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The transformations of Andean vernacular housing in the arid north of Chile

Natalia JORQUERA SILVA[1,a*] and Tomás SEPÚLVEDA SCHWEMBER[2,b]

[1]Department of Architecture, Universidad de La Serena, Amunátegui s/n, La Serena, Chile

[2] Universidad Bernardo O´Higgins, Centro de Estudios Históricos y Humanidades/ Director Ñaupa Estudios, *Avenida Viel 1497, Santiago*, Chile

[a]natalia.jorquera@userena.cl, [b]naupa.estudios@gmail.com

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Abstract. This article presents the transformations undergone in recent decades by the vernacular Andean housing of the Atacama Desert in northern Chile. This architectural typology is a product of the Andean worldview, where architecture and materials (stone or adobe walls and vegetation-based roofs) respond both to the adverse desert climate of this part of the Andes Mountain and the intense Chilean seismic activity. The characteristics of this housing, which had been preserved for around five centuries, have rapidly transformed in just a few decades due to global economic, political, and social processes that rebound in local transformations in the desert, especially based on intense mining activity and mobility of the labor force. These changes have encouraged the use of industrialized materials from urban areas, which have gradually replaced the natural materials traditionally used in vernacular housing. This shift has altered not only the appearance and harmonious relationship with the surrounding landscape and impacted community-building practices but also the thermal-acoustic performance and structural capacity to withstand the frequent earthquakes that affect the area. Based on years of architectural and ethnographic research on fieldwork, a comparative analysis will be presented between the characteristics of vernacular Andean housing and new houses built with industrial materials, with an emphasis on seismic and climatic performance, as both are major conditions in the Atacama territory.

Introduction

The Andean area is a vast geographic region that extends along the Andes Mountains, the longest mountain system in the world, located in the western part of South America. It covers territories of several countries: Venezuela, Colombia, Ecuador, Peru, Bolivia, Chile, and Argentina, and is characterized by having great ecological diversity, due to its mountainous configuration, which generates different altitudinal levels or ecological zones (Fig. 1).

In this region, different communities that have shared the geographic space dominated by the presence of the Andes Mountains have developed, since pre-Hispanic times, a complex system of knowledge and symbolic construction of the cosmos, territory, and life [1], allowing them to adapt to the challenging environmental conditions of the Andes. Some societies reached high degrees of complexity (such as Tiwanaku and the Incas), evident in the extensive agricultural terraces on the mountains, irrigation canals, transportation systems, and some monumental constructions. Today, numerous Indigenous communities exist as heirs of these cultures, primarily Quechua, Aymara, Atacameños in the north of the Atacama Desert. All of them are the inhabitants of the study area presented.

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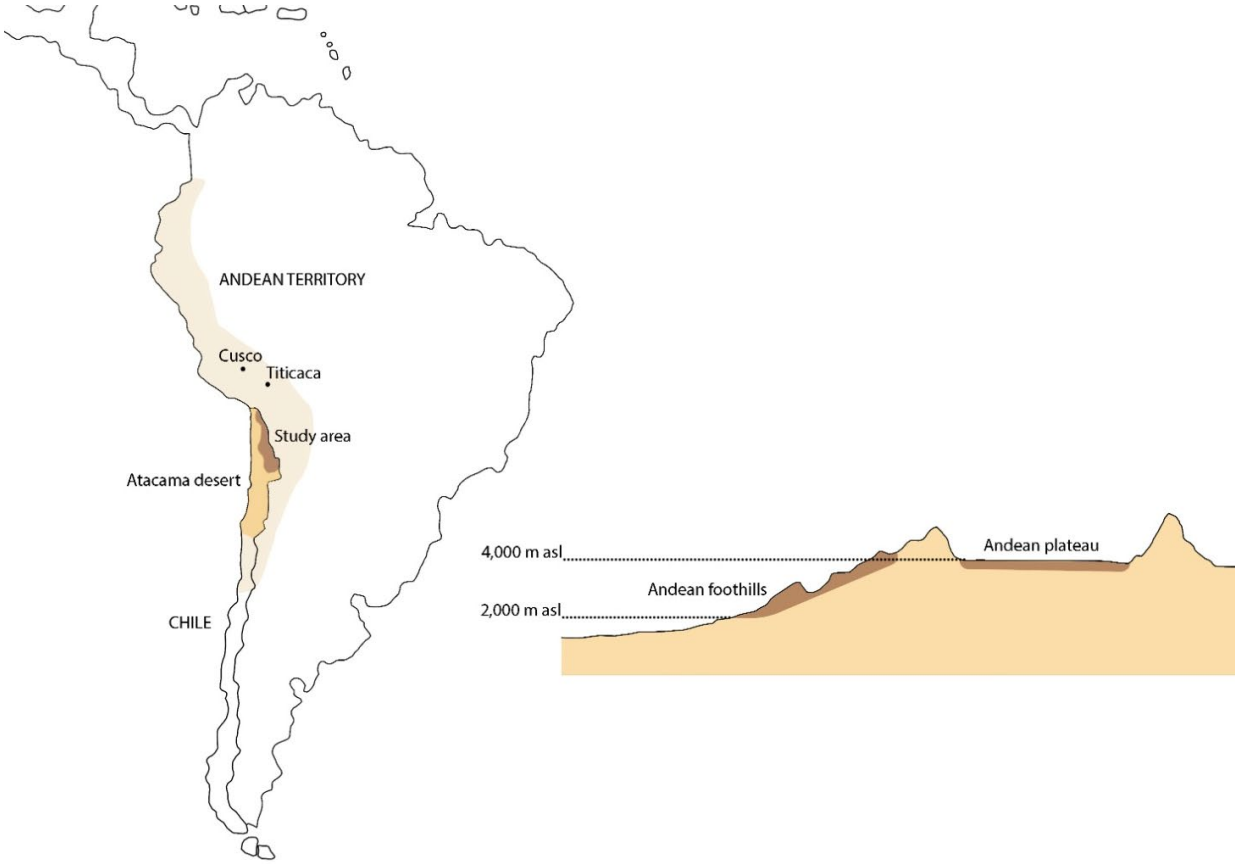

Figure 1. Map and section of the Andean territory and the study area.

In this geographic and cultural context lies the Atacama Desert in northern Chile, considered the driest desert in the world, with human settlements located at altitudes between 2,000 and 4,500 meters above sea level, thus occupying two geographic bands: the foothills, characterized by watercourses that give rise to cultivated oases, and the high plateau (Fig. 2). The study of the vernacular Andean housing located in this area provides a rich opportunity to explore how communities have developed adaptive and resilient architectural solutions in response to this geographic and material environment.

Adopting Marvin Harris's cultural materialism [2, 3] as a key theoretical framework for analyzing the spatiality, infrastructure, and materials used in these dwellings, it reveals how ecological, economic, and social conditions shape construction practices and settlements.

Cultural materialism focuses on how material needs and the availability of resources determine the cultural and social forms of a community. By applying this approach to Andean housing, it can be understood that the choice of materials such as earth and stone, as well as construction techniques, are strategic responses to the extreme conditions of the desert and the highlands, where water scarcity, the intense seismic activity that characterizes Chile and drastic temperature changes demand efficient and durable structures. Furthermore, the knowledge, beliefs and rituals that accompany the construction and organization of settlements can be interpreted as reflections of this relationship between communities and their material environment.

Figure 2. Comparison between the Andean foothill and plateau.

This material basis and the relationship with the environment also explain the animistic ontology that characterizes traditional Andean societies and religions, where mountains, springs, the earth, and the ancestors who inhabited the desert symbolically engage with local communities. This interaction occurs through collective and individual ritual practices that foster harmony between humans, environmental elements or phenomena, and the archaeological remains of their ancestors.

Following cultural materialism, John Murra's theory of “Vertical Archipelagos” [4] explains how Andean societies have organized their settlements across different ecological floors for accessing complementary resources since ancient times. The notion of an archipelago is used here to describe a settlement system that integrates various ecological floors and locations that concentrate subsistence resources, characterized as "islands," separated by vast stretches of desert and complex circuits of trans desert mobility in the case of Atacama. This concept is fundamental for analyzing the location and distribution of vernacular housing in the Atacama landscape, where settlements are determined not only by proximity to immediate resources but also by their integration into a broader network of circulation, exchange, and reciprocity among different ecosystems. The human traces of this way of inhabiting the desert have been recorded in thousands of archaeological sites and multiple heritage, architectural, ethnographic, and ethnohistorical records.

Vernacular houses in this context are part of a settlement system characterized by the use of a wide variety of places, through small towns and pastoral ranches, shelters, rocky eaves, caravan camps, and ancient human and animal trafficking routes, considering all ecological floors of territory and its distinctive qualities.

In the case of the vernacular housing of Atacama, the theory of Vertical Archipelagos helps to understand how Andean communities planned their settlements based on the availability of resources, facilitating access to building materials, water, and land suitable for grazing or agriculture, according to the altitude and climate of the desert. This, in turn, determines how settlements are organized and interconnected.

In this relationship of interdependence between dwelling and environment, the traditional life of local communities and how they organize and construct their settlements and homes have been progressively affected and frequently abandoned in recent decades due to transformations inherent to modernization processes, urbanization, migratory phenomena, and water scarcity, especially related with the exponential growth of large-scale mining in the Atacama Desert.

These changes have led to an increasing incorporation of industrialized materials from the cities, primarily concrete blocks and zinc sheet roofs, which have progressively replaced the natural materials used in traditional housing. This transition has significantly altered local architecture, weakening the harmonious relationship these structures maintained with the landscape and affecting both living conditions and traditional community-building practices. Additionally, the thermal-acoustic performance of the homes and their structural capacity to respond to the frequent earthquakes that impact Chile have also been affected.

Characteristics of Andean vernacular housing

As a result of the cultural contact produced in the Southern Andes between the traditions introduced by the Spanish invaders (circa 1500)—which, in turn, brings together Mediterranean legacies from Europe, Africa, and Asia—and the indigenous construction traditions of the Americas, the Andean housing emerged. This type of housing is present, with local particularities, in numerous towns across the macroregion that encompasses southern Peru, western Bolivia, northwestern Argentina, and northern Chile—including the Atacama Desert and Andean plateau—up to the present day.

From the perspective of cultural materialism [2], these houses are not mere functional responses to environmental conditions but rather complex expressions of sophisticated cultural adaptation that articulate the relationship between society, territory, and economy. Furthermore, housing is part of a larger domestic space, consisting of the house, and, according to Villagrán [5], includes three other local economic-social units: the garden plot (*'chacra'*), or family cultivation space, relative to each house; the field (*'campo')*, or collective space dedicated to gathering and grazing, and the hill. Each one of these units, has as well, animist religious connotations as the place where reside together non-human spirits of mountains, water outcrops, earth, and the souls of the ancestors.

Figure 3. The four units of housing space.

Architecturally, Andean housing possesses common characteristics and repetitive typological patterns throughout the mentioned macroregion: it is a hermetic rectangular parallelepiped with a slightly pyramidal shape, featuring a sharply sloped gabled roof, a central entrance door, and sometimes one or two small window openings—all characteristics that reveal its function as a refuge against the harsh climate of the Andes [6]. The dimensions are rather small, with average measurements of 3 meters wide by 6 meters long in plan; the height generally reaches 3 meters at the ridge [7]. These small dimensions reflect the fact that enclosed living space is limited to sleeping and cooking, while social, sacred, and productive activities occur outside, in the surrounding territory, where there is a deep connection with the elements of nature [8]. Simultaneously, the small dimensions of housing are due to the scarcity of long wood suitable for constructing roofing structures.

The basic housing module described can be duplicated or tripled as the family grows. Additionally, it is common for the housing to be surrounded by small structures, such as chicken coops, other domestic animal enclosures, and an oven, forming a small complex.

Building in the Andean territory is a sacred act, where 'Mother Earth', or *Pachamama*, provides all the necessary materials. Thus, in an environment that might appear hostile and resource-scarce,

Andean communities have effectively managed water, found stone quarries, and clay soils to erect walls, as well as gathered local woods and grasses to create roofing structures, demonstrating a deep knowledge of an extensive territory. Consequently, Andean housing is built with adobe or stone with clay mortar, featuring roofing structures made from the scarce local woods (cactus, Chañar *Geoffroea decorticans* and Algarrobo *Neltuma chilensis*), bound with llama leather or wire, and topped with a layer of vegetable fiber, a stratum of clay for insulation, and a finish of wild straw (Fig. 4).

Figure 4. Exterior, interior and roof details of an Andean vernacular house in the town of Huatacondo.

All variations and local construction particularities adhere to what the local natural environment offers, according to the different ecological floors and its own characteristics in different areas. For example, looking for describe botanically salt flat basin of *Salar de Atacama*, based on local communities' categories of environment, Villagrán et al. [5] subdivide the geographic grounds of foothills and the Andean plateau in four ecological floors, associated to altitude, vegetation characteristics and shared cultural significances of landscape. The authors call these floors: *Pampa, Tolar, Pajonal y Panizo* (Table 1):

Table 1. Prepared by the authors based on Villagrán et al. [5].

Floor local name	Other denominations	Description
Pampa	***Piso Desértico o Prepuneño***	Term used to refer to desert plains or those with very sparse vegetation, characterized by shrubs with very little coverage.
Tolar	***Piso Puneño***	Semi-desert environment, characterized by the predominance of shrubs designated by the generic name of *tolas*.
Pajonal	***Piso Altoandino***	Environment with a steppe physiognomy and dominated by grasses in clumps and plants in cushions, located immediately above the *tolar* and characterized as a colder area with a predominance of *ichu* (straws).
Panizo	***Piso Subnival***	Environment located on the summits of hills and defined by the absence of vegetation.

Therefore, as in all vernacular architecture, Andean housing is materialized using the natural resources of the immediate environment as construction materials [9, 10], blending harmoniously with the surrounding landscape.

Transformations of Andean vernacular housing

The socio-economic changes that have occurred in recent decades, particularly the intense mining activity in the Atacama Desert—mainly associated with copper and lithium—and its subsequent

water usage, have led to ecological, social, and economic impacts in the region, affecting ancestral construction practices. This has resulted in a transformation of settlements and traditional housing. Additionally, the pressure from international tourism, centered in San Pedro de Atacama (the communal capital), has led to modifications of many vernacular homes, converting them into hotels and restaurants.

Other very specific phenomena have directly affected vernacular construction techniques: since 1978, the use of artisanal explosives, which were used to extract stones from quarries in the hills, has been prohibited. A similar situation happens with the Cardón cactus used for beams and other carpentry, whose felling has been prohibited by the National Forestry Corporation since 2009. Finally, a significant factor hindering the preservation of traditional techniques is the generational continuity of builders. One of the grandmothers from the town of Camar recounts having built her stone house with her deceased husband; however, due to her lack of physical strength for necessary maintenance, she has moved into a new home made of concrete blocks.

Nowadays, most Andean houses keep some traditional elements and are in an intermediate state between the vernacular and the industrialized. One of the most common modifications is the replacement of doors, windows, and roofing, where metal carpentry has replaced traditional cactus-based carpentry and zinc sheets have replaced wild straw. The stone or adobe walls are often preserved, but in many cases, they are coated with cement. Therefore, many Andean houses are in a state of architectural hybridization, where it is still possible to recognize Andean patterns—such as the general dimensions of the houses and their morphology —mixed with contemporary construction elements (Fig. 5).

However, there is another percentage of housing that is entirely new and made from industrialized materials, which does not respect any—or hardly any—Andean construction patterns and is instead conceived as housing inspired by the architecture of large cities. As such, it features a broad repertoire of exogenous architectural elements, such as large windows, balconies with balustrades, and bow windows (Fig. 6). This new housing is often two stories high and is mostly constructed with unreinforced concrete block masonry, resulting in wall thicknesses of 20cm.

Figure 5 and 6. Andean houses in a state of constructive hybridization in the town of Caspana (left) and contemporary houses integrated into the Andean town of Huatacondo (right).

Comparative analysis of seismic vulnerability between traditional and contemporary housing

Seismic vulnerability in unreinforced masonry structures—such as the adobe and stone masonry that make up Andean houses and the concrete blocks used in contemporary homes—is determined by two fundamental factors: the geometry of the building and the connections between the various constructive elements [11].

Regarding geometry, there are several parameters that contribute to better seismic performance in unreinforced masonry, both in terms of global capacity of the buildings and the local in-plane and out-of-plane capacity of walls: symmetry, simple and regular shape, the ratio between the

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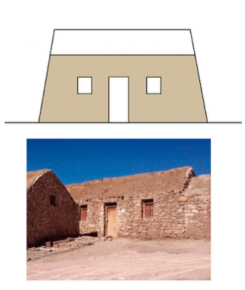
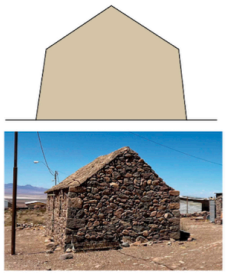
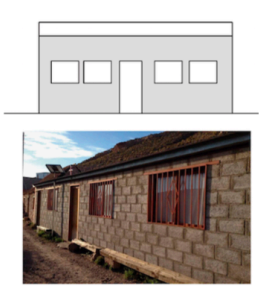
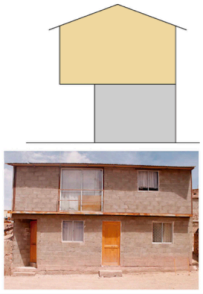
length and width of the building in plan (less than or equal to 2), the ratio between the height and width of the building, the density of the structure, the vertical slenderness of the walls, the free length of the walls, and the location and size of openings relative to the mass of the walls [12, 13, 14, 15].

These characteristics are fully met by Andean housing, which has a symmetrical plan shape with a ratio of 1:2, a high structural density due to thick walls and a small space, a pyramidal shape in height (ensuring a low center of gravity), thick walls (approximately 60 cm in thickness and 2 m in height, giving a slenderness ratio of 3.33), and small and centered openings that do not weaken the simple masonry walls.

Regarding contemporary homes, although if there is a lack of geometric pattern that allows generic analysis, there are certain common aspects that make them more seismically vulnerable, mainly the fact that despite being constructed with modern concrete blocks, they remain unreinforced masonry structures. Contemporary houses do not feature pyramidal morphology, they exhibit significantly higher wall slenderness, and they have wide window openings to the wall mass. In many cases, there is a second level that is larger than the first one (Table 2).

Table 2. Comparison of seismic performance between the Andean vernacular housing and the industrialized housing.

COMPARISON OF SEISMIC PERFORMANCE	
Andean vernacular housing	**Industrialized housing**
 	 
One-store house	One, two, or three-story houses
Symmetrical plan	Symmetrical plan
High density of the structure	Low density of the structure
Pyramidal shape that ensures a low center of gravity	Parallelepiped volumes, where sometimes the upper floor is larger than the lower one
Walls with low slenderness	Walls with medium-high slenderness
Small and well-placed openings	Large openings that are not always well-placed

Comparative analysis of thermal comfort between traditional and contemporary Housing

The thermal performance of a building is one of the most important variables for assessing environmental sustainability, as it directly influences energy consumption and the ability to create comfortable interior spaces with a low impact. This performance fundamentally depends on two factors: Thermal Transmittance and Surface Mass [16].

The Thermal Transmittance value U (W/m^2K) is an expression of the thermal behavior of the wall: the lower it is, the better is the thermal insulation of the building envelope elements. The Surface Mass of the envelope elements is directly related to the density of the materials (kg/m^3) and affects the damping and delay of heat waves; therefore, the surface mass value should be sufficiently high, ideally above 200 kg/m^2 [17]. Considering that traditional Andean housing is built with adobe or stone walls, while contemporary housing typically uses industrialized hollowed concrete blocks (which are low in density), the following is a comparative table with values for Thermal Transmittance and Surface Mass for the three materials:

Table 3. Comparison between Transmittance and Surface Mass

Material	Thermal Transmittance U (W/m^2K)	Surface Mass (kg/m^2)
Adobe	0.5 - 0.7 W/m^2K	425 kg/m^2
Stone	1.0 - 1.5 W/m^2K	810 kg/m^2
Concrete blocks	2.0 - 3.0 W/m^2K	96 kg/m^2

The previous values indicate that adobe is the best in terms of thermal insulation, having the ability to retain heat and maintain stable interior temperatures due to its low transmittance; this is followed by stone, and lastly by the hollowed concrete block, which, with a higher thermal transmittance, loses more heat compared to adobe and stone, resulting in lower thermal performance.

Regarding the evaluation of Surface Mass, which indicates the ability to efficiently store and release heat, the stone is the most efficient, possessing a high surface mass. This is followed by adobe, which also performs well, while the hollowed concrete block has the lowest surface mass and, therefore, a limited capacity for heat storage, which can lead to more pronounced fluctuations in interior temperature.

In addition to the values mentioned, there are also differences in architectural design that make traditional housing more suitable for the local climate. Specifically, the design of the sloped roof ensures effective drainage of rainwater and snow in winter, while the small openings guarantee temperature control. These characteristics are often not respected in many contemporary homes, where roofs are frequently flat or nearly flat, and window openings are large.

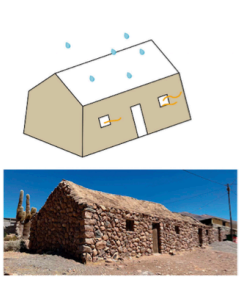
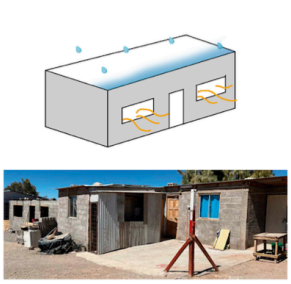
Conclusions

As in all vernacular architecture, there is a deep interrelationship between the environment and the ways of living and building; if one of the factors changes, the entire system is altered. This is the case of Andean housing, where it is evident how socio-economic, productive, and environmental changes have rapidly transformed the characteristics of vernacular housing and its harmonious integration with the surroundings.

In just a few decades, local and collective construction methods, based on the natural materials of the environment, have been replaced by industrialized materials with standardized and global characteristics, which, among other things, undermine traditional construction practices. Nevertheless, many homes retain certain traditional elements, resulting in a state of architectural "hybridity" rather than a total replacement of Andean architecture.

The comparative analysis between vernacular housing and industrialized housing reveals that the former, due to its geometry, has a better seismic performance. Instead, new concrete block housing, although it has allowed many architectural liberties, is considered a seismically vulnerable example, as the technique corresponds to unreinforced masonry, putting local inhabitants at risk.

Table 4. Comparison of thermal performance between the Andean vernacular housing and the industrialized housing.

COMPARISON OF THERMAL PERFORMANCE	
Andean vernacular housing	**Industrialized housing**
	
Steep roof pitch to evacuate rain and snow	Flat or nearly flat roof that does not ensure proper drainage of rain and snow
Few openings to ensure thermal control	Big openings that don't ensure thermal control
Thick walls that ensure thermal inertia	Thin walls that do not ensure thermal inertia or insulation
Adobe and stone have low thermal transmitance, which ensures good thermal insulation	Concrete block with high thermal transmitance is unable to provide insulation
Adobe and stone have a high surface mass, which ensures their capacity to efficiently store and release heat	Concrete block with low surface mass has a limited capacity for heat storage

Regarding thermal performance, it is evident that industrialized housing does not provide the same thermal benefits needed to respond to the climate of the foothills and the Andean plateau of the Atacama Desert. In summary, contemporary housing is considered less suitable and resilient compared to the vernacular constructions that existed to face the geographical challenges of the region.

It should be noted, however, that certain patterns present in contemporary homes, such as large window openings or smooth surfaces covered with ceramics, reveal that traditional Andean housing does not entirely meet the current requirements of Andean communities. Good lighting, which allows residents to spend more time indoors, as well as the ease of cleaning the spaces, are legitimate needs for inhabitants who now spend an important part of their time in urban centers and mines, who face every day the demands of work and modern life, that have internet access, and therefore choice other ways to build and create architecture. Combining the favorable aspects of traditional Andean housing in terms of seismic performance, thermal comfort, and harmony with the landscape with the current needs of Andean communities can ensure relevant architecture and development with identity.

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