009)
1	**Location**	Solukhumbu	Central Mountain, Langtang region	Humla
2	**Settlement pattern**	-	Attached houses, rather compact	-
3	**No of Story**	2	2	3
4	**Building Form**	Rectangular	Compact rectangular floor plan	Rectangular
5	**Orientation**	The main facade faces south	Main facade south-west wards	The main facade faces south

6	**Internal Space Arrangement**	Vertically elevated. The ground floor mainly has living and kitchen space, first floor is a store	Vertically elevated. The ground floor is the main living area with a kitchen and sleeping, first floor is storage	Vertically elevated. Level 1- Stable Level 2- Living cum Bedroom, Store Level 3- Living Room cum guest, Store
7	**Semi-open Spaces**	Balcony, Verandah	Verandah and balcony	Semi-enclosed area in front of rooms on top level
8	**Building Materials/ Thickness/Size**	Wall-stone and mud, plaster both side by cement and painted white (0.5m thick), Inner side partition- are wooden sheets 20mm thick with mud plaster Ceiling- wood Floor type-Cemented, stone, and mud	Wall material-Unplaster stonework (40-60cm) Roof Material- Wood slat weighted with stones, stone slate (if available) Roof type-Pitched roof Foundation-elevated ground floor adapting to the slope Floor- Wooden lathwork Ceiling- Low ceiling	Wall - 450mm thick stone wall Roof- From inside to outside on networks of beam Timber(25mm), bracken(20mm), plastic sheet, slate (30mm), finished on top with earth/ mud (40mm)

As per Table 2, in the mountainous regions of Solukhumbu, Central Mountain, Langtang region, and Humla, distinct building characteristics define the local architecture. The settlement pattern varies, with attached houses in a rather compact layout. Houses typically have two to three stories, featuring rectangular forms and orientations with main facades facing south or southwest. Internal space arrangements involve vertical elevation, with ground floors serving as living and kitchen spaces, while upper floors are designated for storage or additional living areas. Semi-open spaces like balconies and verandahs are common, providing connections with the surrounding landscape. Building materials include stone and mud walls, often plastered with cement and painted white, along with wooden partitions. Roofs are pitched, and constructed with wood slats weighted with stones or stone slates. Foundations adapt to the elevated mountainous terrain, and floors are made of a combination of wood, stone, and mud. This architectural style reflects the pragmatic adaptation to the challenging mountain environment, blending traditional materials and construction methods.

Table 3: Planning and building materials in the Hilly region of Nepal

Geographical Zone b.Hilly Region		**Author Name**				
		(Pokharel et al., 2020)	(Upadhyay et al., 2006)	Bodach et al., 2014)	(Shrestha, 1981)	(Rijal, 2009)
1	**Location**	Panchthar	Kathmandu	Dolakha	Kathmandu	Dhading
2	**Settlement Pattern**	-	Houses in continuous rows facing the street with interconnected courtyards.	Scattered	Compact with row houses	-

3	**No. of Story**	2	3.5	2-2.5	4-5	3
4	**Building Form**	Rectangular floor plan	Rectangular plan with tiled sloped roof	Rectangular floor plan	Rectangular	Rectangular plan with slope roof
5	**Orientation**	Longer side southwards	-	Longer side southwards	-	West facade (longer side N-S axis)
6	**Internal Space Arrangement**	Ground floor-living, kitchen, and bedroom; 1st floor-store	Ground Floor-Storage of farm implements, cattle First Floor-Bedrooms Second floor- main living area Attic floor- kitchen, prayer	Ground floor-kitchen and living First floor- store and sleeping	Ground floor-store, First floor-bedroom Second floor-living, 3rd floor (attic story)- kitchen and dining	Ground Floor-Veranda, Kitchen, Bed, and Prayer area First Floor-Store, Bedroom, and Balcony Second Floor-Storage
7	**Semi-open Spaces**	Shaded Verandah and covered Balcony	Interconnected Courtyard space for light and social interaction	Shaded Verandah and Balcony	Square Courtyard	Veranda on the ground and balcony on the first floor
8	**Building Materials/ Thickness/ Size**	Walls= stone and mud with mud plaster (0.45m thick) Floor= earth floor Ceiling= timber and mud	Wall material - bricks, mud mortar, wood, lay Wall thickness-almost 1m Unburnt brick inside, burnt brick outside Floor and opening material - Wood Roof material-Tiles, Straw (25 mm tile + 75 mud layer+ 25 mm wooden board)	Wall material-Stone, plastered and painted (40-50cm), Roof material-Stone slates on timber structure, Foundation-Stone plinth covered by mud/ earth Floor-Mud layer Ceiling-wooden beams and lathwork	Walls- load bearing, with central thick wall, sun-dried or fire burnt bricks Openings-wooden, lattice Floor- mud plaster over the horizontal poles interspersed with thin planks or bamboo reeds. Roof-overhanging roof with jhingati tile Load-bearing wooden pillars	Wall-450mm thick Stone wall on mud mortar Roof- CGI sheet

As per Table 3, in the hilly regions of Panchthar, Kathmandu, Dolakha, and Dhading, diverse architectural characteristics are observed. Settlement patterns range from scattered structures to houses in continuous rows with interconnected courtyards. Buildings exhibit varying stories, with rectangular floor plans and orientations, adapting to local topography. Internal space arrangements include diverse configurations, such as living and kitchen spaces on the ground floor, storage areas, and bedrooms on the upper levels.

Semi-open spaces, such as shaded verandahs and balconies, or interconnected courtyards, are integral components. Building materials and construction methods reflect local resources and traditions. Walls often consist of stone, mud, and bricks, with mud plaster, varying in thickness. Floors are made of earth or wood, and ceilings feature timber and mud components. Roof materials range from tiles and straw to stone slates on timber structures, with variations like CGI sheets. Foundations adapt to the terrain, incorporating stone plinths or elevated ground floors. This diverse architectural landscape demonstrates the fusion of traditional materials and innovative adaptations to the hilly environment, creating unique and context-specific building styles.

Table 4: Planning and building materials in the terai region of Nepal

Geographical Zone c.Terai		**Author Name**		
		(Datta Bhatta et al., n.d.)	(Pokharel et al., 2020)	(Bodach et al., 2014)
1	**Location**	Kailali and Kanchnapur	Jhapa	Chitwan
2	**Settlement Pattern**	Scattered	-	Scattered clusters
3	**No. of Story**	1 with mezzanine	1	1
4	**Building Form**	Rectangular	Rectangular	Rectangular
5	**Orientation**	The main house facing towards the east And other side house is arranged to form U shaped courtyard space	Main facade east, north-south axis	North-South longer facade
6	**Internal Space Arrangement**	Ground floor-living, sleeping Mezzanine floor -storage space for grains	Ground floor-living, kitchen, and bedroom	Horizontal, few divisions
7	**Semi-open Spaces**	Wide open verandah opens out on long Courtyard, 5-8' projecting roof	Covered Balcony	Verandah
8	**Building Materials/ Thickness/Size**	Wall- timber and bamboo wall plaster on both side With mud/ cow dung etc. Roof -12" thick thatched roofs, khaprahels (baked earthen tiles), GI sheet Opening-door window framework made up of wood Floor- earth floor Ceiling- wooden	Wall -timber and bamboo, brick and cement plaster (0.13-0.75m thick) Floor- earth floor Ceiling- wooden and bamboo	Wall material and daub, straw and mud, timber, bamboo Roof material-Thatch, pitched roof Foundation-Plinth of stone and mud Floor-compacted earth with a fine mud layer

As per Table 4, in the Terai region, characterized by locations like Kailali, Kanchanpur, Jhapa, and Chitwan, distinctive architectural features reflect the local environment and lifestyle. The settlement pattern varies from scattered structures to clusters. Buildings predominantly have one-story with mezzanine levels or single-story configurations. The architectural form is often rectangular, with orientations adapted to local conditions.

In Kailali and Kanchanpur, houses typically feature a U-shaped courtyard space formed by arranging structures with the main house facing east. Internal space arrangements on the ground floor encompass living and sleeping areas, while mezzanine floors serve as storage spaces for grains. Wide-open verandahs with projecting roofs create inviting outdoor spaces. Construction materials include timber and bamboo for walls, with mud or cow dung plaster, thatched roofs, khaprahels, and GI sheets for roofing. The opening frameworks are made of wood, and the floors are composed of earth. In Jhapa and Chitwan, the houses have a similar rectangular form with the main facade facing east on the north-south axis. Ground floors typically include living, kitchen, and bedroom spaces. The construction materials involve timber, bamboo, brick, and cement, with wattle and daub walls, straw and mud, and bamboo for ceilings. Thatched roofs with pitched designs, plinths of stone and mud for foundations, and compacted earth floors complete the construction. Verandahs provide covered outdoor spaces for social interactions. These architectural styles in the Terai region showcase a harmonious blend of traditional materials and construction methods, reflecting the adaptability of the structures to the local climate and cultural preferences.

Table 5: Climatic responsive design strategy in mountain, hill, and terai regions of Nepal

Climate-Responsive Design Strategy	Status	Mountain				Hill				Terai		
		Pokharel et al., 2020)	(Bodach et al., 2014)	(Fuller et al., 2009)	Pokharel et al., 2020)	(Upadhyay et al., 2006)	(Bodach et al., 2014)	(Shrestha, 1981)	(Rijal, 2009)	(Datta Bhatta et al., n.d.)	(Pokharel et al., 2020)	(Bodach et al., 2014)
The high thermal mass of walls and floor	Existing	+	+	+	*	+	+	*	+	*	*	*
	Recommended	+	+	+	*	-	+	*	*	*	*	*
High thermal mass with night ventilation	Existing	*	*	*	*	+	+	*	*	*	*	-
	Recommended	*	*	*	*	+	+	*	*	*	*	*
Building orientation north-south	Existing	+	*	+	+	+	+	+	-	+	+	+
	Recommended	+	+		+	+	+	+	*	*	+	+
Compact settlement and building layout	Existing	*	+	*	*	+	*	+	*	-	*	*
	Recommended	*	+		*	*	*	+	*	*	*	*
Low thermal mass of walls and floors	Existing	*	*	-	*	+	*	*	-	*	*	+
	Recommended	*	*	-	*	+	*	*	*	*	*	+

Shading device	Existing	*	+	+	+	+	+	*	+	+	+	+
	Recommended	*	+		+	*	+	*	*	*	+	+
Heavy roof	Existing	*	*	+	*	+	*	+	-	*	*	*
	Recommended	*	*		*	-	*	+	*		*	*
Enhancement of air movement in summer	Existing	*	-	*	*	+	+	*	*	+	*	+
	Recommended	*	-		*	+	+	*	*	*	*	+
Small openings to reduce heat losses	Existing	*	+	+	+	+	*	*	*	-	*	*
	Recommended	*	+		+	-	*	*	*	*	*	*
Semi-enclosed areas	Existing	*	*	+	*	+	+	+	+	+	+	*
	Recommended	*	*	+	*	*	+	+	*	*	+	*
Reducing infiltration	Existing	+	*	+	-	*	*	*	+	*	+	*
	Recommended	+	*	+	+	*	*	*	+	*	-	*
Ceiling insulation	Existing	*	*	+	*	+	*	*	-	+	*	*
	Recommended	*	*	+	*	+	*	*	+	*	*	*
Sunspace	Existing	*	*	-	*	*	*	+	*	*	*	*
	Recommended	*	*	+	*	*	*	+	*	*	*	*

+ : applied/recommended; − : not applied/not recommended; ± : partly applied/partly recommended; * : not discussed

The analysis of diverse passive strategies employed in building design, as well as strategies recommended from research to improve thermal comfort, has been conducted. This analysis is facilitated through a table where various climate-responsive design strategies are outlined, and each case is compared against these strategies. In the mountain region, all buildings studied incorporate high thermal mass in walls and floors, while two instances in the hilly region adopt this strategy, with no discussion of its application in the Terai region. For better thermal comfort the strategy is recommended for the mountain region. Interestingly, in the case of (Upadhyay et al., 2006), high thermal mass is not advised. The strategy remains unexplored in any of the cases from the Terai region.

The utilization of high thermal mass with night ventilation is observed in the hill region, and this strategy is also recommended for improved comfort. However, there is no discourse on this strategy in both mountain and Terai cases, except for (Bodach et al., 2014), where the approach is not implemented in the existing condition. All buildings in the regions are oriented north-south, except (Rijal, 2009) in the hill region. The application of this strategy is either recommended or not discussed in the cases being examined. The compact settlement and building layout strategy is implemented and further endorsed in (Bodach et al., 2014), a case from the mountain region. This strategy is observed in two cases from the hill region, but it is not employed in the Terai, specifically in the case of (Datta Bhatta et al., n.d.).

The utilization of low thermal mass for walls and floors is neither implemented nor advised in the mountain region. In the hills, in the case of (Upadhyay et al., 2006), there is partial adoption of this strategy, along with recommendations for enhanced comfort. On the contrary, the strategy is implemented in the case of (Bodach et al., 2014) in the Terai region, and it is also recommended as a climate-responsive design strategy. Shading devices have been incorporated in all cases, excluding (Shrestha, 1981), where there is no information provided about their usage. The strategy is recommended in all regions, although there are instances where the strategy has not been discussed. A heavy roof is observed in one case from the mountain region and two cases from the hill region. The strategy is recommended for (Shrestha, 1981) in the hill region. However, the strategy is not implemented in the case of (Rijal, 2009) from the hill region, and it is not recommended for the (Upadhyay et al., 2006) case, also from the hilly region. Enhancement of air movement in summer is not discussed in the Mountain region; however, it is implemented in both the hilly and Terai regions. Moreover, it is recommended as an effective measure for better climate response.

The use of small openings to minimize heat losses is observed in the mountain region. This strategy is partially applied in the hill region and is not utilized in the Terai region. Recommendations include implementing the strategy in the mountain region. However, for the hill region, it is advised for the case (Pokharel et al., 2020) but not explained for the case (Upadhyay et al., 2006). Semi-enclosed areas are present in cases across all geographic regions, and the strategy is recommended for enhancing comfort whenever it is discussed. The strategy to reduce infiltration is observed partially in the Mountain region and is recommended for enhanced comfort in that context. In the hill region, the strategy is not applied in the case of (Pokharel et al., 2020) partially applied in the case of (Rijal, 2009), but is recommended for use in both cases. In the Terai region, the strategy is partly implemented and is not recommended as a climate-responsive design strategy. Ceiling insulation is partially applied as a climate-responsive strategy in the mountain region. In the hill region, the strategy is partially implemented in the case of (Upadhyay et al., 2006) and is not applied in the case of (Rijal, 2009). However, the strategy is recommended for use in all three geographic regions. Sunspace is not evident in Mountain but recommended to have it in the (Fuller et al., 2009) case. In the case of hilly regions sunspace has been discussed in the (Shrestha, 1981) case only and recommended to have it in the same case. There is no discussion on Sunspace in the Terai region. Sunspace is not present in the Mountain region, but it is recommended for use in the (Fuller et al., 2009) case. In the hilly region, sunspace is discussed only in the (Shrestha, 1981) case and is recommended for implementation in that case. There is no discussion of sunspace in the Terai region.

In summary, Nepal's diverse geographical regions, including the mountainous, hilly, and Terai areas, exhibit distinct vernacular architectural styles rooted in local traditions, topography, and climatic conditions. In the mountainous regions of Solukhumbu, Central Mountain, Langtang region, and Humla, buildings showcase pragmatic adaptations to the challenging mountain environment. Two to three-story houses with rectangular forms and south or southwest-facing facades feature vertical internal arrangements. Semi-open spaces like balconies connect with the surroundings, while stone and mud walls, pitched roofs with wood slats, and elevated foundations reflect the blend of traditional materials and innovative construction methods. In this region, where the climate is cold, the planning, use of local materials, and design strategies are tailored to maintain warmth indoors. These strategies include employing high thermal mass on walls and floors, orienting buildings to the south, creating compact settlements and building layouts, using small openings to minimize heat losses, providing semi-enclosed areas, reducing infiltration, insulating ceilings, and incorporating sunspaces. These strategies are observed to be applied partially in some cases, fully in others, and not discussed in some

instances. The overarching aim of these strategies is to preserve indoor warmth by preventing cold air from entering and minimizing heat loss while maximizing solar radiation gain.

The hilly regions of Panchthar, Kathmandu, Dolakha, and Dhading exhibit diverse settlement patterns, from scattered structures to interconnected courtyards. The architecture adapts to local topography with varying stories, rectangular floor plans, and versatile internal arrangements. Stone, mud, and bricks form walls, with floors made of earth or wood. Roof materials range from tiles to stone slates, showcasing a fusion of traditional and innovative design elements that respond to the hilly environment. In this region, a combination of strategies is identified to address both cold winters and hot summers. Similar to the Mountain region, strategies include orienting buildings towards the south, creating compact settlements and building layouts, using semi-enclosed areas, reducing infiltration, and incorporating sunspaces. Additionally, specific to the hilly region, strategies such as employing high thermal mass with night ventilation, utilizing low thermal mass for walls and floors, incorporating shading devices, enhancing air movement in summer, and installing heavy roofs are observed. Certain strategies, such as high thermal mass for walls and floors, compact settlement and building layout, heavy roofs, and the use of small openings to minimize heat losses, are suggested for specific instances within the same geographical region but are not recommended for other cases.

In the Terai region, represented by Kailali, Kanchanpur, Jhapa, and Chitwan, one-story houses with mezzanine levels or single-story configurations prevail. Rectangular forms with east-facing orientations and U-shaped courtyard spaces characterize the architecture. Timber, bamboo, and thatched roofs are prominent, highlighting a harmonious integration of traditional materials and construction methods, adapting to the local climate and lifestyle. Especially, orientation on the eastern side is specific to Terai, while low thermal mass for walls and floors, shading devices, and enhancement of air movement in summer are common strategies used and recommended, akin to the hilly region. Commonly employed strategies across all regions include the use of semi-enclosed areas and ceiling insulation.

Fuller et al.'s (2009) paper focuses on enhancing comfort levels in traditional high-altitude Nepali houses. The study is significant as it addresses the crucial issue of improving living conditions in a specific geographical context, considering the unique challenges posed by high-altitude regions. By focusing on traditional housing, the paper acknowledges the cultural significance of vernacular architecture in the region and the need to preserve it while enhancing comfort.

The paper could provide more detailed insights into the socio-cultural aspects influencing housing preferences and practices in high-altitude regions. Future research could explore the economic feasibility and scalability of the proposed interventions, considering factors such as cost-effectiveness and community acceptance. Despite its strengths, the paper also acknowledges the challenges and threats faced by vernacular architecture in Nepal. Modernization, influenced by global trends and socioeconomic factors, poses a significant threat to traditional building practices and cultural identity. The potential impact on sustainability and tourism underscores the need for preservation efforts and policy interventions.

4. Conclusions

Preserving vernacular architecture for future generations involves emphasizing traditional construction techniques through educational initiatives. It is crucial to document and pass down skills related to local materials and building methods. Additionally, the preservation of significant architectural features ensures the authenticity and cultural value of these structures. Integrating sustainable practices from vernacular architecture into modern design contributes to eco-friendly buildings aligned with

contemporary sustainability goals. However, adapting vernacular structures to meet modern comfort needs poses challenges, requiring interdisciplinary research and innovative design solutions that respect cultural heritage while addressing evolving societal requirements. Striking a balance between preservation and adaptation is essential for the continued relevance and resilience of vernacular buildings.

Also, due to limited access to various search engines, particularly restricted to Google Scholar, research on vernacular architecture in Nepal reveals a notable scarcity in literature, with a predominant focus on the hilly region. Among seven selected articles, only two each address the vernacular architecture of Nepal's mountain and terai regions, emphasizing the need for future research to bridge gaps in understanding thermal comfort, climate considerations, and design recommendations in these specific zones.

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