# Resilience: Insights from Vernacular Architecture

ANALYSIS OF INCAN, SHERPA, AND EASTERN BLACK SEA VERNACULAR ARCHITECTURE FOR LANDSLIDE-PRONE PRECIPITOUS TERRAIN IN BOGOTA'S INFORMAL SETTLEMENTS

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## Abstract

*This paper examines the causes of landslides and the resilient architectural strategies employed in three vernacular case studies from the Inca Empire, Sherpa communities in Nepal, and the Eastern Black Sea region of Turkey. It explores how their architecture integrated climate-responsive techniques, local materials, and structural systems to withstand natural disasters such as earthquakes and landslides. The analysis highlights the significance of settlement layouts, passive design strategies, structural foundations, wall systems, and roofing methods that harmonize with the steep terrain and minimal environmental impacts, offering valuable insights for current sustainable and resilient design approaches for social housing in Bogota's periphery in steep terrain.*

**Keywords:** *Landslide mitigation, Vernacular Architecture, Climate-Responsiveness, Resilient Design, Mountains, Social Housing.*

## I. Introduction

Landslides pose a significant global challenge, causing substantial damage and loss of life, especially on steep terrains. Between 1900 and 2018, Colombia experienced 30,730 documented landslides, resulting in the loss of 34,198 lives[1], and devastating entire communities. According to the landslide susceptibility map, 78% of Colombia's regions are classified as high-risk[2]. This threat highlights the vulnerability of areas prone to natural disasters triggered by heavy precipitation, steep topography, deforestation, and human intervention.

Many residents of Colombia's informal settlements are victims of forced displacement due to ongoing armed conflict, often instigated by outlaw groups. This conflict has led to the exodus of 13% of Colombia's population, reaching 6.8 million by the end of 2022[3]. The influx of rural residents into urban areas exacerbates poverty cycles, worsened by limited government support and resources, which hinder communities from mitigating risks and perpetuate socioeconomic disparities.

### 1.1 Problem Statement

Displaced individuals resort to constructing their dwellings and settling wherever possible, often driven by necessity. According to Martin-Molano, more than 50% of Bogotá has grown from informal settlements. Furthermore, socioeconomic limitations hinder access to adequate infrastructure and materials, resulting in detrimental effects. Lacking technical expertise, they excavate and build structures

[1] Gómez, Derly & García, Edwin & Aristizábal, Edier. (2021). Spatial and temporal patterns of fatal landslides in Colombia.
[2] GFDRR. Think Hazard. Colombia 2020
[3] Colombia Situation. The United Nations High Commissioner for Refugees (UNHCR). 2024

with little to no structural integrity, utilizing scavenged materials such as plastic, sticks, wood planks, asphalt screens, and zinc tiles. These inadequate practices facilitate water flow through the mountain system, leading to ground fissures and increasing the risk of landslides, perpetuating recurring devastation despite continuous, albeit erroneous, reconstruction efforts[4].

## 1.2 Landslide Inducing Factors- *Rain, Deforestation, and Wildfires*

During Bogotá's monsoon season, heavy rainfall saturates the ground from June to November, increasing the risk of landslides. Insufficient drainage systems in informal settlements exacerbate water accumulation and slope instability.

Deforestation and vegetation clearance further contribute to soil erosion, making slopes highly vulnerable to landslides during intense rainfall. Nelson Grima's study, conducted under the International Union of Forest Research Organizations, found that landslides are six times more likely to occur in non-forested areas compared to forested regions in Colombia[5]. Deforestation and wildfires amplify vulnerability to landslides by inducing soil hydrophobicity, disrupting the natural binding effect of soil roots, vital for soil cohesion and stability. In 2017, IDEAM classified the Andean region of Colombia as the second most deforested area in the country, following the Amazon[6], as in the last two decades, Colombia has experienced a loss of 5.7% of its tree cover, about 4.7 million hectares, particularly affecting informal settlement areas such as Triángulo Alto.

***Uncontrolled Anthropogenic Interventions***

While climate change continues to play a significant role in deforestation, so does rapid demographic growth and migration to Urban Centers as found in a study conducted by Ojeda and Donelly[7]. In Bogotá, the spatial redistribution of displaced rural populations has occurred in localities such as San Cristobal, Ciudad Bolívar, and Usme. The influx of residents relocating to informal settlements around the periphery[8], coupled with uncontrolled and uninformed anthropogenic interventions and migration, is directly linked to an increase in shallow landslide activity[9].

In the majority of Bogotá's informal settlements, residents construct their own homes using subpar materials and methods unsuited for the steep terrain, increasing the risk of landslides. These dwellings often feature unreinforced masonry, adobe bricks, and recycled metal sheets. Due to their informal status, these settlements lack proper foundations and adherence to building codes and are not part of formal urban planning. Without engineering oversight, these construction methods and materials make structures highly susceptible to landslides and other natural disasters, increasing the likelihood of collapse or severe damage.

***The Impact of Earthquakes: Seismic-Induced Landslides***

Throughout Colombia's history, landslides triggered by seismic activities have been a recurring challenge. The ongoing interaction among the Nazca, South America, and Cocos tectonic plates, uplifts mountain systems and sustains seismic activity. Historically, landslides in Colombia coincide with seismic events of at least a 5.0 magnitude, though occurrences at lower intensities have also been documented.

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[4] Diaz, D. (2024). Learning from Vernacular Architecture to Develop Potential Methods in the Colombian Periphery to mitigate the housing crisis in Landslide prone topography. Delft.
[5] Grima, N. et al Landslides in the Andes: Forests can provide cost-effective landslide regulation services. International Union of Forest Research Organization.
[6] Garcia-Delgado et al. (2022)
[7] Ojeda J, Donnelly L (2006) Landslides in Colombia and their impact on towns and cities.
[8] Lambin EF, Geist HJ (2003) Regional differences in tropical deforestation.
[9] Glade T (2003) Landslide occurrence as a response to land use change

Pérez-Consuegra's research highlights the significant impact of tectonic forces on slope dynamics in the Eastern Cordillera region, where Bogotá lies, intensifying landslide risks beyond rainfall's influence.

### 1.3 Research Objective

The primary objective of this research is to analyze the resilience of vernacular architecture in regions susceptible to landslides and earthquakes and to identify aspects that can be adapted and combined with modern technology to inform the design of housing typologies for the informal settlement of Triangulo Alto in Bogota's San Cristobal locality. Furthermore, developing a methodology for introducing construction techniques using locally available and upcycled resources, aiming to empower residents in constructing their dwellings with accessible building methods suitable for non-skilled labor, addressing housing shortages and vulnerability to landslides in peripheral areas.

The research will examine three vernacular case studies: Peru, Nepal, and Turkey with comparable topography, altitude, and materiality. Despite their commonalities, each case study will present unique cultural needs, climatic conditions, and challenges, providing comprehensive insights into the adaptability and efficacy of vernacular architectural strategies across varying environmental parameters.

### 1.4 Relevance

The decline of traditional building methods has led to construction practices that often overlook environmental factors and climate adaptability. Embracing these traditional techniques can make construction more accessible for everyone and better withstand natural disasters.

The project aims to support communities living in Bogota's mountainous areas, where they face unique challenges. Limited access to construction materials due to economic factors has inspired the exploration of alternative options like repurposed materials such as tires and resilient natural materials like bamboo. This not only addresses their structural needs but also promotes sustainability.

According to the Technical Document of Support to the Territorial Order Plan of Bogotá, many areas on the city's outskirts are at risk of landslides. While the focus is on San Cristobal, similar areas like Usme and Ciudad Bolivar share common geological features, making them vulnerable to landslides as well. Efforts in San Cristobal can serve as a model for addressing similar challenges in these areas.

### 1.5 Methodology

This study delves into traditional architectural practices in regions akin to Colombia, focusing on mountainous areas' management of landslide and earthquake risks with a focus on the three case studies. Comparing aspects such as settlement layout, climate responsiveness, and structural elements.

Additionally, examining how traditional methods and modern technology can address the housing crisis on the outskirts. Special attention will be paid to the use of recycled and natural materials in Colombia's Cundinamarca region, one of the most densely populated areas prone to landslides, to seek sustainable solutions for people and the environment.

## II. VERNACULAR ARCHITECTURE: A PARADIGM FOR RESILIENT AND SUSTAINABLE DESIGN

The concept of Vernacular Architecture encompasses a diverse range of definitions and interpretations, spanning from ancient to simple, and Indigenous traditional structures[10]. This approach has often been categorized as crafted or reared at home[11], in contrast to 'scholarly' architecture. Amos Rapoport highlighted the importance of anthropological and cultural parameters in understanding vernacular architecture in *House, Form, and Culture*. He proposed a two-phase approach to its study:

1. N*atural history stage*: describing, documenting, and classifying the vernacular buildings.
2. The problem-solving phase: comparative and comprehensive studies, leading to the development of theories and concepts[12].

Following Rapoport's *model system* approach, this dissertation takes a practical and technical view of vernacular architecture. Focusing on uncovering the underlying principles and construction techniques, functionality, and adaptability to local conditions, offers valuable insights for future applications.

## III. UNRAVELING COMPLEXITY: THREE RESILIENT VERNACULAR CASE STUDIES

The three vernacular case studies chosen exhibit remarkable resilience against earthquakes and landslides. Despite their varying climates, available local materials, and distinct cultural influences shaping their designs, they share a common steep topography. This shared geographical feature adds an intriguing dimension to the analysis, highlighting how diverse environmental factors can influence architectural resilience. Moreover, their locations on different continents offer a unique opportunity to explore strategies across distant regions, providing valuable insights for the conclusion. The introduction of each case study will involve contextualizing its prominent features, including geographical and climate context, settlement layouts, climate responsiveness, and an in-depth analysis of the structural integrity.

### 3. 1 The Inca Resilience: Engineering in the Andes Mountains

This section will explore Incan methodologies, from Ollantaytambo, Pisaq, and Machu Picchu. The Incan civilization thrived from the thirteenth to sixteenth centuries, showing adaptability across diverse landscapes. Nestled amidst the Andean peaks, Incan cities showcased architectural ingenuity and urban planning, crafted to withstand seismic activity and landslides while prioritizing sustainability. Terracing supported both construction and agriculture, seamlessly blending with natural contours. Ceremonial spaces and royal residences were meticulously aligned with astronomical movements, reflecting a connection between culture and landscape.

***Housing and Settlement Layouts***

In Incan urban planning, complexes were arranged into distinct sectors, often featuring two plazas and spacious vestibules. In Ollantaytambo, *Kancha, a system* organizing quadrilateral buildings into functional complexes, were enclosed areas with four residential buildings bordering a central courtyard, each accessible from the central street. Buildings followed a north-south axis layout, with plazas facilitating communal interaction. While most houses were single-story, some featured high gable roofs,

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[10] vernacular architecture. *Oxford Reference.* Retrieved Feb. 2024, from https://www.oxfordreference.com/view/10.1093/oi/authority.20110803115517898.

[11] Frey, P. (2010). *Learning from vernacular towards a new vernacular architecture*. Actes Sud.

[12] Rapoport, Amos, Vivienda y cultura, G.Gili, Barcelona, 1972

suggesting additional levels. Multi-level houses included shelves in their rear walls to support upper-floor construction. The structured organization of administrative centers, plazas, and Kanchas was foundational to Incan cities, facilitating governance and community engagement. The strategic placement of residential units and city structures integrated with the natural topography exhibited resilience against landslides.

***Climate-Responsive and Adaptive Architecture***

The Incas employed design strategies that embraced climate-responsive and adaptable architecture, as evidenced by stepped terracing and close arrangement of buildings which provided aerodynamic benefits, effectively deflecting strong winds. Negative pressure zones formed between the roofs and the rear portions of the highest buildings. Model tests and qualitative analysis conducted by Jean-Pierre Protzen revealed that smoke near lower buildings would be drawn in and promptly expelled through rear windows, preventing smoke from reaching central buildings[13]. This was facilitated by strategically positioned windows in a cross-ventilation system.

Furthermore, the Callejón in Ollantaytambo situated between one to six meters below the terrace surface and spanning approximately sixty meters in width, creates a unique microclimate protected by lateral retention walls. Fostering a conducive environment for crops and enhancing urban integration. The walls absorb and gradually release solar radiation, promoting warmth and facilitating the growth of crops adapted to warmer climates. The air temperature within the lower part of the depression is consistently two to three degrees Celsius higher than that of the tallest terraces, as the area benefits from significant protection against strong evening winds that traverse the Alluvial fan[14].

***Structural System and Foundations***

Most of the Inca structures were built on solid rock or large stone foundations, ensuring stability and evenly distributing the weight of the buildings. Utilizing locally sourced materials in their architecture the Inca relied predominantly on rocks such as rhyolite, tuff, rhyolite breccia, limestone, granite, and ignimbrite. In areas that seemed to be less stable, the Incas constructed raised platforms or used deep foundational stones. The stones were meticulously fitted together without mortar in a masonry technique called *ashlar,* relying on the precise cutting and shaping of each block resulting in highly stable structures and resistance against earthquakes.

Additionally, as the Incas followed natural contours, they also incorporated natural bedrock outcroppings into the foundations for extra stability. The largest and flattest stones are laid at the bottom to create a level base in trenches dug into the ground, with smaller stones used for the upper courses. This method enabled resiliency, capable of enduring the test of time and natural forces.

***Walls***

The cities were surrounded by large contention walls that would protect them from possible avalanches and landslides. The process of stone extraction was meticulous and had to be carefully planned, as the extraction sites had to be protected at strategic locations with retention walls. The walls, in most cases, were a continuation of the stacked stones from the foundation without the use of mortar. The wall was able to stand due to an interlocking mechanism via "T-shape' and 'U-shape' notches employed on one side of the stones. The interlocking system allows walls to slightly move during an earthquake and resettle, enhancing the structural integrity by eliminating weak stress points and vibrations due to the tight connections between the stones. Then, the inferior part of the wall would also incline at a 10% average per meter in height toward the mountain's slope to form a trapezoidal form, acting as a retention wall,

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[13] Diaz, D. (2024). Learning from Vernacular Architecture to Develop Potential Methods in the Colombian Periphery to mitigate the housing crisis in Landslide prone topography. Delft.

[14] Protzen,P. (2005). Arquitectura y Construcción Incas en Ollantaytambo. Second Edition. Pontificia Universidad Catolica del Peru. (Pg.132)

supporting the pushback of the slope. Often, the retention walls were built with two or more layers anchored together in a staggering manner depending on the height, protruding stones from the lower layer would interlock with the next.

In many housing units, the use of *Nichos* was incorporated as a practical characteristic, and aesthetic as well. The walls were generally thicker and heavier at the bottom, and lighter at the top. In some cases, if the wall was to be high, the Inca would use adobe.

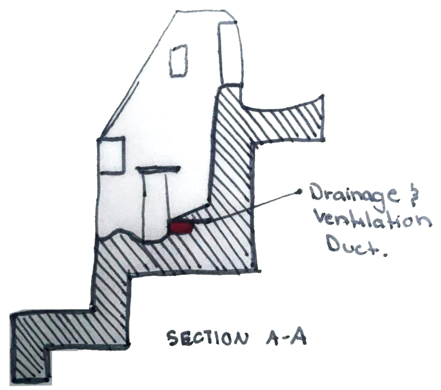


Figure 1.1 - The drawing shows a cross-section of a wall structure, highlighting drainage and ventilation canals. Drawn and annotated by the author, based on Jean-Pierre Protzen (2005, fig 5.5).

Figure 1.2 -Image of Inca ruins in Pisaq, Peru. Image by the author.

***Roofs***

Incan roofs, evidenced by remaining gables, were steeply pitched, generally around 60 degrees, with some variation. Despite covering smaller areas, larger structures like expansive halls are indicated by discovered ridge beams positioned approximately 10 meters above the eaves. These beams were supported by beams extending up to 12 meters long.

Inca carpenters likely employed braces for structural reinforcement against lateral forces in expansive structures. Agurto's calculations suggest that the weight and angle of longitudinal walls resisted thrust forces. Steeply pitched Inca roofs aimed to counter thrust forces but increased vulnerability to wind loads. Wind passing over the roof could create low-pressure zones, potentially causing uplift surpassing the roof's weight, requiring secure attachment methods. Therefore, to secure mats over joists, tie-down forks were strategically placed for stability in adverse weather conditions, while exterior nails acted as anchors, safeguarding against wind damage.

In the Punkuyoq Mountains, a distinctive architectural style emerged, featuring gable bases notched at every corner and sloping walls that created interior shelves. These gables, embellished with mooring forks and horizontal stone nails, utilized notches as joist supports and *Nichos* for rounded wood tripods. Tie-down forks secured mats over joists for stability in harsh weather, while exterior nails acted as anchors, protecting against wind damage. At Inkwazi, the ledge on longitudinal walls and anchored ridge beams likely prevented roof detachment effectively.

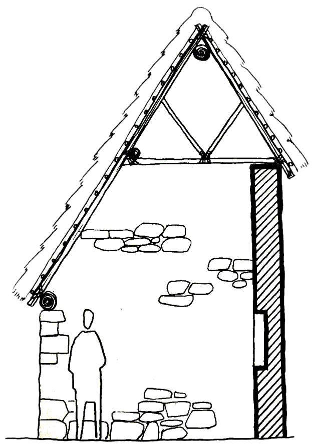

Figure 1.3- Drawing of roof slopes and lengths by Gasparini & Margolies

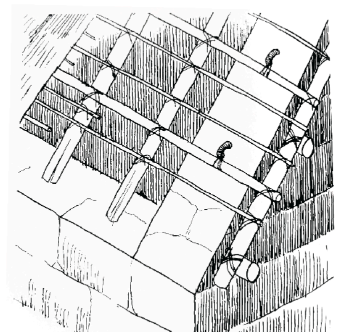


Figure 1.4 - Drawing by Gasparini & Margolies, annotated by the author.

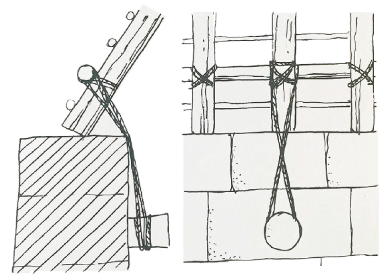


Figure 1.5- Drawing by Gasparini & Margolies annotation by the author.

## 3. 2 Nepal- Sherpa architecture

The second case study explores the Khumbu region in Nepal, where Sherpa villages are nestled in the Himalayan mountain range bordering Tibet. Buildings in this area face diverse geomorphology and altitudes over 3,000 meters. They must endure heavy rains and hazards associated with the Himalayan fault line, including a high risk of earthquakes, landslides, and avalanches. A study by Nripal Adhikary documented that vernacular houses and modern buildings incorporating traditional materials like bamboo and rammed earth survived the catastrophic 2015 earthquake[15].

***Housing and Settlement Layouts***

In the Khumbu Region, settlements are typically found in the alluvial fan, between the mountainside and river gorges. Villages incorporate a uniform layout, with dwellings grouped in small clusters, terraced on slopes forming a semicircle similar to an amphitheater surrounded by cultivated land, incorporating an open space or yard in front of the house, serving both as a social space and a landslide mitigation measure. Furthermore, Sherpa communities, deeply religious and nature-respecting, incorporate a *Gompa* at the settlement center. Their reverence for nature extends to climate-responsive strategies integrated into their architectural practices.

***Climate-Responsive and Adaptive Architecture***

Sherpa houses employ various climate-responsive techniques, such as maximizing sun exposure, promoting cross-ventilation, and using local materials thoughtfully. Construction is a deliberate equilibrium between wood and stone, fostering environmental harmony. Strategically positioned on a southeast axis, doors and windows enhance solar heating exposure and natural lighting, particularly advantageous during the extended winter. This integration and features like thick insulating walls and flooring create more comfortable living spaces. In the summer months from June to September, natural ventilation avoids overheating. Wood, brick, and stone are employed for their weather-resistant capabilities.

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[15] Adhikary, N. (2016). Vernacular architecture in post-earthquake Nepal. *International Journal of Environmental Studies*, *73*(4), 533–540.

***Structural System and Foundations***

Sherpa houses, similar to those of the Inca Empire, feature a rectangular form parallel to the slope and are elongated to integrate into the terrain. These structures are occasionally two storeys high, with the ground floor used for cattle storage during the cold months and the upper floor serving as the living area. Additionally, some L-shaped houses incorporating private worship spaces have also been documented.

Sherpa houses utilize two main structural components and materials. The foundation, embedded into the ground and constructed from large rocks, integrates the hillside into the ground floor[16]. The inner framework comprises wooden pillars, and beams, while the outer structure features large stone walls. Additionally to support the floor above a rectangular wooden joists system is atop the main framework of beams. Windows are framed with tenons or projecting tongues of wood, assembled without nails, and seamlessly integrated into the stone walls.

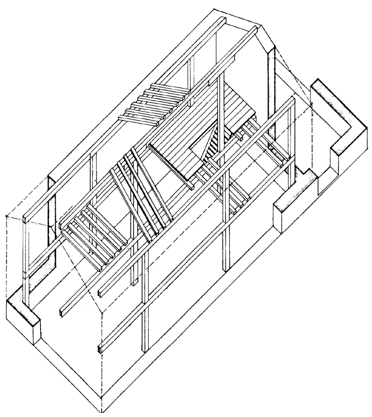

Figure 2.1- Axonometric of Sherpa dwelling. Drawing by Valerio Sestini and Enzo Somigli.
Figure 2.2- Image of Sherpa dwelling by Sonia Halliday.

***Walls***

The walls are made from large, locally sourced stones up to one meter thick, are load-bearing, and are crucial for withstanding wind and earthquake forces. These stone walls are bound with rudimentary mortar or clay, with more evenly shaped stones reinforcing corners, doorways, edges, and windows. The walls are often plastered with clayed earth for weatherproofing. Finely carved wooden windows and doors, featuring graceful lines and vivid colors, enhance the aesthetic appeal.


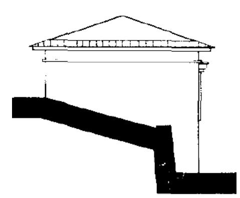


Figure 2.3- Elevations of a dwelling-house at Phortse. Drawings by Valerio Sestini and Enzo Somigli.

[16] Khadka, S. S., Acharya, S., Acharya, A., & Veletzos, M. J. (2023). Enhancement of Himalayan irregular stone masonry buildings for resilient seismic design. *Frontiers in Built Environment*, *9*, 1086008. https://doi.org/10.3389/fbuil.2023.1086008

***Roofs***
In the Khumbu mountains, local architecture is designed to withstand heavy rainfall and strong monsoon winds that could lift lighter materials. Houses typically have ridge or sloping roofs, often constructed from heavy stone slabs for added durability. The roof's supporting framework consists of closely spaced rafters resting on main beams. Simple eaves are created by extending the roofing material slightly beyond the walls, reflecting practical adaptations to the region's challenging weather conditions.

## *3. 4 Turkey- Eastern Black Sea Region*

The third case study, located in the steep mountains of Turkey's Eastern Black Sea region, showcases a vernacular settlement shaped by physical and cultural factors. Generational knowledge allows for optimal use of local materials[17], resulting in architecture that reflects the relationship between users and consciousness of the environment[18]. Due to the region's topography, buildings are constructed parallel to the slopes and are spaced apart to adapt to the uneven terrain. Furthermore, the climate is characterized by high moisture levels and frequent rainy seasons receiving around 2309 mm annually compared to Turkey’s 615.6mm average[19].

***Housing and Settlement Layouts***
A characteristic of the black sea region settlements is scattered clusters of housing built into the mountain slope following its natural contours, favoring rockier ground as it proves to be more stable terrain during the rainy season. They are often classified as compact scattered or rose settlements. To encourage social connections, the houses are close together, forming small streets and neighbourhood units, facing the valley and arranged in a repeating pattern of one house and one serender[20].

As an ecological strategy to combat soil erosion and prevent landslides, each house is surrounded by tea gardens with zigzag terraced rows and the community prioritizes planting trees in settlement areas. The region’s architecture aligns with nature with minimal land alteration, blending into the terrain.

***Climate-Responsive and Adaptive Architecture***
Rather than treating nature as an obstacle, the vernacular architecture in the Black Sea Region challenges the mountainous topography leading to self-sufficient housing units through effectively utilizing local biobased resources such as stones and wood. Furthermore, the passive systems employed consider the climatic conditions such as the wind, rain, and sun[21], addressing the well-being of the occupants, protecting them from harsh weather, and minimizing heat loss in cold months.

Practical orientation and land-use strategies are employed to achieve cross-ventilation techniques utilizing the natural airflow through calculated openness ratios on walls via windows and ventilation gaps. The large eaves like the *Kara Saçak* act as rain-shielding elements for the building. Furthermore, the design encourages natural light and features adaptable interiors with wooden dividers, allowing for versatile space utilization.

The design and ability of disassembly and reassembly of *Serenders* is particularly innovative in vernacular architecture, allowing the structures to be temporary, portable, or moved to another place.

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[17] Karahan and Davardoust, 2020
[18] Senosiain, 2003
[19] Turkish State Meteorological Service, 2021
[20] Özen, Keleş and Engin. Journal of Civil Engineering and Architecture, Vernacular Building Heritage in the Eastern Black Sea Region in Turkey. 2012.
[21] Oktay, 2010

Furthermore, the *Serenders* also incorporate local and recycled materials, which reduces waste and promotes circular design.

***Structural System and Foundations***

Most houses incorporate two levels with the first level serving as a warehouse barn, aligning the structure with the landscape. The second level is for the residents. The main construction material is timber due to its insulation capabilities and resistance against humidity. Two timber structural systems are common:

1. The Timber Masonry system employs overlapping and interlocking mechanisms, eliminating the need for nails or mortar. The rectangular structure features square cross-section support columns placed at regular intervals. Both interior and exterior walls are constructed simultaneously using notched and neck joints, with timber elements extending 20-30 cm from jointing points for support.
2. The Timber Frame System features load-bearing elements standing vertically on stone foundations. Basement joists, set at 15x15 cm intervals, utilize interlocking neck joints for strength. The posts above these joists determine each floor's height, with ceiling joists positioned over the corner and middle posts, resulting in a lightweight structure with a flexible floor plan.

The timber structures are supported by masonry foundations integrated into the land, following its contours. Some houses partially bury the foundation for insulation and humidity protection, using locally sourced granite.

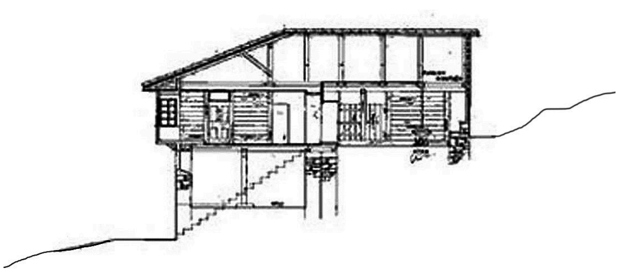

Figure 3.1- Cross sections of dwelling (Batur, 2005)

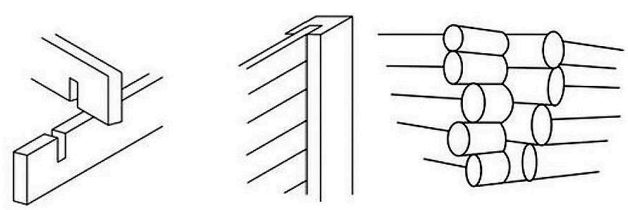

Figure 3.2 - The different types of structural interlocking systems. Retrieved from Elif Berna Var.

***Walls***

The subsequent analysis pertains to the structural composition and components of the walls. The Kurt boğaz and Kara boğaz techniques align with the timber masonry system and function as load-bearing connections. In addition, two primary façade systems are prevalent: Göz Dolmasi, a rectangular cell infill system, and Muska Dolgu, a triangular cell infill system.

The *Göz Dolmasi* integrates stone and timber elements. Initially, joists are positioned above the stone walls, followed by timber posts at intervals. Each segment is filled with wooden pieces creating rectangular cells horizontally and vertically. These cells are then filled with stones and other regional materials, with leftover spaces filled using clay or lime mortar. Typically, 20-25 cm wide plates are placed between pillars both internally and externally[22], facilitating the creation of window and door gaps, and ensuring secure fixation through an interlocking method.

[22] Construction Techniques of the Vernacular Architecture of the Eastern Black Sea Region. 2013.

The *Muska Dolgu* wall system uses similar components and incorporates metal binding elements instead of timber joints. Diagonal supports between the posts create triangular divisions, filled with small stones. While nails expedite construction, they affect the structure's demountability.

Both techniques often feature interior walls lathed with plaster or timber veneer. Over time, the elements darken, creating a contrast with the stones. *Artuma*, porch-like/balcony structures around the building, were made of timber frames resting on the masonry foundation, accessible from bedrooms and protecting lower floor openings.

Figures 3.3 and 3.4- Wall cell infill systems. Images by Hamiyet Özen.

***Roof***

The vernacular roof types prevalent in the Eastern Black Sea Region primarily feature steep-hipped designs, which are subdivided into three main variations: double-pitched, triple-pitched, and quadruple-pitched. These variations are determined based on factors such as the required space and the climatic conditions of the region, particularly focusing on efficient water drainage with exterior and wall protection. The roofs also doubled as functional storage units, with height directly correlating to increased storage capacity.

The region is recognized for the *Kara Saçak* cantilevered eaves extending up to 2.5m in length[23] and are about 80-180 cm in width. The timber truss system is then constructed according to the roof's desired height, pitch, and slope. The shingles were predominantly made out of wood (chestnut) or thatch (straw or reed), as these biobased materials are moisture-resistant and durable.

## IV. CONCLUSIONS

Comparing Incan architecture in the Andes, Sherpa architecture in Nepal's Khumbu region, and Turkey's Eastern Black Sea region reveals the resilience of vernacular engineering's resilience over time. These cases showcase how vernacular architecture, molded by both physical and cultural elements, embodies an understanding of steep terrain, local materials, and climate-responsive techniques, offering lessons adaptable to modern sustainable, and resilient designs.

In settlement layouts, these cases integrate with natural contours, minimizing ecosystem impact through terracing techniques for mountain construction. Clustered formations optimize resource utilization and support networks for swift crisis response, while cultural features like courtyards, plazas, and gardens foster community bonds and unique identities.

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[23] Şen, Necati. 1967. *Rize'de Beş Ev*. İstanbul: Technical University Publishing.

For contemporary designs, incorporating vernacular techniques such as passive cooling through cross-ventilation and strategic window placement is crucial for promoting natural airflow and cooling within buildings. Solar orientation ensures maximum exposure to sunlight for heating and lighting, especially during winter. Insulation and thermal mass, facilitated by thick walls, regulate indoor temperature and humidity. Rainwater management, including steep roofs and terracing, efficiently directs runoff to protect structures from moisture damage. Vernacular designs emphasize the use of local and durable materials, simple structures, and open-plan layouts.

Analyzing the structural systems and foundations is critical to understanding which elements and techniques rendered vernacular architecture resilient against landslides. Interestingly, none of the vernacular structures were raised on stilts, as seen in some current constructions in various slums in Bogota to avoid flooding. Instead, these structures are embedded into the landscape, following the contours of the land. To address flooding, Inca vernacular techniques involved canalizing rainwater and rerouting it through small channels underneath the houses for cooling. Additionally, both the Sherpa and Black Sea regions utilize terraced gardens and plantations to mitigate runoff water. These strategies could be incorporated into the Triangulo Alto housing design.

Moreover, two out of the three vernacular cases employed interlocking structural and wall techniques, utilizing either large stones arranged in lego-like or wooden interlocking joint mechanisms. While only one of these cases incorporated an inclination of the walls towards the mountain, all of them adopted a rectangular shape for the buildings, aligning them parallel to the slope. Therefore, when designing in steep terrain prone to landslides, it is essential to consider strategies such as mitigating runoff rain, integrating thick retention walls into the mountain slope, and assessing potential interlocking mechanisms to enhance construction accessibility and building flexibility.

The vernacular studies revealed that steep-hipped roofs were the most efficient in terms of structural integrity and water drainage, with larger eaves providing wall protection. Each case study employed bio-based structures and coverings like thatch. Notably, in the Eastern Black Sea Region, some houses merged into the ground with grass serving as a natural roof covering, resembling a green roof design.

Finally, the only case study that employed a ‘future-proof’ strategy was the Eastern Black Sea Region through modular techniques, recycled materials, and design for disassembly, which is an aspect that should be considered when designing social housing in Bogota.

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## APPENDIX I - Glossary

*Akapana:* Stone blocks in the base of a structure in the form of a parallelepiped with smooth surfaces and perfect joining.

*Artuma:* Porch-like/balcony structures in the Eastern Black Sea region in Turkey.

*Cordillera:* Mountain Range

*Depression*: In geomorphology, a depression is an area of the Earth's relief located at a lower elevation than the surrounding regions.

*Gompa:* Shrine/religious buildings for Buddhists found in Sherpa Vernacular settlements.

*Göz Dolmasi:* a rectangular cell infill wall system.

*Kallanka:* Large unpartitioned hall with wooden pillars to support the roof. Served as temporary lodging for individuals rather than families.

*Kancha:* Group of several housing units. Two *Kanchas* would make an 'apple'.

*Kara Saçak*: Rain-shielding eaves that can reach up to 2.5m in the Eastern Black Sea region in Turkey.

*Kara boğaz:* an interlocking technique with logs used in the Eastern Black Sea region in Turkey

*Kurt boğaz technique*: an interlocking technique with wood planks in Vernacular Turkish architecture.

*Qollqa*: Storage units also called Deposits in Peru.

*Informal Settlements*: Refers to housing arrangements where residents lack legal land ownership and operate outside government regulations

*Muska Dolgu:* a triangular cell infill wall system.

*Tampu:* Rest stations in the Inca empire. There was a *tampu* in the road at the end of each day's travel.

*Slum:* According to UN-Habitat, 'slums' are characterized by a lack of essential amenities such as durable housing, clean water, improved sanitation, adequate living space, and secure tenure.

*Surrender:* Traditional Turkish granary or storage building.

*Suyu:* Quarter (in the sense of a region).

*Usnu*: A stepped structure, a platform, the base of a throne, a place intended for high-ranking personages. May also be an altar in the Inca empire.

# APPENDIX II - Case Studies

## Inca settlements

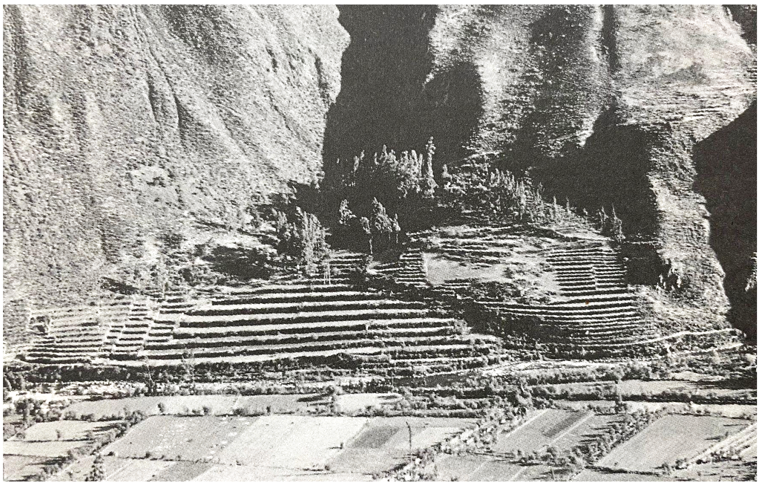


Figure 2.3
The Terraces of Sima Pukyu are embedded within the highest ravine zone and are watered through a subterranean current that remains active all year round. Image Courtesy of Jean-Pierre Protzen.

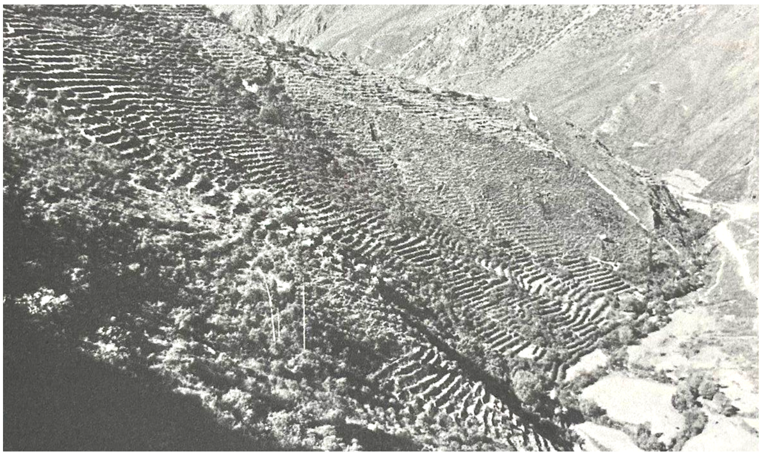


Figure 2.4
The stepped terraces of Choquebamba have a vertical incline of more than 700m. Only a third of the inferior part appears in the image. Image Courtesy of Jean-Pierre Protzen.

Figure 2.5
Terraces of Fortress Ollantaytambo view from the bottom looking up. Image taken by author.

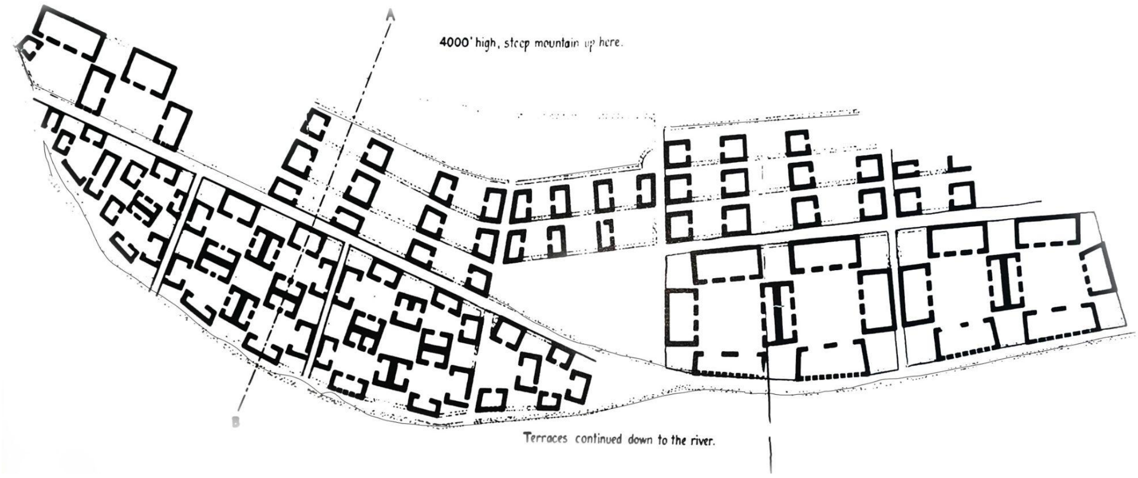



Figure 2.15 - A plan of *kancha* and other buildings following the natural contours of a mountain. Image drafted by Hiram Bingham in 1911.

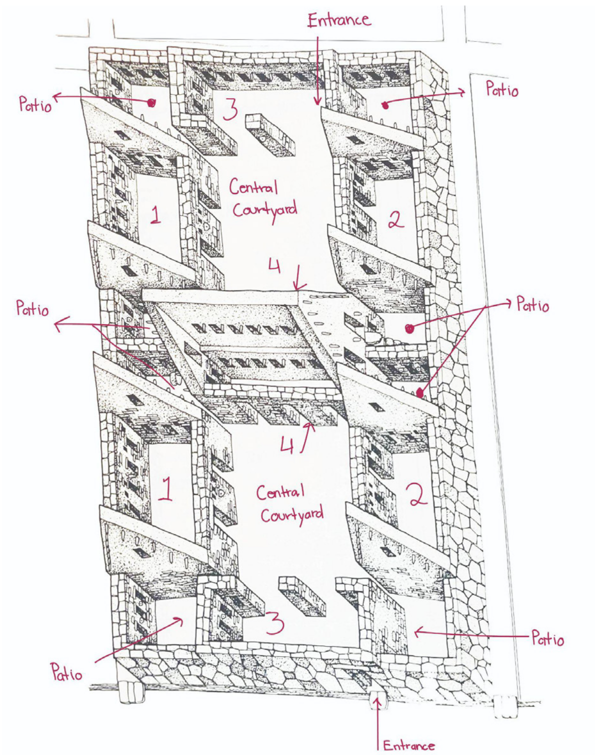


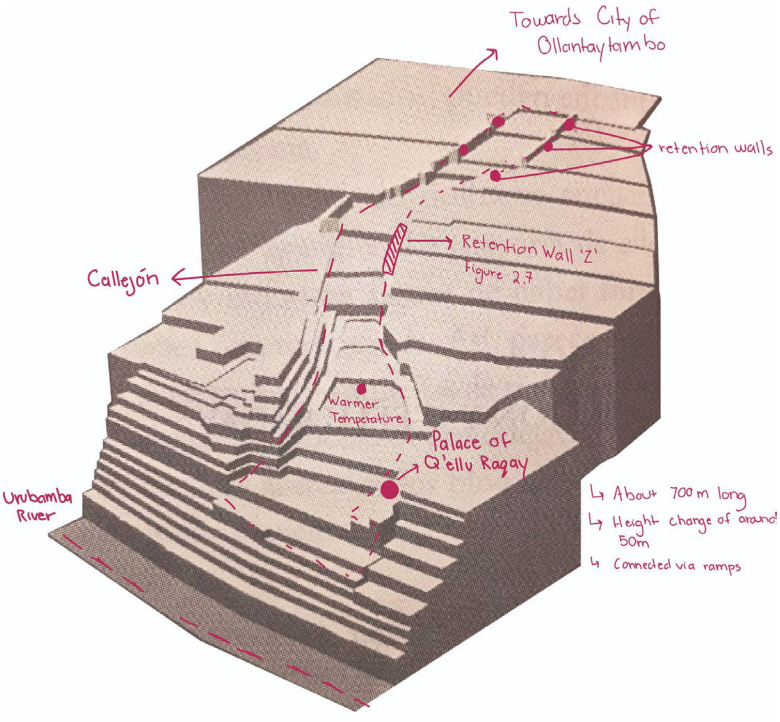


Figure 2.13 -An isometric view of an 'apple' two *kancha* highlighting each zone and entrance. Drawing by Jean P. Protzen. Annotation by author.

Figure 2.14- a visualization of a *kancha* unit with roofs. Image courtesy of En Peru Blog 2009. Annotation by author.

# Climate-Responsive/Adaptive Architecture

***Callejón/Alley***



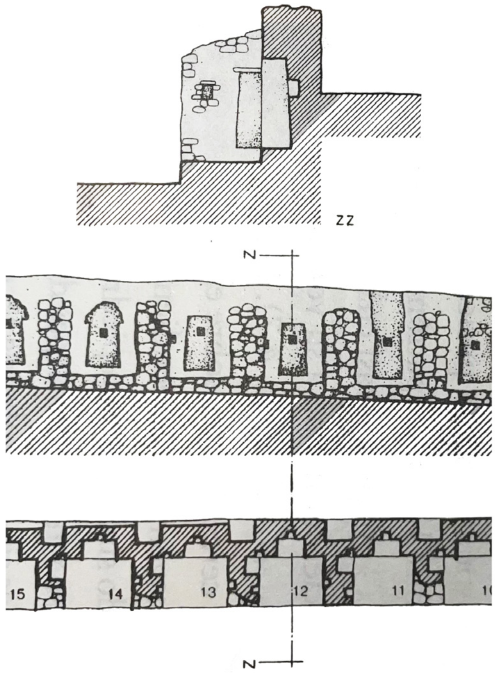




Figure 2.6 - 3D model of terraces by Jean-Pierre Protzen annotated by Author.

Figure 2.7 Retention wall 'Z' section by Jean P. Protzen

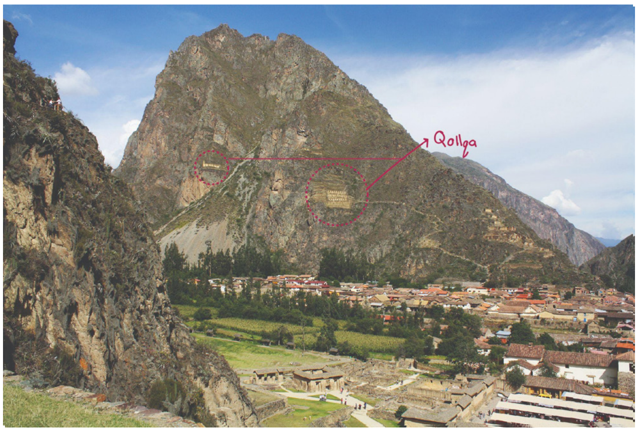



Figure 2.8 - Image highlighting the position of the *qollqa* in Ollantaytambo. Image and annotation by author.

Fig 2.9- A closer view of the *qollqa* depicting the current condition they are in 2019 since their construction in the sixteenth century. Image by author.

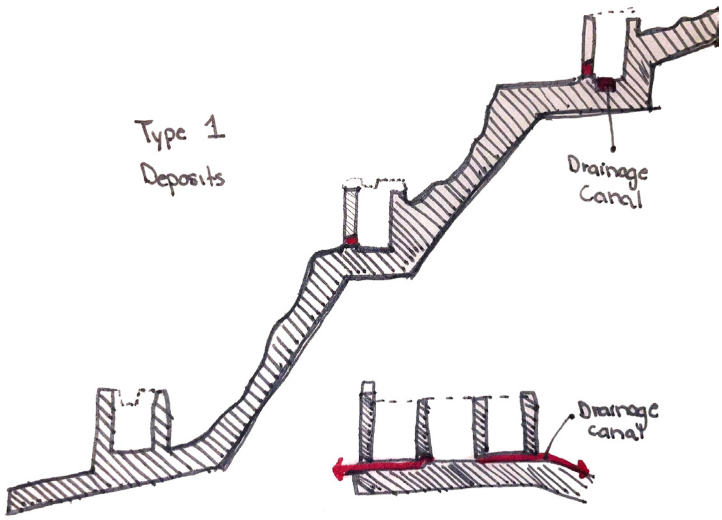



Figure 2.10 - The drawing demonstrates a transversal section of the deposit type one structures, highlighting the drainage and ventilation canals. Drawing and annotation by the author (redrawn from Jean-Pierre Protzen 2005, fig 5.5)

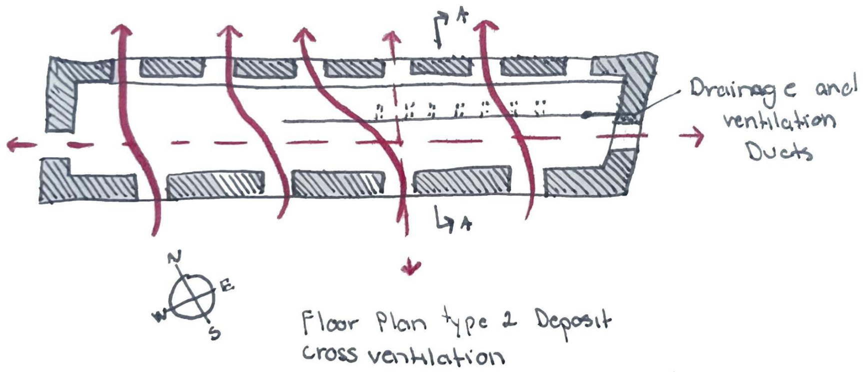



Figure 2.12 A plan of a rectangular type two *qollqa* in Ollantaytambo. Highlighting the cross ventilation and ducts. Drawing and annotation by the author, (redrawn from Jean-Pierre Protzen 2005, fig 5.19)

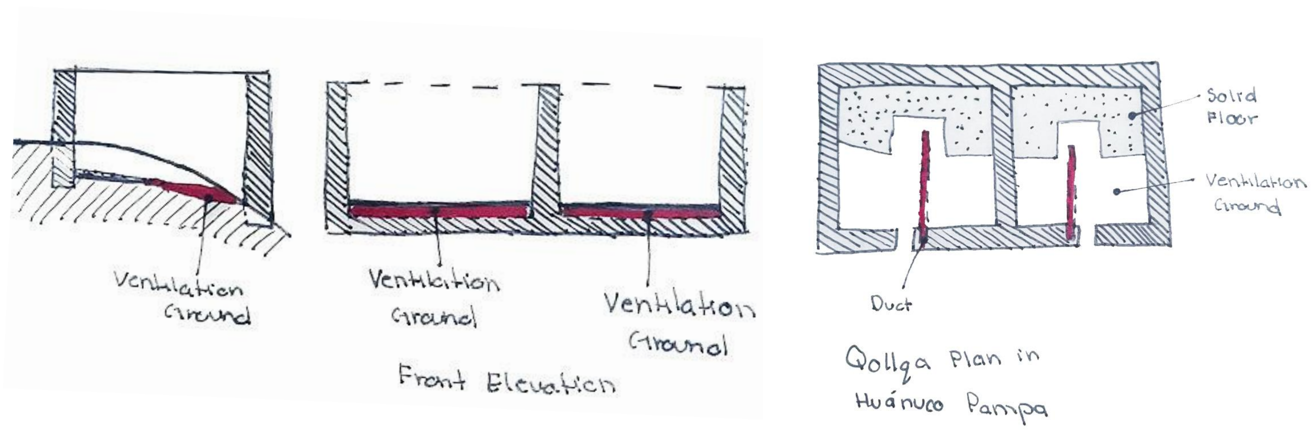
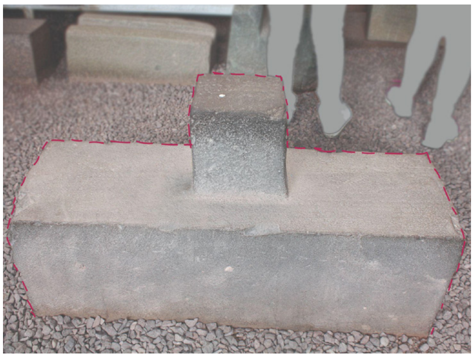



Figure 2.11 A plan of two rectangular *qollqa* in Huanuco Pampa. Highlighting the ventilation ducts as well as the entry doors. Drawing and annotation by the author, (redrawn from Morris and Thompson 1985 fig 18).

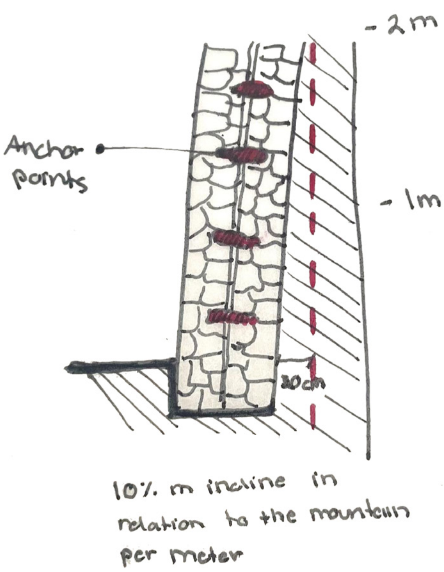
## Walls Techniques



Figures 2.20 and 2.21 demonstrate two examples of the interlocking technique. Images and annotation by author.
Figure 2.22 courtesy of  Atticus Drake

Figure 2.19 depicts the different interlocking techniques the Incas employed on the stones, similar to what in the modern day is known as Lego. Image by author.


Abuilding corner in Ollantay-tambo highlighting the large rock dimensions in reference to human scale. Image and annotation by author



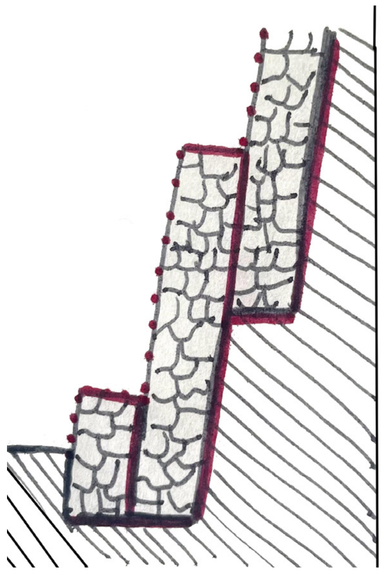
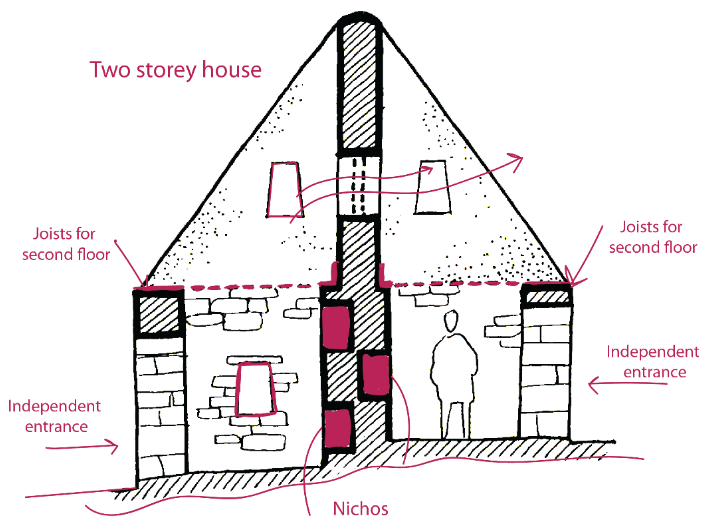



Figure 2.25- Incline towards the mountain with anchor points highlighted. Drawing by the author.

Figure 2.26- Staggered walls for greater stability. Drawing by the Author.

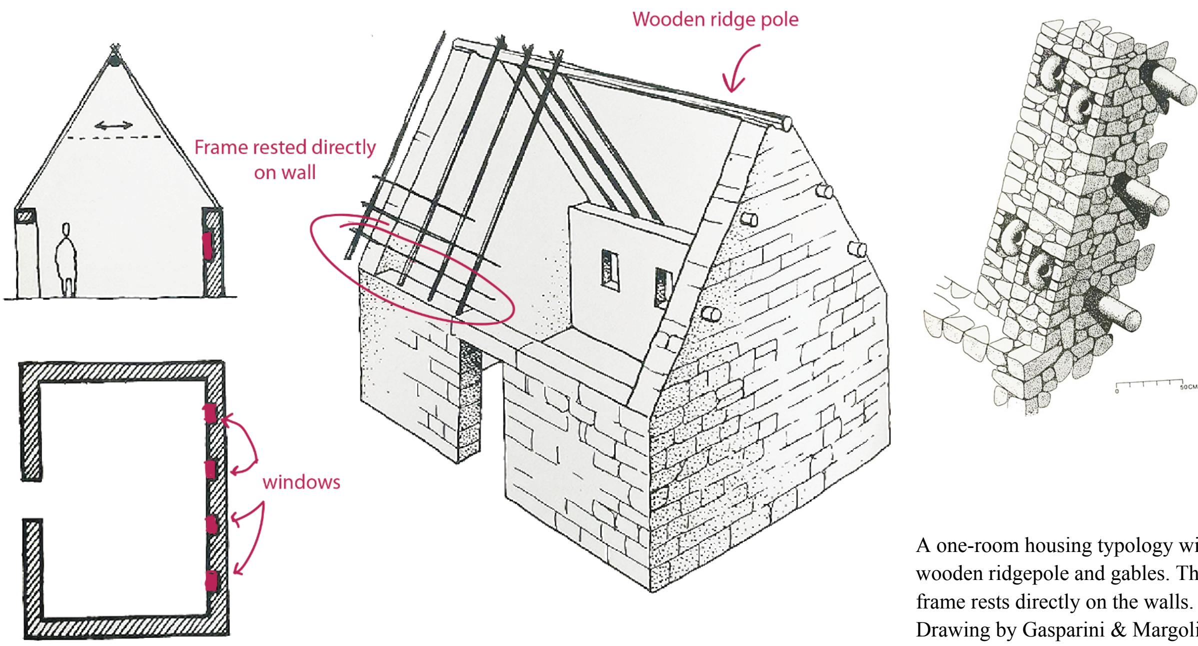



The drawing depicts a two-story house divided by a central wall with nichos, trapezoidal windows, and joists highlighted in red to support the second floor. Drawing by Gasparini & Margolies annotation by author.

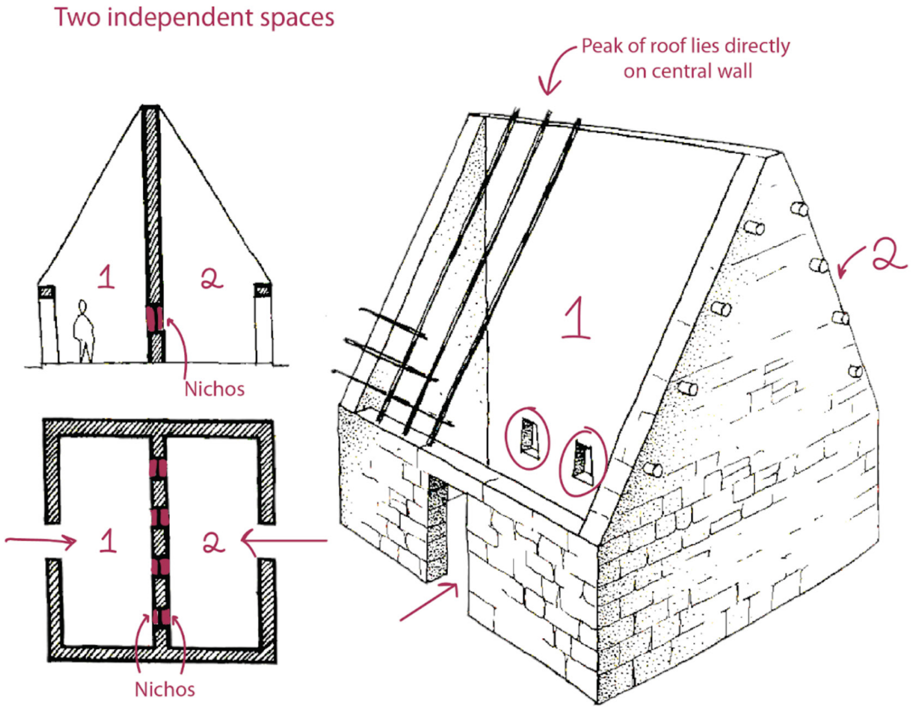
Image shows the nichos that were used as interior shelves of the houses. Image by Jean-Pierre Prtozen..


Infographics describing parts of an Inca housing and techniques and materials used for its construction. Retrieved from Pixels.com

## Roof Construction

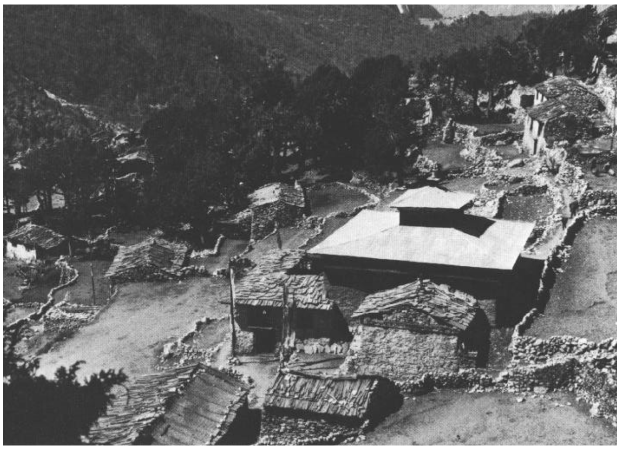
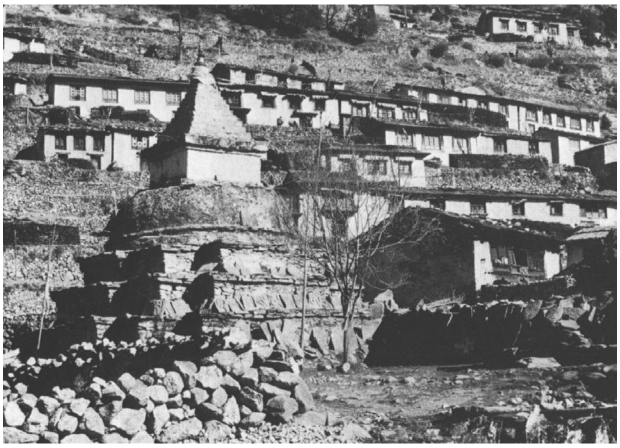



A one-room housing typology with a wooden ridgepole and gables. The frame rests directly on the walls. Drawing by Gasparini & Margolies annotation by author.




A housing typology with two independent spaces that are divided by a central wall where the peak of the roof lies. Drawing by Gasparini & Margolies annotation by author.

## Sherpa Settlements

Sherpa Settlements- Images courtesy of Valerio Sestini and Enzo Somigli


The Namche Bazaar in the Khumbu region. Images courtesy of Sherpa Village Lodge Trek.

## Climate-Responsive and Adaptive Architecture

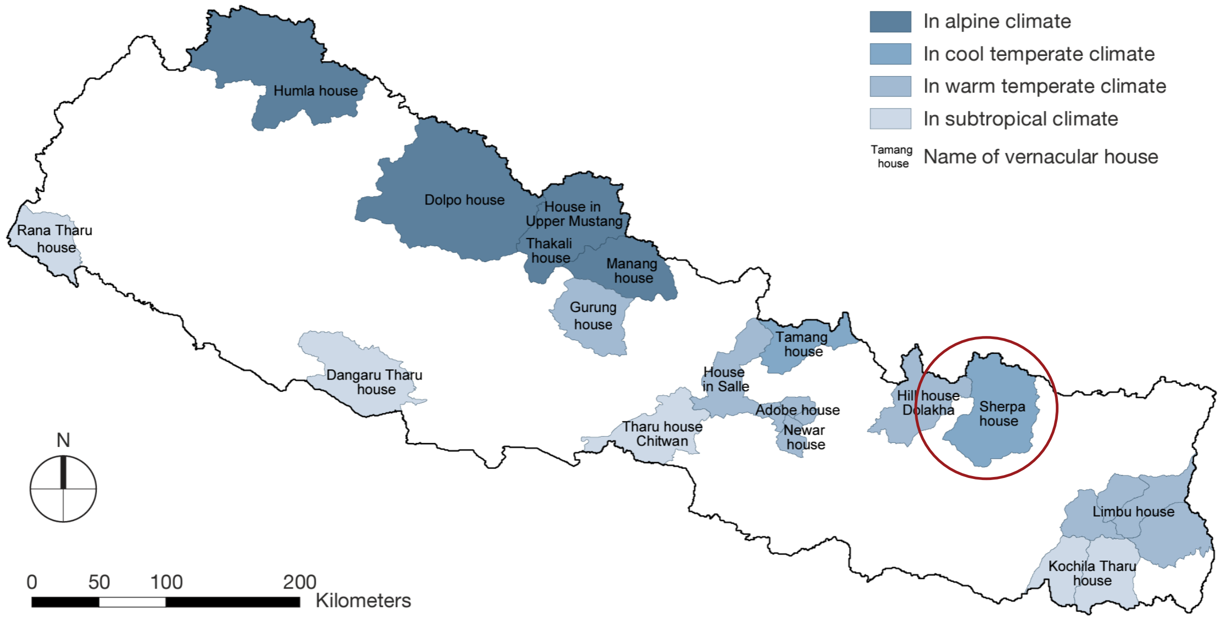
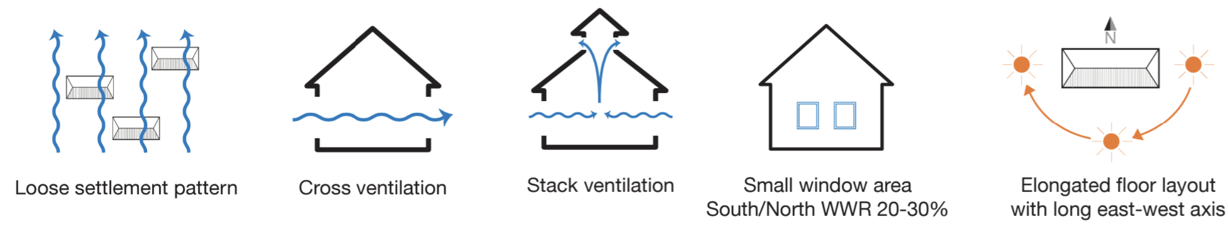



**Figure 2.1:** Nepal map with the location of analysed vernacular houses

Diagrams courtesy of Bodach, S., Lang, W., Hamhaber, J.




Diagrams courtesy of Bodach, S., Lang, W., Hamhaber, J.

This article was originally published in Energy and Buildings 81 (2014) 227–242. Please cite as following: Bodach, S., Lang, W., Hamhaber, J., 2014. Climate responsive building design strategies of vernacular architecture in Nepal. Energy and Buildings 81, 227–242. Find figures and tables at the end of this document.

**Table 6: Characteristics of vernacular houses in Cool temperate climate of Nepal**

| | **Tamang houses** | **Sherpa houses** |
|---|---|---|
| **Location** | Central mountain, Langtang region | Eastern mountain region |
| **Settlement pattern** | Attached houses, rather compact | Houses in small groups along the slope |
| **Building form** | Compact rectangular floor plan, attached houses | elongated rectangular or L-shape |
| **Building orientation** | Main façade south-west wards | The longer side towards the slope |
| **Stories** | 2 | 2 |
| **Internal space arrangement** | Vertically, elevated ground floor is main leaving area with kitchen and sleeping, 1st floor storage | vertically, ground floor as thermal buffer space |
| **Semi-open spaces** | Veranda and balcony | Veranda |
| **Wall material** | Unplastered stonework | stonework dry or with mud mortar, mud plaster |
| **Wall thickness** | 40-60 cm | up to 1 m |
| **Roof material** | Wood slat weighted with stones, stone slate (if available) | wooden pillar and beam structure with heavy stone slabs |
| **Roof type** | Pitched roof | pitched roof |
| **Roof overhang** | Yes | yes |
| **Foundation** | Elevated ground floor adapting to the slope | ground floor partly built into the slope |
| **Floor** | Wooden lathwork | wooden floor with carpet |
| **Ceiling** | low ceilings | double wooden ceiling |
| **Openings** | Small wooden windows only in entry facade | small openings, only one large living room window faced southwards |

Table describing the characteristics of Sherpa Vernacular architecture in cool climates. Table by Bodach, S., Lang, W., Hamhaber, J.

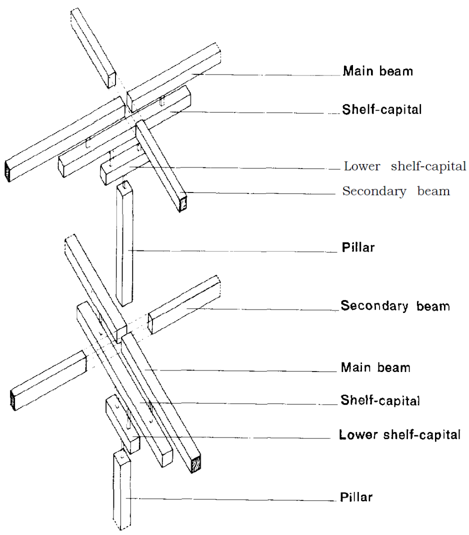
## Construction Techniques

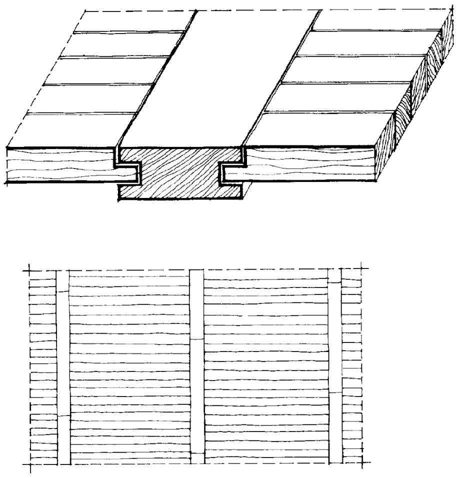
The Namche Bazaar in the Khumbu region. Images courtesy of Sherpa Village Lodge Trek.

Sherpa Village- Courtesy of Timon Schneider

Sherpa House courtesy of Photo Voyages.
Steep roof, roof overhang on two levels , small windows, retaining wall made out of stone in back garden, along with trees and plants to prevent soil erosion.

Image of a window in a Sherpa home. Image courtesy of Valerio Sestini and Enzo Somigli.



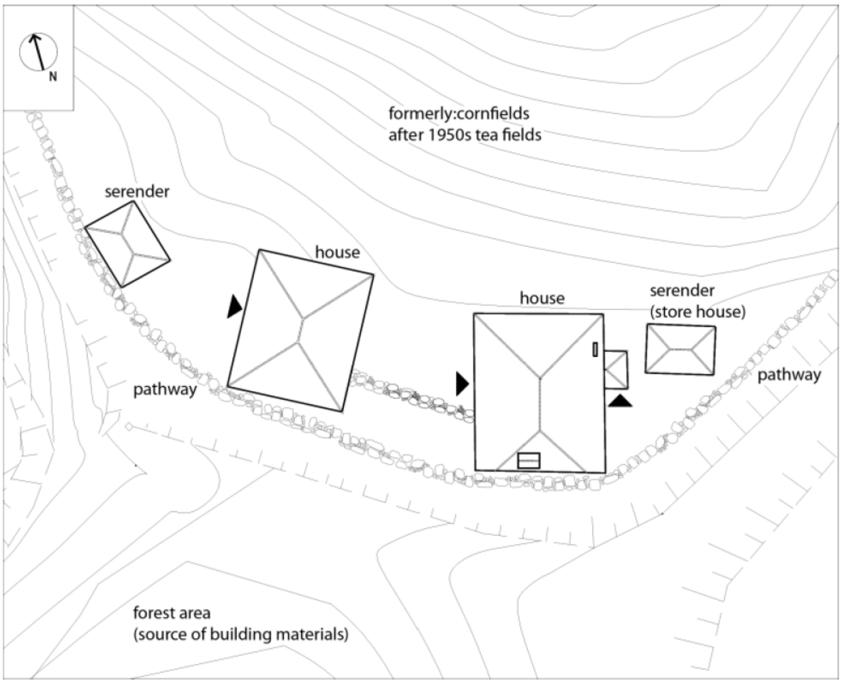



The first diagram is an axonometric of the main beams and shelfcapitals in a gompa.

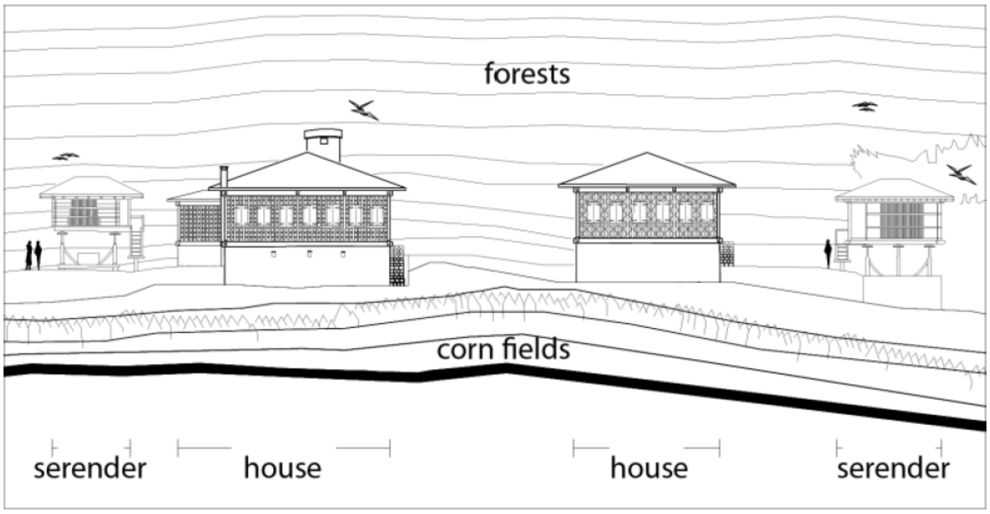
The second diagram is the interlocking system employed for the floors. Diagrams by Valerio Sestini and Enzo Somigli.

Housing inbedded in the mountain. Surmener/ Trabzon. Image courtesy by Gur and Batur 2005.

## Eastern Black Se Region Settlements

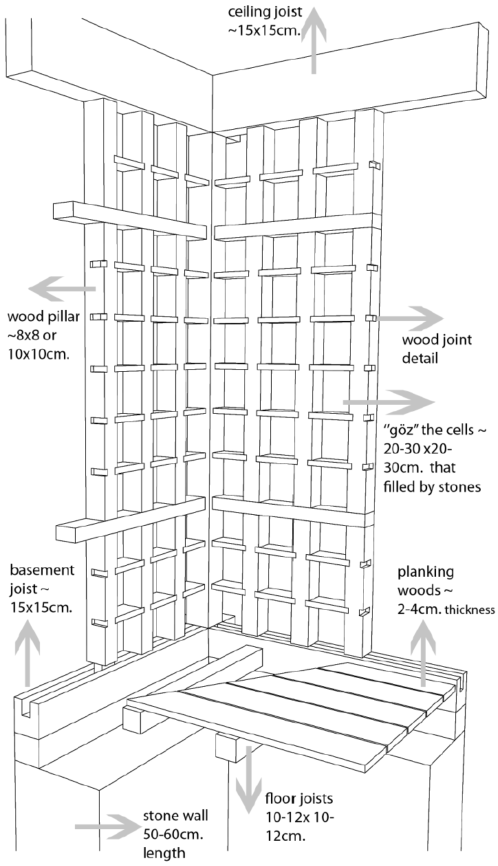



Settlement sample from Fındıklı, Rize (Güler, 2012).




Elevation of housing clusters and teh religious serender (Güler, 2013).

A view of traditional house, serender and tea fields in Fındıklı (Güler, 2013).




Perspective drawing of the construction of a timber frame structure with cell infilling system (Güler, 2013).

Figure 7. A closer view to cells (Bilge, 2013).

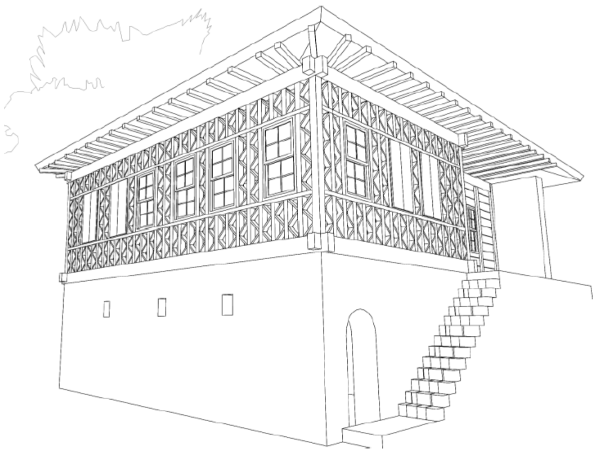
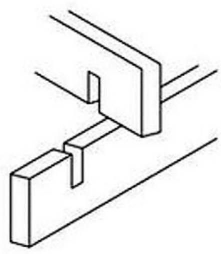
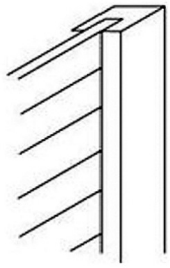
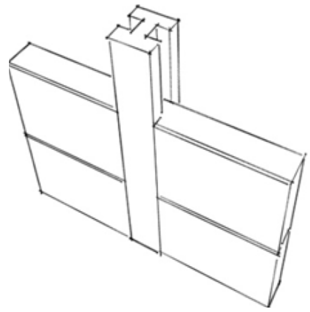


Figure 8. A model of amulet infilling system (Güler, 2013).

Wooden infill facade system. Photographed by Ömer Faruk Bayram

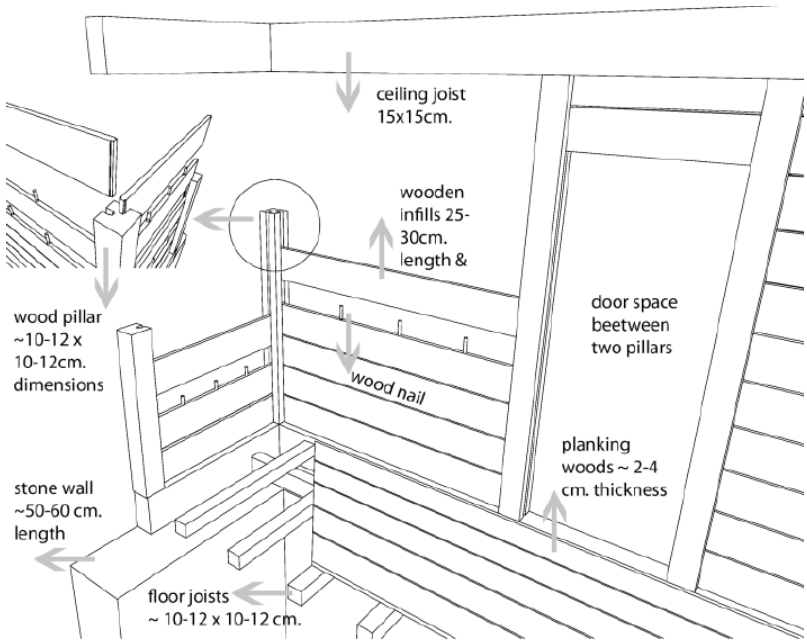






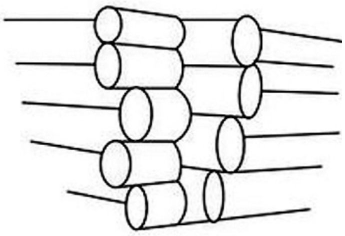
The wood infill structural system diagram. Retrieved from Elif Berna Var.

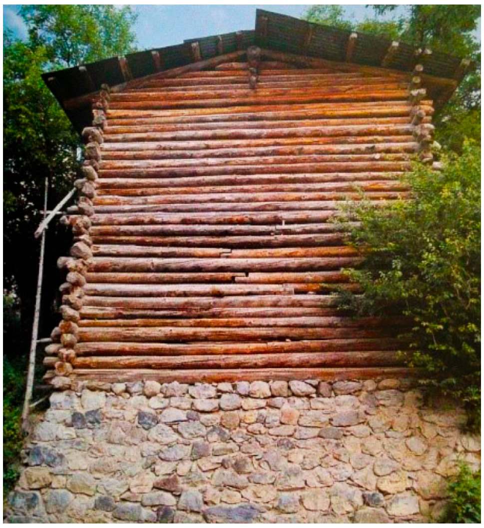
Diagram courtesy of Selda Al Şensoy, Sibel Kukoglu.




Perspective drawing of the construction of wood infill system (Güler, 2013).

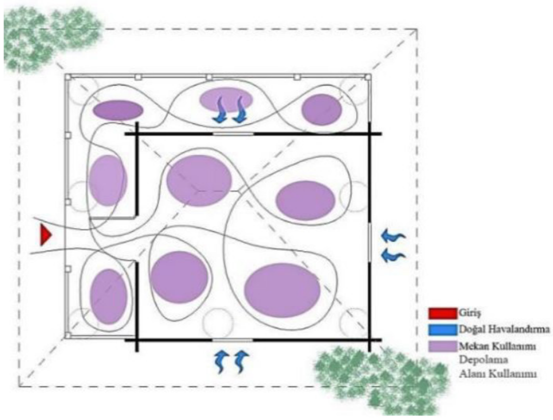
Timber masonry system, Meyveli Village Mosque in Fındıklı, Rize (Güler, 2012).

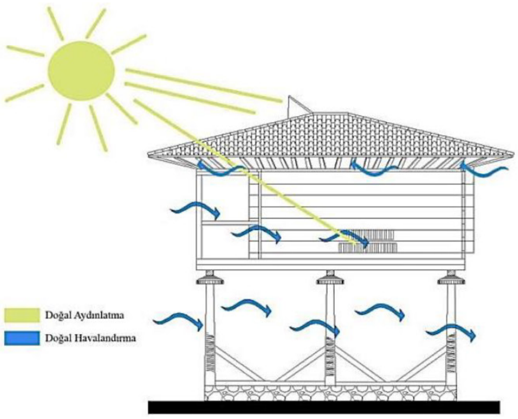




house at Cevizli Village/Artvin at present (Gür and Batur 2005

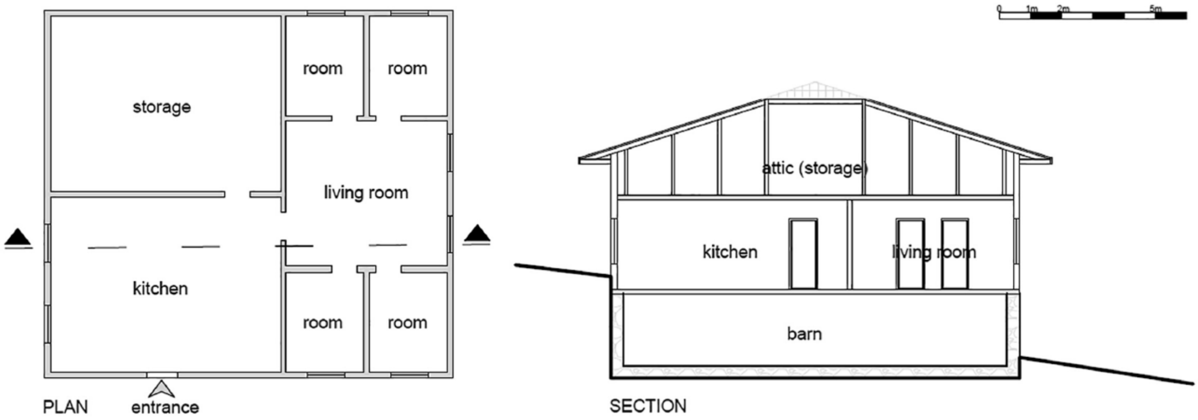
A close up view of the corner. Photographed by Ömer Faruk Bayram




Climate Responsiveness of a Serender. Diagram courtesy of Selda Al Şensoy, Sibel Kukoglu

A traditonal house and its relationship to the Serender, Sürmene-Aksu District/Trabzon




Plan and section drawing of building in the Eastern Black Sea Region. Drawing courtesy of Salih Ceylan.

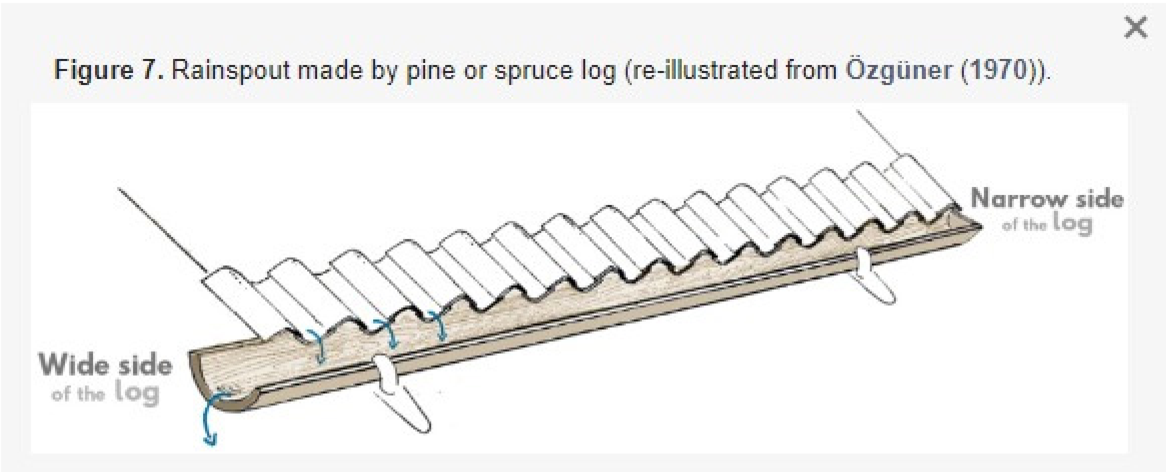
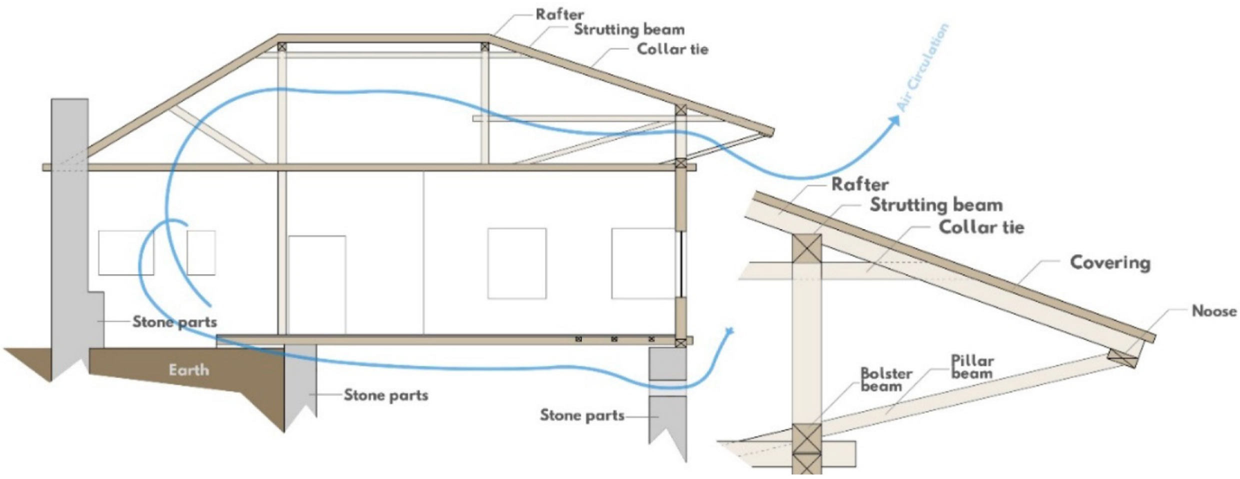



**Figure 7.** Rainspout made by pine or spruce log (re-illustrated from Özgüner (1970)).




Air circulation and natural ventilation detail. Diagram courtesy of Burcu Salgın , Ömer F. Bayram, Atacan Akgün and Kofi Agyekum.

## APPENDIX III - A STUDY ON SAN CRISTOBAL

### 1.2 Exposing Landslide Vulnerability in San Cristobal's Informal Settlements: A Critical Concern in Triangulo Alto

San Cristobal, Bogotá's fourth locality among twenty, lies in the southeastern mountainous terrain. Dating back to pre-Columbian times, it thrived as an agricultural hub with diverse industrial and artisanal pursuits, notably glass and brick factories. In the 1930s, Barrio 20 de Julio emerged as an urban center for displaced populations fleeing rural violence, fostering community around a central sports field. By the 1950s, an influx of displaced individuals shaped new neighborhoods. The demographic is predominantly young adults, with a density of 248.2 residents per hectare in 2012, exceeding Bogotá's average. Spanning 4909.8 hectares, San Cristobal encompasses 1648.28 hectares urban, 3261.5 hectares rural, and 206.1 hectares of protected land.

### 1.3 Geological and Climate Characteristics

Colombia's diverse landscapes encompass flat coastal plains, three mountain chains in the Andean region, and forests. These mountains cover roughly one-third of the country's mainland, housing about 60% of its 52.3 million inhabitants[1]. The Eastern Cordillera, with peaks reaching up to 5,410 meters ASL, runs through Bogotá and neighboring areas, a focal point of this study

San Cristobal, nestled in Bogotá's eastern Andean slopes at about 3,650 meters ASL, features predominantly soft, clay-rich terrain and sedimentary rock formations from the Cretaceous and Tertiary periods. This area forms a fold and thrust belt due to westward compression along the Bogotá Fault. Recognized as a vital ecological structure by the Ministry of Agriculture and Rural Development, San Cristobal is Bogotá's primary green space and contributes significantly to air production.

Colluvial and alluvial deposits from hillside streams accumulate on slopes, with lower, more populated areas characterized by recent Quaternary fillings. Soil conditions vary, ranging from highly eroded soils to severe erosion pockets, abandoned quarries, and significant urbanization pressure. Additionally, anthropogenic actions such as pollution, invasion by introduced species, water circuit invasion, mass removal, and erosion processes further impact the area.

In San Cristóbal, yearly rainfall averages 1,437 mm, mainly from April to November, making up 84.8% of the total annual precipitation, with June to August being the rainiest months. A humid Neotropical biome climate characterizes San Cristobal, averaging a temperature of 12°C, with higher elevations averaging 10.5°C and lower areas 13.5°C[2]. December to March usually see higher temperatures with variability, often featuring dry, sunny days, and chilly nights with occasional frost.

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[1] International Union for the Concentration of Nature, Information Brief 6. 2022

[2] Reporte de Diagnóstico Ambiental Local, Alcaldía de San Cristóbal, Bogotá, 2019.

### 1.4 Self-Built Housing: Materials and Construction Techniques

A study at the Nueva Esperanza Settlement in Colombia found that almost all homes (98%) used esterilla (split bamboo mat). Plastic sheeting (70.6%) and metal sheathing (58.9%) were also common, alongside wood, fabric, and raw earth. Roofs were mostly made of asbestos cement (56%) and clay tiles (16%), with some zinc sheeting, cartons, and concrete for future expansions.

Half the homes had wooden doors, often second-hand, while metal doors (49%) were seen as status symbols. Nearly half the homes featured glass windows, some with metal bars for security. Though only 11% of the homes were entirely self-built, 75% of residents helped with construction, often using household labor.

Initially considered temporary, these homes gradually incorporated more durable materials like brick as finances improved. Modern training has decreased bamboo construction skills, leading to mixed labor for foundations, often not built to high standards. Skilled workers were employed for bricklaying, plastering, and roofing, especially in more established areas. Over time, increased financial stability led to more skilled labor being used. Construction practices and materials have stayed largely the same from 1992 to 2024.

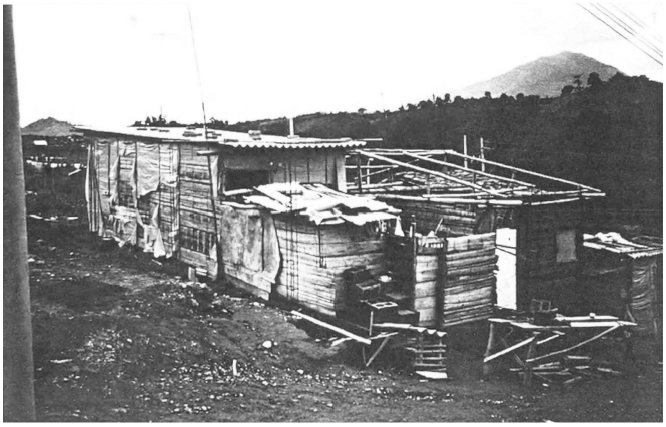

Figure 3.8- Foundations were laid around the outside of a bamboo house in 1992. Image by Katherine Gough
Figure 3.9 - Barrio Egipto in Bogota 2023- Image courtesy of Karin from the Breaking Borders Tour

Figure 3.10 - Comuna Ramirez Bogota. Image by Ramírez favela tour.

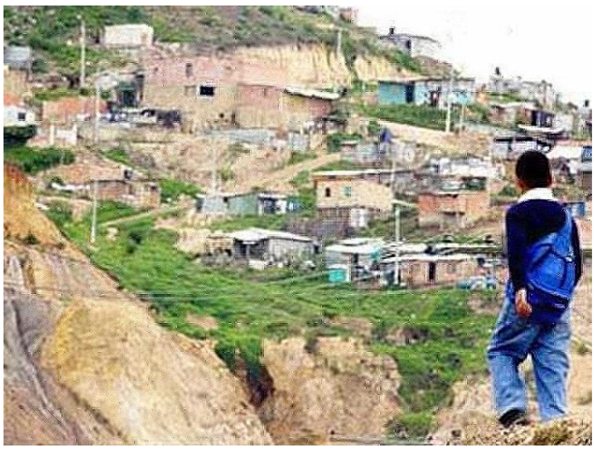

Figure 3.11- Soacha neighborhood. Image by Caracol Radio. 2010