Advances in Engineering and Technology
An International Journal

Architectural Change as a Socio-Ecological Transition in Lo Manthang

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Abstract

Vernacular architecture in extreme environments embodies a long- term adaptation to ecological constraints, material scarcity and socio-cultural governance. Its traditional building practices, characterised by thick earthen walls, compact settlement morphology, integrated livestock stables, dry sanitation systems, courtyards and small openings, represent long-standing adaptive responses to harsh climate, limited biomass and agro-pastoral livelihoods. Drawing on the Socio-Ecological System (SES) framework, this article conceptualises architecture as a mediating mechanism between climate, resource use and cultural practices, rather than a material entity. Using qualitative case study methods including architectural documentation, field observations, and semi-structured interviews, this article traces recent architectural transitions, driven by infrastructural connectivity, tourism-oriented economies and changing social lifestyles. The recent shift towards using imported materials and construction technologies, such as cement, CGI roofing, septic tanks and altered spatial organisation signals a growing detachment of architecture from local ecological limits. Findings indicate that while contemporary materials improve hygiene, comfort and economic opportunities linked to tourism, they also disrupt local material ecologies, circular nutrient cycles, and thermal symbiosis between human and livestock, increasing reliance on external resources. The article discusses that the SES lens enables a more nuanced interpretation of architectural change beyond the traditional and modern debate. It concludes that recognising vernacular architecture as a socio-ecological process yields context-sensitive adaptation in the fragile Himalayan landscape.

Keywords: *Architectural transitions; cultural adaptation; ecological adaptation; Socio-ecological system; vernacular architecture*

1. Introduction

In recent decades, Himalayan vernacular architecture has undergone significant transitions driven by tourism, infrastructure and exposure to modern material [1]. These transitions involve reinterpretation of traditional forms in response to contemporary ecological and socio-cultural pressure, not merely stylistic changes. So, understanding those vernacular architectural changes requires an interdisciplinary perspective that recognises the interaction between a socio-cultural meaning and physical environment adaptation to explore those changes.

Many authors believe vernacular architecture represents a collaborative knowledge shaped by cultural norms, values, worldviews and vernacular dwellings evolve in response to climatic and ecological constraints [2, 3]. Theoretical discourses in vernacular studies have developed two strands for interpreting vernacular architecture. Much of the classical literature on vernacular architecture focused primarily on cultural interpretation. Most notably, Amos Rapoport asserts that house form is a manifestation of socio-cultural structures integrated with environmental adaptation [2]. Oliver further highlights that vernacular dwelling is the result of a community's ability to adapt their traditions and is a process of continuous adaptation, where traditional knowledge is passed down and modified to meet changing needs [3]. Furthering this discourse, Mete Turan critiqued the tendency to view vernacular building as static heritage, but as a dynamic cultural process, where communities transform forms while maintaining cultural identity [4]. Recent scholarship stresses that vernacular architecture is a dynamic cultural process capable of adapting, in which communities transform forms while maintaining identity [5].

Similarly, another stream of scholarship emphasised climate-responsive design, focusing on technical adaptation. For instance, Lamsal, Bajracharya and Rijal highlight the technical and physical necessities such as site planning, layout, building orientation, opening sizes and placement, thermal mass, insulation, and building envelope in high altitude climates [6]. Their study emphasises that vernacular architecture's reliance on thick walls and passive solar orientation was not merely a cultural choice, but a sophisticated response to heat loss that modern transitions often overlook.

Many studies seem to highlight the architecture's climatic responsiveness or building tradition through symbolism, spatial organisation, and lifestyle. Neither stance treats vernacular architecture as a dynamic interaction between social institutions and ecological process but tends to emphasise either cultural meaning or environmental performance. This is particularly evident in the study of Himalayan settlements, even though architectural typology is inseparable from agricultural cycles, livestock management and ritualistic traditions [7].

With this backdrop, this article argues that both cultural and ecological perspectives are inseparable; vernacular architecture needs to be examined as an evolutionary process, highlighting the continuity of building tradition through reinterpretation rather than replication while integrating new technologies and social needs [8]. This perspective allows us to perceive architecture as a living system with a network of connections affecting different components within it. To understand the complex relationships among social practices, environmental processes, and the built environment, systems thinking is necessary [9]. From a systems thinking

perspective, vernacular architecture is conceived as a single system in which social and physical components are treated as separate entities but as interconnected and co-evolving parts [10]. In this sense, architecture becomes part of a coupled human-environment system, which means human actions directly reshape ecological processes through a tight feedback loop, considering both physical and social components. This allows spatial organisation, material choices, and construction to be shaped by dynamic relationships among ecological constraints, social norms, and the governance system.

Conventional architectural approaches often emphasise descriptive dimensions such as spatial organisation, materials, and technological shifts in traditional built forms [1]. Many studies examine architectural changes through a narrow lens, often isolating physical aspects from cultural aspects [12]. Likewise, Dahal highlights a thermal separation between traditional and contemporary buildings, in which modern constructions often ignore climatic-responsive principles, resulting in altered spatial organisation and reduced thermal efficiency [1]. Although these approaches document what buildings look like, how they are built, and how they have changed over time, they fail to explain why particular architectural forms developed in the first place. By only documenting what exists without investigating the forces and circumstances that shaped it, the full meaning and adaptive intelligence of vernacular architecture remain poorly understood.

Under these circumstances, the socio-ecological system framework provides a more integrative analytical lens by examining how the resource system, users, and governance system (rules, customary norms, collective practices) interact to articulate the built environment [10]. Within this framework, vernacular architecture can be understood as an adaptive system in which cultural knowledge, environmental conditions and resources co-evolve to produce architectural forms. Folke discusses that built form is co-produced through ecological constraints, adaptive human behaviour and institutional mediation [13]. Sustainability and resilience emerge from interaction among ecological processes, local knowledge systems and institutions rather than from environmental conditions alone [11]. Hence, Socio-ecological system theory aims to provide a holistic perspective to resolve modern problems such as climate change and habitat loss that fall outside the boundaries of a single discipline [14].

Ostrom identified four core subsystems: the resource system, the resource unit, the governance system, and the users, to study common-pool resources, as resource management could not be studied by separating ecological and social factors [10]. SES is used analytically by identifying core subsystems, analysing their interactions, and mapping feedback loops. Studies describe SES frameworks as boundary tools that enable interdisciplinary analysis by connecting ecological dynamics with governance systems and actor interactions [15]. That is why this framework helps analyse buildings as a living and active part of the community, connected to the land, the people, the resources, and the rules or norms that govern how they work together. However, the framework has notable limitations. It relies primarily on qualitative observations at a single point in time and does not capture the speed or scale of rapid changes [13]. While it excels at identifying social norms and interactions, it lacks the quantitative depth to measure precise environmental impacts, such as soil nutrient loss and groundwater contamination.

In the case of the Lo Manthang settlement, located at approximately 3810 meters above sea level, architecture is not merely a passive shelter but a network of intertwined beliefs, policies and practices that must respond to extreme climate and resource scarcity. Khattri and Pandey explore the Loba community empirically, where indigenous institutions (King, *Lama*, *Ghenba*, *Dhongba*) form an adaptive system that encodes resilience through religious values, equity, and resource governance [16]. As demonstrated in Ostrom's work on common-pool resource management, informal institutions and locally crafted rules are central to sustaining shared resources [10]. When translated to Lo Manthang's architectural contexts, this suggests that building practices cannot be understood, separating them from institutional systems that regulate access to land, timber, labour and maintenance. Therefore, a study of human-environment relationships in architectural settings remains incomplete if it isolates physical factors from socio-cultural practices and governance structures. The authors have chosen a discursive approach to address the gap and to understand the human-environment relationship expressed through architectural adaptation, in which building forms and techniques manage resource scarcity, responding to extreme climate and socio-cultural practices in the context of Lo Manthang. This article contributes to vernacular architecture discourse by shifting the analytical focus from a purely aesthetic analysis to a systematic understanding of built forms. While traditional scholars like Amos Rappoport emphasise cultural manifestations, and others like Lamsal, Bajracharya, Rijal and Dahal argue technical necessities, this study bridges their views using an SES lens. This positions architecture as an active mediator rather than a static material entity. By doing so, it offers a methodology to analyse how specific architectural elements are not merely features but vital nodes in a settlement's ecological cycles. In terms of sustainable adaptation, this study challenges the modernisation-as-improvement narrative by documenting the transition from autonomous resilience towards an external dependency. By applying the framework of Ostrom, the article demonstrates that sustainability in a fragile landscape like Lo Manthang is not just about material choice, but about maintaining the human-environment relationship.

2. Materials and methods

In order to investigate vernacular architecture as a mediator between human interaction and socio-cultural practices, resource scarcity and climate change, this article analyses a case study of the Lo Manthang settlement, Upper Mustang, Nepal. The case study was an in-depth study of observations, structured interviews, and architectural documentation, which is usually considered a limitation for the validity of the findings. However, the main concern was to interview and observe the human-environment interaction in Lo Manthang, as lived and experienced by the locals, rather than to gather a large amount of data. Hence, the qualitative method was selected to capture lived experiences, local knowledge systems and context-specific dynamics that cannot be adequately explained through quantitative measures. Two field visits were made, a seven-day winter visit and a ten-day summer visit. The first visit focused on vernacular buildings, and the second visit concentrated on buildings that had undergone architectural changes.

Photographs were taken throughout to support and verify the findings, as these visual records served as empirical evidence for subsequent analysis and helped triangulate findings derived from interviews and documentation.

The structured open interview's purpose was to obtain on-ground insights to interpret their meaning. In-depth interviews were conducted with locals aged 30 to 65, selected purposively to ensure familiarity with both past and present living patterns, thereby enabling reflection on intergenerational transitions in housing practices and resource management. In addition to community interviews, one expert interview was conducted to provide a broader contextual understanding and professional interpretation of architectural changes and environmental adaptation. Informed consents were obtained from all participants before the interviews, granting permission to record their narratives. Triangulation between field observations, community interviews, expert insights and architectural documentation strengthened the methodological rigour of the study.

The two buildings selected for documentation were a vernacular building and a newly built contemporary house, both owned by the same resident, which were documented using digital tape. Interpretive analysis was guided by the socio-ecological system framework, which provided a structured lens to examine the dynamic interaction between ecological constraints, resource availability, institutional norms, and socio-cultural practices.

3. Results and discussion

Lo Manthang has been undergoing several architectural changes, which have revealed a significant shift from a tightly coupled, circular socio-ecological system (SES) towards a more open system increasingly influenced by external forces and modern infrastructure. The findings are categorised by the primary architectural mediators that have historically defined the human-environment relationship in the settlement, which are described below.

3.1. Local material ecologies: Openings and Terrace

3.1.1. Vernacular material logic

The sizes of openings in vernacular houses in Lo Manthang were equally governed by the intersection of ecological constraint and cultural norm. As per the locals, window and door frames required timber, a resource that was scarce in Lo Manthang. Timber had to be transported on horseback from lower -altitude settlements such as *Jomsom* or *Lete*, making it a costly and limited option. This material scarcity directly constrained the dimension of openings; small windows were not a design choice imposed from outside, but a rational response to the limited resources. The cultural and spiritual overlay reinforced this constraint. Likewise, local beliefs about the movement of spirits and protection of the domestic threshold further regulated opening sizes, embedding a spiritual governance logic on top of the material one. The result was a settlement-wide pattern of small, carefully proportioned openings that minimised heat loss.

Moreover, the terrace of vernacular houses in Lo Manthang constituted one of the most ecologically intricate components of the entire building system. A layer of pang, a locally harvested moss-like soil, was applied as an insulating membrane to protect the parapet from moisture deterioration in the cold arid climate. Above this, firewood (daura), locally called Bhotey peepal, was stacked and stored, serving a dual function: as insulation for the roof and a culturally regulated resource reserved for ritual events such as marriages and deaths. The quantity of stored firewood also signalled socio-economic status, particularly among the *Bista* household, transforming an ecological resource into a marker of social identity. As one resident explained:

> "*In old days, when you walked through Lo Manthang, you could tell the wealthy houses from the poor ones by the firewood on the roof. They were stored for big events like weddings or funerals only. Also, we used to collect the pang ourselves from the hills. It protects the roof from moisture. Now, people do not use pang in residence; instead, they build cemented houses.*"

This account illustrates the multi-layered function of vernacular architectural elements: the terrace was simultaneously an insulating membrane, a fuel store, social signal. It exemplifies the SES concept of a coupled human-environment system in which ecological resources, norms and cultural values are organised and expressed through built form, presented in Table 1.

Table 1: SES interactions and outcome in vernacular building

S.N.	Vernacular architecture	SES interactions	Outcome
1	Openings	People utilise smaller openings as timber shall travel from Jomsom or Lete and spiritual norms drives windows to be smaller.	Lower heat loss from the building in cold climate and low consumption of timber (resource) enhance resource efficiency.
2	Terrace	People store firewood (Bhotey Peepal) on roof, extracted from owned land, for utilisation in emergency situations like marriage or funeral.	Emergency fuel security, visible wealth status and insulation from moisture.

3.1.2. Contemporary material decoupling

The introduction of cement corrugated galvanised iron (CGI) roofing sheets, fired brick and imported glass has fundamentally reconfigured the material ecology of Lo Manthang's built environment. These materials arrive from outside the settlement's ecological catchment area, entirely manufactured in distant factories, transported by road infrastructure that was impossible in the past decade and procured through cash-based market transactions rather than collective labour and local knowledge. Large windows are now possible due to improved transportation that enhances daylighting but increases heat loss significantly in the absence of any compensating insulation technology. The disappearance of pang and firewood from terraces is perhaps the most

visible symbol of decoupling: the terrace, once a social identity, has been reduced to a structurally functional surface. The building envelope is no longer embedded in local ecological and cultural circuits; it has become a product of external supply chains, as shown in Figure 1.

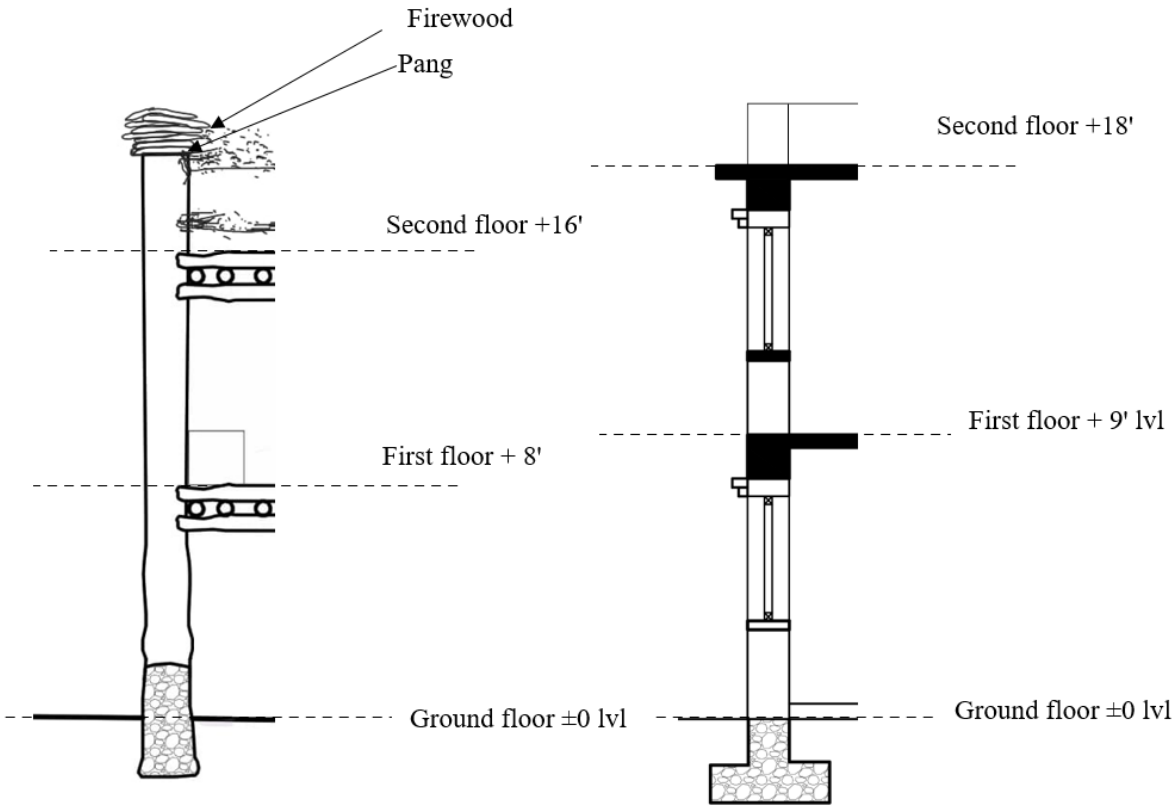

Figure 1: Wall section comparison of a vernacular (Left) and contemporary (right) house in Lo Manthang

Table 2: SES interactions and outcome in contemporary buildings as illustrated in the wall sections

S.N.	Architectural Transitions	SES interactions	Outcome
1	Openings	The increased availability of timber from Jomsom, Lete and China, facilitated by improved road connectivity, has led residents to adopt larger openings which is also a local preference for maximizing natural daylighting within interior spaces.	Higher heat loss from building in cold climate and increases more energy demand as to maintain comfortable room temperature, loss in spiritual norms
2	Terrace	Concrete buildings miss out firewood on terrace as people utilises other storage rooms as well as no use of "Pang" on parapet.	No visible wealth status and insulation from moisture in contemporary buildings.

3.2. Circular Nutrient cycles: The dry toilet Transition

3.2.1. Vernacular circularity

The dry toilet system of Lo Manthang's vernacular houses represents one of the most architecturally and ecologically sophisticated examples of circular resource management in the settlement's-built environment. Traditional dry toilets, as shown in Figure 2, are positioned on the upper floor of the residence, operated as adaptive architectural mediators that convert human waste into a valuable agricultural fertiliser. A mixer of human waste, ashes and cow dung is collected in the pit. In temperatures that regularly fall far below freezing during winter, human waste rapidly desiccates rather than decomposes anaerobically, producing a dry, relatively odourless organic material that could be stored, collected and transported with minimal infrastructure. This was not a compromised arrangement born of poverty or technical limitation, but an adaptive architectural response to the specific climatic and ecological conditions of high altitude with severely limited water resources.

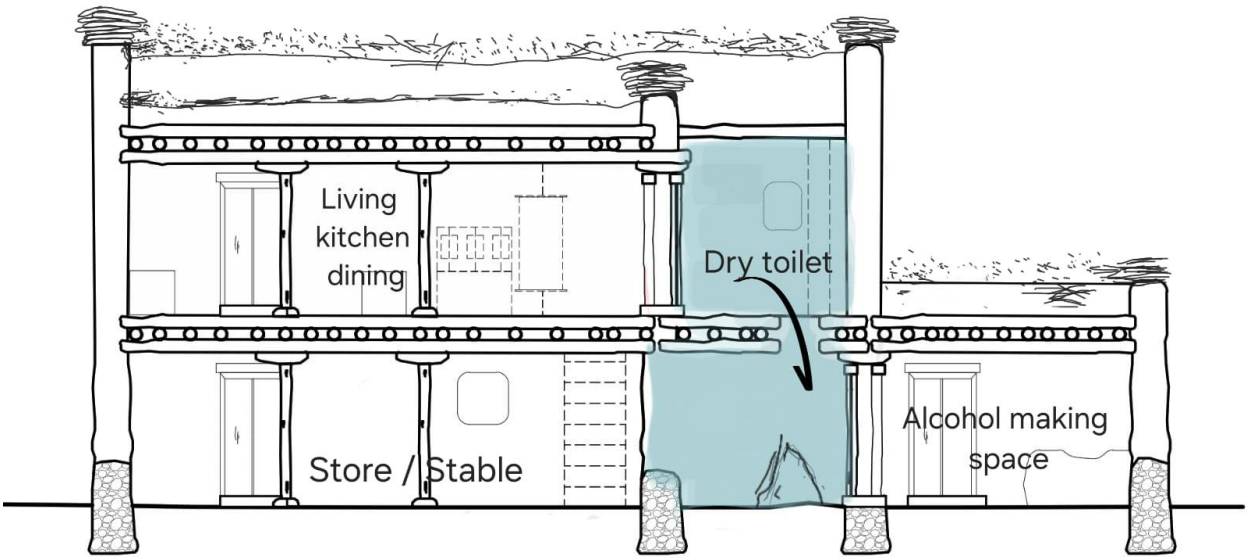

Figure 2: Section of vernacular house showing dry toilet in Lo Manthang

The ecological significance of the dry toilet lies in its role as a key node within the settlement's circular nutrient cycle. The desiccated waste accumulated over 2-3 months was collected periodically and transported to agricultural land. This human-derived organic material functions as a primary soil amendment, supplying limited nutrients available in the high-altitude agricultural zone and maintaining soil fertility without depending on external chemical fertilisers. The collection and transportation of waste was predominantly performed by women, embedding the sanitation function of the house within the gendered labour patterns and linking the domestic interior directly to the agricultural exterior through bodily practice and routine. As one middle-aged male resident described:

> "*We would collect the waste from the dry toilet and use it for agricultural land. Nothing was wasted. Those who still use dry toilets continue this process.*"

This account reveals the depth of integration between agricultural design, domestic labour and agricultural ecology. Residents did not experience the dry toilet as a sanitation technology in itself; rather, it was understood as one stage in a seasonal cycle that connected the household to the agricultural land. The architectural chamber, the collection practices of people, the transportation routine, and the agricultural application constitute a single socio-ecological process, whose outcome is presented in Table 3.

Table 3: SES interaction and outcomes in vernacular architecture

S.N.	Vernacular architecture	SES interactions	Outcome
1	Dry toilet	Characterised by frozen water resource and fragile soil ecosystem, residents adhere to a longstanding social practice in which women periodically spread human waste onto agricultural land, making use of a dry toilet system that requires no water.	Improve soil fertility, food security and reduced dependency in water for sanitation.

Hence, the dry toilet also exemplified the broader principle of ecological closure that characterised the vernacular socio-ecological system. Nothing was wasted: human biological output was processed by architecture and climate into a resource that fed the food system, which in turn sustained the human population that produced the waste. The circuit was complete and self-regulating. Water, which is acutely scarce in the region, was not required at any stage of the sanitation process. The architectural design had resolved the tension between human biological necessity and environmental resource constraint in a manner that reinforced rather than disrupted local ecological balance.

3.2.2. Contemporary linearization

The transition to a septic tank system, driven by hygiene norms and perceptions, tourism infrastructure requirements, and availability of piped water connections, has disrupted the traditionally integrated nutrient cycle with significant ecological consequences. The septic tank system processes waste through water-based anaerobic decomposition and discharge, generating liquid effluent rather than collectable dry organic material. The nutrient value that was previously returned to agricultural soils is now lost. This may contribute to groundwater contamination over time.

The immediate agricultural consequence of this transition is increased dependency on livestock manure as the primary soil amendment. However, the simultaneous decline of livestock integration within the household, driven by the spatial re-organisation of contemporary buildings and changing livelihoods, means the supply of manure is also decreasing. Interviewees

both noted that only livestock manure is not enough to maintain soil fertility, resulting in reduced yields of traditional crops such as Barley and buckwheat in the current context.

This observation captures the material reality of the nutrient linear process, which was previously an internal cycle, free of cost. The septic tank system also introduces significant water demand, a serious concern in a settlement where water is a limited resource. The architectural transition from dry toilet to water-flush septic tank thus represents a compounding of dependencies like greater water consumption and reduced soil fertility arising from a single change in sanitation. The building's relationship to the nutrient system has been fundamentally severed.

3.3. Thermal symbiosis between humans and Livestock

3.3.1. Vernacular thermal integration

The vertical organisation of the vernacular house in Lo Manthang enclosed a sophisticated multi-species thermal management strategy that drew on the biological heat output of livestock to moderate the extreme cold of the high-altitude environment. In the traditional residential typology, the ground floor was designated as the livestock stable, housing yaks, horses, sheep and goats within the footprint of the building. The first floor above contained the primary living, cooking and sleeping spaces of the human household. This vertical stacking was not incidental but was a deliberate spatial strategy that utilised the metabolic heat generated by animals as a passive energy input to the human living environment above. Livestock generate substantial body heat through their continuous metabolic processes, and in the confined space of the ground-floor stable surrounded by thick earthen walls, this heat accumulates and conducts upward through the floor structure into the room above. Field observations and resident testimony both confirm that the first floor living spaces of vernacular houses maintained significantly warmer room temperature than would be achievable through solar gain alone.

Similarly, thermal strategy extends beyond the livestock-human interface. The entire spatial organisation of the vernacular house was oriented around heat conservation and efficient fuel use. Domestic activities like cooking, eating, gathering, and even sleeping were concentrated within a single thermally dense space: a combined kitchen-living-dining hall in summer and a dedicated winter room in winter, the warmest heated chamber in the house. Rather than distributing functions across multiple separately heated rooms, the household organised cooking, eating, social interaction, and sleeping around a single central stove. This concentration of activity ensured that the heat produced by cooking was also used for space warming and that human body heat contributed to maintaining ambient temperature. The spatial compactness of the vernacular layout was thus a thermal strategy as much as a cultural preference. One elderly resident reflected on this arrangement:

> "*The ground floor was reserved for storing firewood (daura) and housing cattle and horses, whose body heat contributed to warming the upper floors. We also rely on by-products of cattle for survival. We also live together in a single room in winter. It was warm because of the cooking, the bodies and the animals below.*"

This statement reveals the deeply reciprocal relationship between thermal necessity and social life in the vernacular house. The domestic activity in a single heated space was not experienced as a constraint but a socially generative condition; it fostered prolonged and intensive family interaction, collective routines and strengthened intergenerational bonds. The SES framework identifies this type of relationship as a key feature of the human-environment system.

Table 4: SES interaction and outcomes in vernacular architecture

S.N.	Vernacular architecture	SES interactions	Outcome
1	Livestock stable	A social practice of hosing cattle in ground floor just below the living spaces of human circulate thermal heat towards upper floor, while residents also rely on the by-products of livestock for their daily needs.	Warmer upper floor rooms and sustain winter survival.
2	Winter room	Residents follow a local norm, where they make use of a seasonal winter room, equipped with an adjoining storage space for goods and firewood, fitted with a traditional stove to maintain warmth during the harsh cold climate.	Single heated hall allows social interaction, promote thermal efficiency.

3.3.2. Contemporary thermal and spatial separation

The change in spatial organisation in contemporary buildings has systematically dismantled the thermal symbiosis that vernacular design had developed over centuries. In newly constructed buildings, livestock stables have been relocated away from the main residential structure, either to standalone peripheral buildings or in many cases, eliminated entirely as households transition from agro-pastoral livelihoods towards tourism and services-based economies. This spatial separation removes the ground floor biogenic heat source from the residential thermal equation entirely, increasing the energy required to maintain habitable temperatures during winter.

Simultaneously, the fragmentation of domestic space within contemporary residences has multiplied the number of separately heated zones within each household. Contemporary buildings, as shown in Figure 3, typically include a ground-floor kitchen, separately located sleeping rooms on the upper floors, and distinct spaces for guests, a critical consideration for tourism-oriented households. Each of these spaces requires independent heating. This increased demand is met through imported fuels like LPG gas cylinders and electric heaters, which require external supply chains and market expenditure. The household has moved from a condition of thermal self-sufficiency to a condition of thermal dependency, in which comfort is purchased from external sources like electricity.

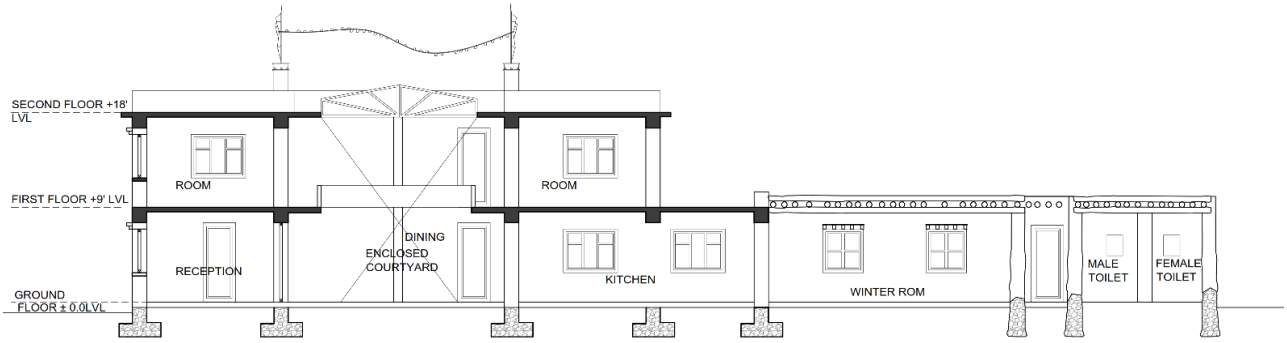

Figure 3: Section of a contemporary building in Lo Manthang

Hence, the findings from the study invite a fundamental reorientation in how architectural changes in the vernacular context are conceptualised and analysed.

3.4. Rethinking architectural transitions as systematic reconfiguration

When architectural changes are viewed through the lens of SES, the architectural changes in Lo Manthang are neither straightforwardly progressive nor regressive. They are better characterised as a systemic reconfiguration, a reorganisation of relationships through which settlement manages its interactions with climate, resource and social practices. This reconfiguration involves the replacement of internal resource circularity with externally dependent linear flow, substitution of embedded ecological intelligence with market-purchased services and dissolution of governance arrangements that were previously encoded in vernacular architectural forms and social-cultural practices. That is why, it is a reorganisation of living adaptive system, with consequences that extend well beyond appearance into the domain of resource security, ecological adaptation and institutional coherence.

3.5. Architecture as a processor of waste and mediator of resources

One of the most significant conceptual contributions of this study is the reframing of vernacular architecture as an active processor of waste and mediator of resource flows within the settlement system, rather than a passive shelter. The dry toilet system provides the clearest illustration of architecture as a waste processor as it acts as a component of a nutrient management system that resolved problem of sanitation, water scarcity, and soil fertility. Similarly, vernacular SES of Lo Manthang exemplified circular metabolism across multiple scales, like human waste to soil fertility, livestock to domestic warmth, and terrace material to insulation and moisture management.

Likewise, the concept of institutional norms (social norms, rules, values) is equally critical to understanding the resource governance dimensions of vernacular architecture in Lo Manthang. The findings also demonstrate that vernacular architecture was saturated with such institutional arrangements: the spiritual governance of opening sizes, the cultural regulation of terrace firewood, the gendered labour norms governing dry toilet collection, and the communal knowledge systems governing pang harvesting all constituted informal institutions embedded in

and reproduced through architectural practice. While contemporary construction in Lo Manthang does not carry a comparable set of locally crafted governance rules, it is governed instead by market price, manufacturer specification, and a municipal infrastructure, replacing the institutional richness of the vernacular SES without an equivalent substitute.

4. Conclusions

This research has demonstrated that the vernacular architecture of Lo Manthang is not a static relic of the past but a dynamic mediator of the socio-ecological system. The primary conclusion of this study is that the transition from vernacular to contemporary forms represents a shift from autonomous resilience to external dependency. Traditional built forms facilitated closed-loop systems, such as a nutrient cycle supported by dry toilets and thermal efficiency of winter rooms, which allowed the Loba community to thrive under extreme resource scarcity and climate stress. In contrast, the adoption of modern materials and spatial layouts, while offering perceived convenience and alignment with tourism-driven market needs, has introduced linear resource flows that increase vulnerability to external supply chains for water, energy and food security.

Furthermore, the research highlights that architectural change in Lo Manthang is as much a socio-cultural transition as it is a physical one. The erosion of traditional building practices signifies a weakening of indigenous governance and collective knowledge systems that historically regulated human - environment interactions. The disappearance of firewood and pang from terraces, for instance, marks the decoupling of the building envelope from its role as a site of social identity.

Ultimately, this research argues that for the future development of Lo Manthang to be sustainable, it must move beyond the binary choices between " traditional" and " modern". The findings suggest a need for a hybrid approach that integrates ecological logic and closed- loop feedback mechanisms for a vernacular architecture with the necessary comforts of contemporary life. By positioning architecture as an active component of SES, this study provides a framework for planners and residents to make informed decisions that support both cultural continuity and environmental resilience in one of the world's most fragile high-altitude ecosystems.

Conflict of interest

“No conflict of interest”.

Acknowledgements

The authors sincerely acknowledge the Department of Architecture, IOE Pulchowk Campus, Tribhuvan University. Gratitude is also conveyed to Ar. Shekhar Dongol, Ar. Orna Awale, Ar. Lujja Manandhar, and to the residents of Lo Manthang for their cooperation.

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