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Predicting Sustainable Construction Practices: A Critical Review of Traditional Tharu Mud House Techniques in Kanchanpur, Nepal

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Abstract

A prime example of utilizing traditional mud-based housing systems is to gain knowledge on sustainable, climate-sensitive, and culturally inclined ways of constructing houses. The paper includes a critical examination of the ancient methods of Tharu mud houses in Kanchanpur, Nepal, in terms of their applicability on the global and national systems of vernacular architecture and sustainable building. Based on the global research on earthen construction technologies, e.g., adobe, cob, rammed earth and wattle-and-daub, and various Nepalese traditions, the review appraises Tharu houses within the framework of the essential sustainability indicators, e.g., environmental footprint, thermal comfort, cost/efficiency, and socio-cultural meaning. Tharu mud houses consist of locally available materials, including mud, bamboo, straw, and timber which indicate that they have low embodied energy, carbon footprint, and also effective passive design strategies that can fit the hot-humid Terai climate. Thick earthen walls, shaded verandas, and natural ventilation are among the features that promote the achievement of stable indoor thermal conditions without involving the consumption of mechanical energy. Nevertheless, the available literature gives huge gaps in quantitative evaluation, especially to the methods of thermal performance, lifetime cost evaluation, and structural behavior during environmental risks. The proposal identifies that a multi-dimensional assessment is most effective and possibly that the combination of indigenous Tharu construction expertise and modern sustainability systems would generate resilient and low-carbon residential approaches to housing in the rural and peri-urban areas of Nepal.

Keywords: *sustainable construction, mud house, vernacular architecture, thermal comfort, passive design*

1. Introduction

Traditional building systems form an essential part of Nepal’s architectural heritage, offering valuable insights into sustainable, climate-responsive, and community-driven construction practices. Among these, the Tharu mud houses of Kanchanpur represent a remarkable example of indigenous knowledge that has evolved through generations in response to local environmental, cultural, and socioeconomic conditions. Constructed primarily from natural materials such as mud, bamboo, timber, and thatch, these dwellings have historically provided comfortable living environments in the hot and humid climate of the western Terai. Their low carbon footprint, low embodied energy, and reliance on locally available materials align closely with modern concepts of sustainability and green construction. As global attention increasingly turns toward environmentally responsible and culturally appropriate construction methods, understanding traditional practices becomes essential (Mehra et al., 2021). In recent decades, the rapid growth of the construction industry has contributed significantly to environmental degradation, including excessive energy consumption, depletion of natural resources, and rising carbon emissions. Modern construction materials particularly cement, steel, and synthetic composites, though structurally efficient, often come at the cost of environmental sustainability and cultural heritage (Mehra et al., 2021).

To organize this review systematically, the chapter is divided into some thematic sections. It begins with a global overview of traditional mud construction, examining techniques such as adobe, cob, rammed earth, and wattle and daub. These methods have been utilized for centuries across diverse climatic and geographic zones and offer valuable insight into natural building systems that remain relevant today. This section discusses the advantages of these systems such as low environmental impact and high thermal performance while also addressing their common limitations, including vulnerability to water damage and limited structural capacity, which are often cited as reasons for their decline.

2. Global Overview of Mud Construction Techniques

Earthen construction methods such as adobe, cob, rammed earth, and wattle and daub have been used for centuries across various climatic and cultural contexts, offering environmentally sustainable alternatives to industrialized building systems (Abdulrahman Maghrabi, 1994; El-Sawalhi & Ajwa, 2013; Ibrahim & Osman Ibrahim, 2021). Adobe, composed of sun-dried mud bricks, is widely used in Latin America, the Middle East, and parts of Asia for its thermal mass and low cost. Cob, a mixture of earth, straw, and water molded by hand, is prevalent in the UK, sub-Saharan

Africa, and New Zealand, known for its sculptural flexibility and resilience (Rashid et al., 2025; Sesay et al., 2025). Rammed earth, where moistened soil is compacted into forms, has been revived in countries like China, Australia, and parts of Europe for its high compressive strength and striking aesthetics (EKSI AKBULUT & ALİBEYOĞLU, 2025; Maniatidis et al., 2003; Sesay et al., 2025). Meanwhile, wattle and daub—a lattice of sticks smeared with clay or mud—is still seen in parts of Africa and Southeast Asia due to its simplicity and use of fully renewable materials. Despite their benefits, these techniques face challenges such as poor resistance to heavy rainfall, seismic vulnerability, and social perceptions associating them with poverty or backwardness (Houben & Guillaud, 1994). However, recent innovations in stabilization (e.g., lime or cement additives), proper detailing, and hybrid construction have improved durability and broadened acceptance (Easton et al., 2007; Osman Ibrahim, 2021; Rashid et al., 2025; Sadat, 2021a). These global traditions underscore the potential of earth-based construction to inform sustainable housing in resource-constrained regions like rural Nepal.

3. Vernacular Architecture in Nepal

Nepal's diverse topography, from the lowland Terai to the mid-hill regions and the high Himalayas has shaped a wide range of vernacular architectural traditions. Each region has evolved construction techniques that respond to its unique climate, material availability, and socio-cultural context. In the Terai region, homes built by ethnic groups like the Tharu and Rajbanshi are typically made using mud, straw, bamboo, and timber (Liang et al., 2025; Raj et al., 2019). These materials, which are locally sourced and low in embodied energy, help regulate indoor temperatures in the region's hot and humid climate (Raj et al., 2019). The traditional Tharu mud houses, in particular, use thick earthen walls, thatched or tiled roofs, and shaded verandas to enhance thermal comfort without relying on mechanical systems.

In the mid-hills, communities such as the Gurung, Magar and others have developed stone masonry structures with timber elements (Amit Kumar, 2002; Asmita Dahal, 2019; Prakash Shah et al., 2024). These houses are compact, often built in terraced patterns along the contours of hills, helping to prevent soil erosion and manage monsoonal runoff. Roofs are typically made from stone slates or corrugated metal sheets in more recent adaptations (Pant et al., 2023). Houses are oriented to maximize solar gain and protect against prevailing winds, showing strong climatic responsiveness as shown in Figure 1. Traditional Gurung houses also use central courtyards and inward-sloping roofs to collect water and control internal microclimates. These buildings reflect generations of adaptation to the hilly terrain, harsh winters, and seismic activity.

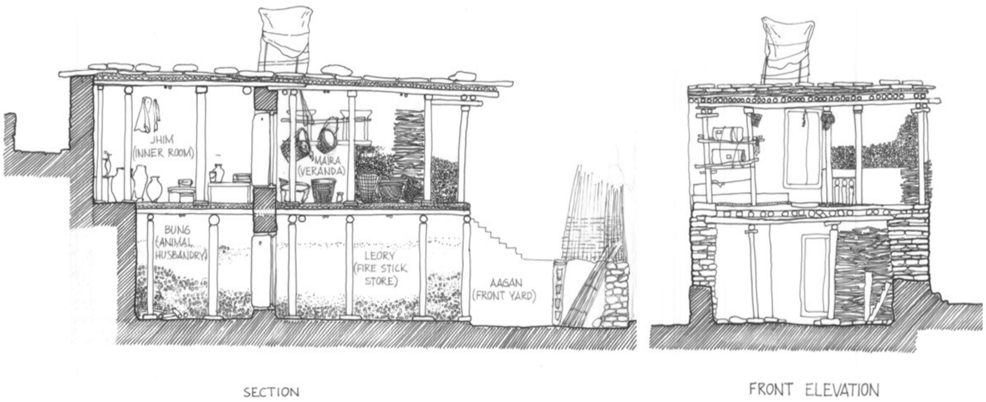

Figure 1: Magar house views (Pant et al., 2023)

In the high Himalayan region, such as in Mustang, vernacular architecture has evolved in response to arid conditions, high wind exposure, and freezing temperatures (Prasad Gyanwali, 2025). As Asmita Dahal's (Dahal, 2019) study in Marpha illustrates, the traditional homes are made from stacked stone walls, mud mortar, and flat roofs used for drying crops or stacking wood. The buildings are clustered to reduce heat loss and to shield from wind, as shown in Figure 2. Settlements like Marpha are laid out in compact formations, creating wind breaks and conserving thermal energy during long winters. Dahal's research also emphasizes the role of solar orientation, thermal mass, and passive solar heating as key elements of sustainability in mountain architecture.

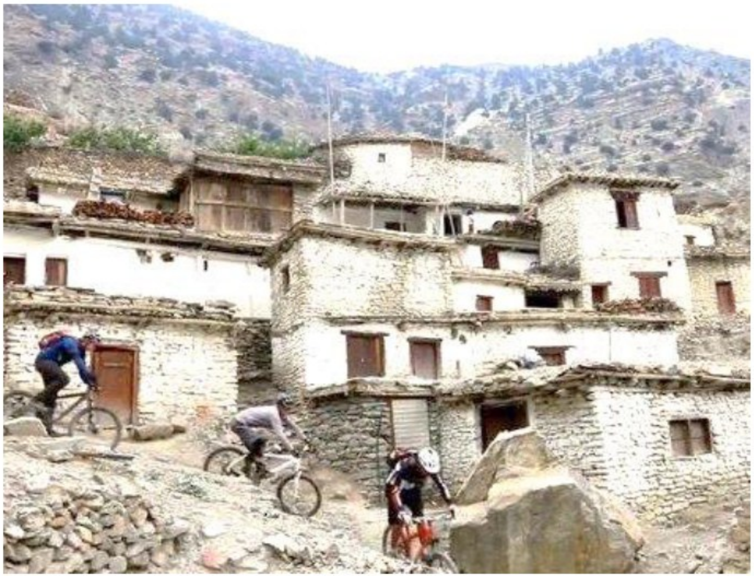

Figure 2: Vernacular Architecture Mustang (Dahal, 2019)

Vernacular architecture across Nepal has demonstrated remarkable disaster resilience, particularly in terms of responding to earthquakes, floods, and extreme weather

(Poudel & Chaulagain, 2024). After the 2015 Gorkha earthquake, studies found that traditional buildings performed better or worse depending on material condition and maintenance, but many mud, stone, and timber structures withstood the initial shocks due to their flexibility and lightweight roofing (See Figure 3). For example, Gurung houses built with timber tie-beams and small openings were observed to perform better than rigid RCC structures with poor detailing (Gautam & Chaulagain, 2016). In flood-prone Terai, the elevated plinths and natural drainage patterns surrounding Tharu and Rajbanshi homes reduce water damage and allow structures to quickly dry after inundation. Such resilience, embedded in centuries of indigenous knowledge, highlights the potential for integrating vernacular features into modern, disaster-resistant building practices (Adhikary, 2016).

Figure 3: Completely Collapsed dry Stone Masonry Houses

Material availability and economic considerations are core to vernacular design across the country. In all three regions, construction relies heavily on locally available materials soil, stone, timber, bamboo, and thatch which reduce transportation costs and support local economies. The cost-effectiveness of these materials makes vernacular architecture accessible to low-income communities while fostering low-carbon construction (Hu, 2023). Additionally, many traditional techniques require communal labor, reinforcing social cohesion and knowledge transfer. In contrast to modern buildings that often rely on imported cement and steel, vernacular structures are biodegradable, repairable, and highly adaptable to local environmental and cultural contexts.

In summary, in Table 1, Nepal's vernacular architecture offers region-specific solutions to climatic adaptation, economic sustainability, and cultural identity. From the mud-based homes of the Terai, the stone and timber dwellings of the Hills, to the climate-responsive courtyard houses of Mustang, these building traditions provide valuable lessons in low-impact, resilient design. As both your research and Dahal's study affirm, documenting and modernizing these approaches can contribute meaningfully to sustainable construction and disaster risk reduction in Nepal's rural and peri-urban areas.

Table 1: Literature Review on Vernacular Architecture and Sustainable Building Practices in Nepal.

Author (s)	**Title / Year**	**Focus Area**	**Key Findings**	**Relevance to Nepal**
(Bodach et al., 2014)	Climate Responsive Building Design Strategies of Vernacular Architecture in Nepal	Bioclimatic design	Traditional houses align with solar passive strategies using local materials; suited to regional climates.	Highlights thermal efficiency of mud-based design in different climate zones.
(Tiwari et al., 2004)	Cultures in Development: Conservation of Vernacular Architecture	Conservation & policy	Vernacular architecture is dynamic; loss due to globalization and lack of protection threatens identity.	Supports policy-driven preservation of local materials and techniques.
(Gautam et al., 2016)	Disaster Resilient Vernacular Housing Technology in Nepal	Earthquake & flood resilience	Rajbanshi, Gurung, Magar houses show disaster resilience with mud masonry and timber framing.	Validates mud and timber-based housing for disaster-prone rural areas.
(K.C. et al., 2025)	Role of Vernacular Architecture in Enhancing Environmental Sustainability	Life Cycle Assessment (LCA)	Traditional buildings emit less CO_2 and use less energy; biogenic materials enable carbon sequestration.	Endorses mud as low-carbon option in Nepal's hydropower-rich context.
(Prakash Shah et al., 2024)	Study of Changes in Vernacular Architecture of Baitadi	Spatial transformation	Architecture adapted to geography and climate; cultural shift threatens traditional identity.	Encourages adapting hill region vernacular features in new designs.

(Sakar Shrestha, 2025)	Newari Heritage, Commoner to Luxury	Identity & urbanization	Newari mud-brick architecture eroded by urbanization and modernization after 2015 earthquake.	Advocates holistic heritage conservation including mud-brick common houses.
(Anupama, 2024)	Greener Materials in Vernacular Architecture	Sustainable materials	Greener materials like adobe and bamboo combined with modern tech for scalable solutions.	Demonstrates integration potential for mud-based methods and green tech.
(Khoja, 2025)	From Vernacular to Verno mimicry: Vernacular Design Principles for Resilient Communities	Climate adaptation	Vernacular strategies offer climate adaptation via simplicity, local resources, and community.	Promotes vernacular-based climate adaptation in Nepal’s urban planning.
(Hu, 2023)	Exploring Low-Carbon Design & Construction Techniques	Circular economy & materials	Bio-based materials support circular construction; vernacular principles suit sustainable design.	Reinforces viability of mud for low-impact, modular construction in Nepal.

4. Existing Studies on Tharu/Rana Mud Houses

The traditional mud houses built by the Tharu and Rana communities in Nepal’s Terai region represent a culturally rich and environmentally responsive form of vernacular architecture. These houses are deeply embedded in the socio-cultural identity of the Tharu people, reflecting their customs, seasonal rhythms, and community-based construction practices (Bhatta et al., 2023). According to ethnographic and anthropological literature, these structures are more than just dwellings they serve as multifunctional spaces for cooking, storing grains, sheltering livestock, and conducting rituals. Built through communal labor systems, their design reflects social cohesion and indigenous knowledge systems passed down across generations (Bhatta et al., 2023; Mary, 2025; Raj et al., 2019).

From an environmental perspective, Tharu/Rana mud houses utilize readily available materials such as mud, straw, bamboo, thatch, and timber, which have low embodied energy and are biodegradable (Bhatta et al., 2023; Kalauni, 2025). Their thick mud walls provide excellent thermal mass, keeping interiors cool in summer and warm in winter—critical for the hot and humid climate of the Terai. The traditional use of natural ventilation, shaded verandas, and overhanging roofs further contributes to indoor thermal comfort without mechanical energy input. These features align with contemporary sustainable design principles, yet remain underappreciated or undocumented in mainstream architectural discourse (Kalauni, 2025; Lam, 2012; Liang et al., 2025; Sharma et al., 2021).

Despite these strengths, existing studies on Tharu and Rana mud houses are limited and fragmented. Much of the current literature focuses on cultural or historical narratives, with minimal technical or quantitative analysis (Chamorro et al., 2025; Kalauni, 2025; Lam, 2012; Liang et al., 2025; Shrestha, 2022). For example, few studies have investigated the structural behavior of mud walls under lateral loads, despite the Terai's increasing vulnerability to floods and windstorms. There is also a noticeable lack of cost-benefit comparisons between traditional Tharu mud houses and modern masonry or RCC structures, especially when considering lifecycle costs, repair frequency, and embodied energy. Similarly, thermal performance data including indoor temperature, humidity control, and energy savings remain largely anecdotal or based on observation rather than scientific measurement.

This lack of comprehensive, multi-dimensional evaluation represents a critical gap in current knowledge. While the cultural and symbolic value of these homes is well acknowledged, their technical performance, economic viability, and environmental sustainability remain under-researched. Your thesis addresses this void by conducting a structured comparative analysis of Tharu mud houses with RCC and masonry buildings in Kanchanpur, using thermal comfort evaluation, construction cost assessment, and environmental impact analysis as core criteria. In doing so, it bridges the divide between tradition and technology, offering insights that can inform both policy-making and community-based sustainable housing initiatives.

5. Sustainability in Construction: Principles and Traditional Practices

Sustainability in construction involves designing, building, and managing the built environment in a way that fulfills current needs without compromising the ability of future generations to meet their own (Dhanchha, 2024a; Madhumathi et al., 2014; Mavi et al., 2021; Yılmaz & Bakış, 2015). It is evaluated through three core pillars: environmental sustainability, which focuses on efficient use of resources, reducing carbon emissions, and minimizing ecological harm; economic sustainability, which emphasizes affordability, local job creation, and long-term cost efficiency; and social sustainability, which ensures that buildings are culturally relevant, inclusive, and promote the well-being of their occupants (Barbhuiya et al., 2025; Madhumathi et al., 2014; Opoku et al., 2019). These principles have been widely adopted into global sustainability frameworks such as the United Nations Sustainable Development Goals

(SDGs)—notably SDG 11: Sustainable Cities and Communities—and are operationalized through green building certification systems like LEED (Leadership in Energy and Environmental Design) and BREEAM. These systems evaluate construction based on energy performance, material use, indoor environmental quality, and the overall carbon footprint, aiming to merge ecological responsibility with functional and resilient architecture.

6. Traditional Tharu Mud Houses and Sustainability Indicators

Traditional Tharu mud houses in Nepal's Terai region inherently fulfill many of these sustainability criteria, despite not being formally recognized by green rating systems (Dhanchha, 2024b). These structures are built using locally sourced and renewable materials such as mud, straw, bamboo, and timber, minimizing the environmental cost of material processing and transportation (Rijal, 2018; Sadat, 2021b; Yu, 2024). Sustainability indicators in construction assess environmental, economic, and social performance, including energy efficiency, carbon footprint, lifecycle cost, cultural relevance, and community participation. These metrics help evaluate how well a building minimizes environmental impact, supports local economies, and enhances occupant well-being, aligning with global frameworks like LEED and the UN SDGs (Gebara et al., 2024; Guan et al., 2024).

7. Thermal Comfort and Passive Design

One of the key sustainability features of Tharu mud houses is their ability to provide thermal comfort without relying on mechanical systems like fans or air conditioning (Arsad et al., 2023; Liang et al., 2025; Mitra, 2022). The high thermal mass of mud walls enables them to absorb heat during the day and release it slowly at night, stabilizing indoor temperatures(Ashraf & Nisar, 2025). Roof overhangs, verandas, and small window openings help reduce solar gain and facilitate cross-ventilation—core principles of passive design (Arsad et al., 2023; Madhumathi et al., 2014).

To quantitatively assess thermal performance, studies often use R-values (thermal resistance) and U-values (thermal transmittance) (Tyagi et al., 2024). Mud walls, especially when built thick (often 300–450 mm), exhibit R-values of 0.4–0.6 $m^2 \cdot K/W$ and U-values around 2.0–2.5 $W/m^2 \cdot K$, which, though not as insulating as modern materials, perform well in combination with passive strategies (Lars Vedder, 2025). These values reflect moderate insulation compared to materials like fiberglass insulation, which can have R-values of 2.5 to 4.0 per inch (Lars Vedder, 2025). However, mud walls have a high thermal mass, meaning they can absorb heat during the day and slowly release it at night, naturally stabilizing indoor temperatures. Mud houses are known for their excellent thermal regulation due to the natural properties of earth materials. The key thermal performance indicators for building envelopes are the R-value and U-value. The R-value measures a material's resistance to heat flow.

The higher the R-value, the better the insulation. In contrast, the U-value indicates the rate of heat transfer through a material. The lower the U-value, the better the material prevents heat loss (Madding, 2008).

To calculate the R-value of a wall, divide the thickness of the material (in meters) by its thermal conductivity (W/m·K) (Madding, 2008). For example, a 0.4 m thick mud wall with thermal conductivity of 1.0 W/m·K would have an R-value of 0.4. The U-value is simply the inverse of the R-value (U = 1/R), making it easy to interpret (Madding, 2008). Compared to modern materials, mud walls may not provide high insulation, but they excel in maintaining thermal comfort through delayed heat transfer. This makes them particularly beneficial for rural and traditional homes where energy consumption is low and natural cooling is essential. Overall, mud construction remains a sustainable and thermally responsive option when designed with proper detailing and orientation (IS 3792, 1978; Madding, 2008; Modi et al., 2024; Wang et al., 2023).

A bioclimatic chart, also known as a bio-thermal comfort chart, is a graphical tool used in architecture and environmental design to assess human thermal comfort in relation to climate conditions such as temperature, humidity, solar radiation, and wind speed (Asmita Dahal, 2019). It helps architects and engineers determine what passive design strategies (like natural ventilation, shading, or thermal mass) are suitable for a building in a specific climate.

Sita Bhusal's (Bhusal, 2021) focuses on the significance of thermal comfort in school buildings, especially in Nepal's Terai region, where rising temperatures negatively affect students' learning. Drawing on ASHRAE standards, the review emphasizes optimal indoor temperature and humidity ranges for human comfort and explores adaptive thermal comfort models, such as Fanger's PMV-PPD framework, which link physiological responses to environmental conditions. It discusses how building envelopes, materials, and passive design strategies significantly influence indoor thermal performance. Previous studies on Nepalese schools highlight that many are naturally ventilated, poorly insulated, and exceed recommended comfort limits, underscoring the need for sustainable, energy-efficient designs. Overall, Bhusal argues that understanding and improving classroom thermal environments through climate-responsive design is essential for enhancing student well-being and academic performance

8. Conclusion

The reviewed literature highlights that traditional mud-based architecture, especially Tharu mud houses in Nepal's Terai, embodies an effective synthesis of environmental responsiveness, cultural identity, and economic viability. Globally, earthen techniques like adobe, cob, and rammed earth demonstrate the potential for low-carbon, affordable construction, while Nepal’s vernacular systems exhibit centuries of adaptation to varied topographies and climates. Despite these strengths, critical research gaps remain: quantitative data on thermal comfort, lifecycle costs, and structural resilience are sparse, and the socio-cultural value of such architecture is often overlooked in modern construction discourse. Addressing these gaps is vital to repositioning vernacular mud housing as a sustainable, climate-adaptive solution for rural communities. This thesis, therefore, builds on existing knowledge by providing a multi-dimensional evaluation of Tharu mud houses, comparing them with modern RCC and masonry systems, and identifying pathways to integrate indigenous techniques with contemporary sustainability frameworks.

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