Learning from seismic culture in the vernacular architecture of Tulahuén, Chile

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Keywords: Adobe Vernacular Architecture, Seismic Threat, Building Cultures, Vernacular Seismic Culture

Abstract. Chile is one of the most seismically active countries in the world, due to the subduction of the Nazca Plate beneath the South American Plate, which causes earthquakes with magnitudes above 7.0 approximately every ten years. This high seismicity has always shaped the characteristics of vernacular architecture and traditional construction techniques, particularly adobe buildings, through a process of trial and error. Seismically vulnerable structures have disappeared, while those that have survived owe their resilience to the development of a seismic culture among the inhabitants and the creation of technical solutions that allow buildings to respond better to seismic events. This is the case of Tulahuén, a village located in the mountains of the Coquimbo region in northern Chile, where vernacular architecture, characterized by the use of adobe, incorporates various types of wooden reinforcements, built by the residents themselves, which have enabled these structures to withstand the intense local seismic activity. This article is the result of two research studies, in which, through direct observation and the collection of oral memories from local inhabitants, the seismic-resistant devices present in Tulahuén were characterized and their role in the resilience of this vernacular architecture was evaluated.

Introduction

In highly seismic regions, where experiencing the consequences of an earthquake is part of the collective memory, societies have developed a seismic culture. This culture consists of knowledge about how to behave during an earthquake and how to prevent damage to buildings. While seismic countries developed building codes during the 20th century to ensure earthquake-resistant designs for new buildings constructed with industrialized materials in urban areas, traditional villages composed of vernacular buildings also have a set of tacit norms. Although these norms are not formally written, they can be observed in the urban morphology (the way buildings are grouped), in the architectural design, and in the construction features of the structures [1].

Some examples of constructive devices adopted in vernacular architecture in areas where earthquakes are a recurrent and well-known phenomenon for the local population [2] include: "counter-arches" (Fig.1-a) placed between two buildings to restrict their lateral displacement; buttresses (Fig.1-b) to reduce the free span of overly long walls; ties (Fig.1-c) that improve the connection between transverse walls; and horizontal wooden “chains” or “keys” (Fig.1-d) that “tie” the walls of a building and reduce the spread of seismic shear cracks. All of these construction solutions enhance the performance of buildings against the lateral forces induced by earthquakes

[3, 4]. Since these strategies represent a "tacit norm," they are widely present throughout the region, identifying them as a “typological” solution.

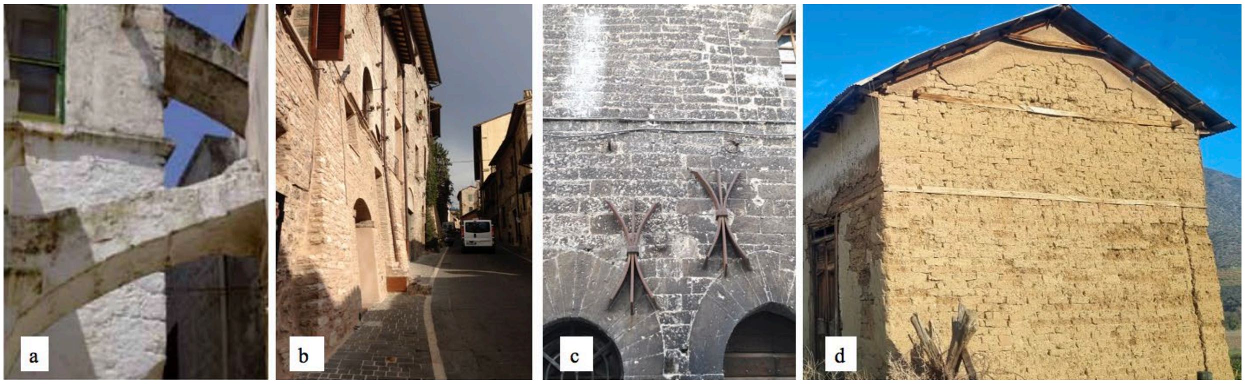

Figure 1. Different types of earthquake-resistant devices (credits: Natalia Jorquera, 2024)

Chile has a deep-rooted seismic culture, derived from one of the highest levels of seismic activity on the planet, caused by the subduction of the Nazca Plate beneath the South American Plate. This process accumulates energy that is released in the form of large and long-lasting earthquakes [5]. The country holds the unfortunate record for registering the highest magnitude earthquakes in history (such as the 1960 Valdivia earthquake, with a magnitude of 9.5, and the 2010 Cauquenes earthquake, with a magnitude of 8.8, among others) as well as the highest frequency of seismic events, with earthquakes exceeding 7.0 in magnitude occurring on average every 10 years [3], according to data from the National Seismological Center.

In this context, various seismic response strategies have been adopted over the years by the different vernacular architectures that have existed in the country. These strategies were developed using the natural resources available, in a territory characterized by great geographic, climatic, and cultural diversity over 4,300 kilometers.

In the arid regions of northern Chile, dominated by the Atacama Desert, structural systems based on adobe or stone masonry walls have been developed. These systems, having very low tensile resistance to seismic forces, based their earthquake response only on their geometric configuration.

In the central regions of the country, where a temperate climate and moderate rainfall have allowed vegetation growth, ductile wooden elements (horizontal "keys") are incorporated into the vernacular adobe masonry buildings, improving their behavior against the tensile forces caused by earthquakes.

Finally, in the rainy southern regions, where vegetation and wood are abundant, vernacular architecture is based on the use of flexible wooden frameworks with lightweight infill, which perform very well under seismic forces due to their ductile behavior.

The architecture and seismic culture of Tulahuén

The Coquimbo Region belongs to Chile's semi-arid north and is considered a transition zone between the Atacama Desert and Chile's fertile central valley. It is characterized by being the narrowest part of Chile, with an average width of 150 km from the Andes Mountains in the east to the Pacific Ocean in the west, and an altitude range from sea level to 6,216 meters above sea level.

The region's semi-arid nature meant that, until the mid-19th century, vegetation was almost exclusively shrubby, limiting building materials to earth, which was used in various techniques, the main ones being adobe masonry and *quincha* (a vegetative structure filled with local earth).

Like the rest of Chile, the Coquimbo region experiences high seismic activity. The most destructive historical earthquakes include the 1943 Ovalle earthquake, with a magnitude of 8.2;

Materials Research Proceedings 47 (2025) 216-223 https://doi.org/10.21741/9781644903391-25

the 1975 Coquimbo earthquake, with a magnitude of 6.9; the 1997 Punitaqui earthquake, with a magnitude of 7.1; and the 2015 Illapel earthquake, with a magnitude of 8.3 Mw [6, 7].

In this region, at 1,200 meters above sea level, Tulahuén is located (Fig. 2). The vernacular architecture there, as in the entire region, is a mixture of the construction traditions of the indigenous peoples who inhabited the territory—especially the Diaguita culture—and the architecture brought by the Spanish invaders who arrived in the Americas and Chile in the mid-16th century. From the former, the use of earth as the preferred building material was inherited, while from the Spanish, the legacy consists of architecture with rooms organized around interior courtyards and houses grouped to form villages with continuous facades (Fig. 3).

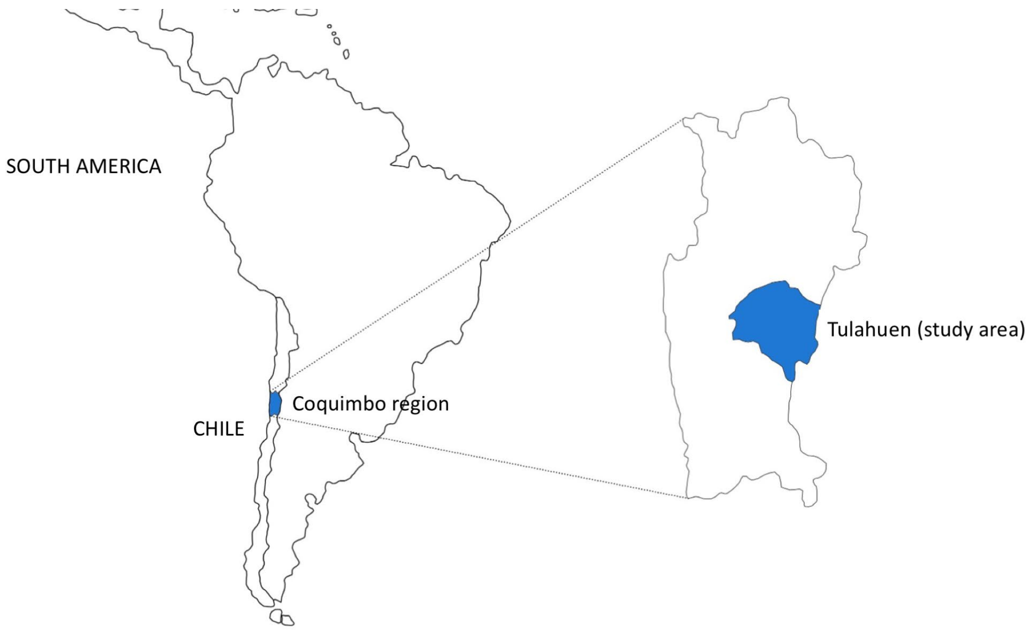

Figure 2. Location of the case study (credits: authors)

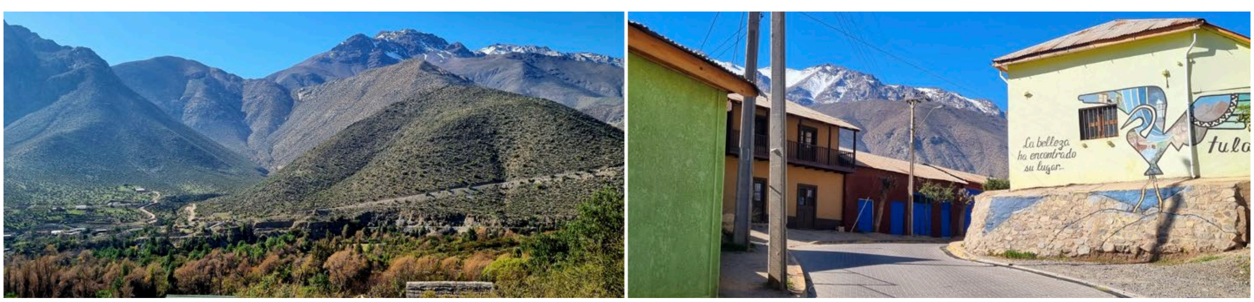

Figure 3. General view of the context and the town of Tulahuén (credits: authors).

Tulahuén, along with other villages in the Limarí Valley, was part of large agricultural estates during the Spanish colonial period (16th-19th centuries). Following the first organization of independence from Spain in 1810, the region underwent a transition from agrarian administration to the formation of the current localities of Carén, Monte Patria, Mialqui, Huamalata, Chañaral, Los Molles, Juntas, and Tulahuén. However, there has been a historical continuity to the present day in agricultural vocation, as the region produces wine, fruits, vegetables, and fodder for livestock. This productive activity gave rise to the so-called agricultural communities that still exist today. These traditional collective organizations, based on principles of cooperation, are formed by farmers who manage and share resources such as land and water. These communities have faced challenges such as drought and increasing pressure from intensive agriculture, but they remain a fundamental element of the traditional agricultural system and the social fabric of the region.

Another fundamental activity in the Coquimbo Region has always been mining, and in Tulahuén specifically, the extraction of lapis lazuli stands out, being the only other place in the world besides Afghanistan where this semi-precious mineral is found.

The vernacular architecture of Tulahuén has been conceived to carry out agricultural activities. Therefore, in addition to the housing (Fig. 4-a), livestock pens, agricultural storage facilities (Fig. 4-b), and "pasteras" (Fig. 4-c)—large enclosures for storing animal fodder—are very common [6]. While this architecture shares characteristics with other traditional adobe constructions in the Coquimbo Region and other parts of Chile, it presents two specific features: it consists of large, tall enclosures for storing tools, food, and fodder related to agricultural activities. For this reason, it features long walls (without transverse bracing) and overly slender walls (with low thickness relative to their height). The second particularity is that, being a mountain village, the roofs have steep slopes for the evacuation of snow and rain, which simultaneously generate thrusts on the walls, subjecting them to stresses that could cause them to overturn (Fig. 5). These two conditions render this adobe architecture particularly vulnerable to the thrusts induced by earthquakes. Consequently, it features a series of wooden reinforcements that counteract these seismic thrusts and improve the connections between all the structural parts of the buildings, preventing damage. These reinforcements, constitute the earthquake-resistant devices that reflect the seismic culture of Tulahuén.

Figure 4. Different architectural typologies are present in the town of Tulahuén (credits: authors).

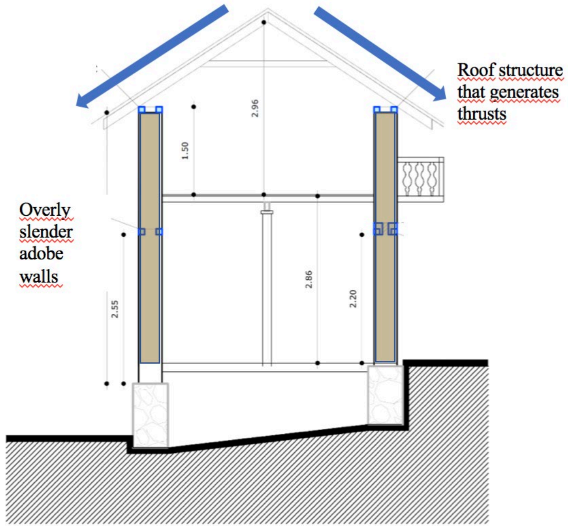

Figure 5. Typological section of a "pastera" (credits: Jaime Ortega y Natalia Jorquera, 2024).

Earthquake-resistant Devices in Tulahuén

In the historic area of Tulahuén, there are around one hundred adobe structures, all of which feature some type of earthquake-resistant device made from wood sourced from Algarrobo (*Neltuma chilensis*), Cordilleran Cypress (*Austrocedrus chilensis*), or White Poplar (*Populus alba*), the latter being a species introduced by the Spanish in this territory.

To characterize the various earthquake-resistant devices, their dimensions, sections (circular, square, or rectangular), geometry, and location within the buildings were recorded. Based on this data, three types of devices were identified [6]:

Device Corner Key.

These are located at the corners of the buildings and primarily aim to ensure the connection between the perpendicular adobe walls, which tend to separate during an earthquake. They consist of two longitudinal wooden pieces and a series of transverse pieces that together form a kind of ladder. They are inserted between the layers of adobe, and at the height of the building, they can appear one or more times (Fig. 6).

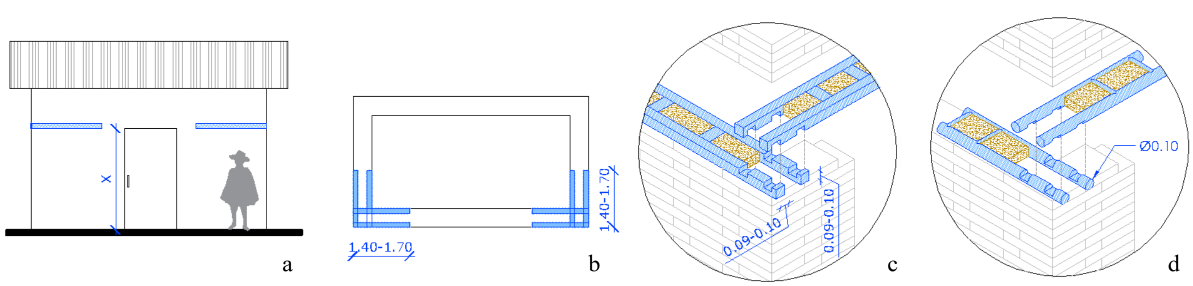

Figure 6. Drawings of the corner device (credits: Jaime Ortega, 2024).

Device Diagonal Corner.

This corresponds to a type of corner reinforcement that, unlike the previous devices, is installed diagonally relative to the adobe walls (Fig. 7) and can be observed from the interior of the buildings. Like the corner device, its purpose is to ensure the connection of the perpendicular adobe walls, preventing their separation and averting any outward tipping.

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https://doi.org/10.21741/9781644903391-25

These diagonal corner devices are generally installed at the height of the lintel of the openings and consist of two essential parts: a wooden piece that crosses the wall diagonally and stakes that secure the brace within it.

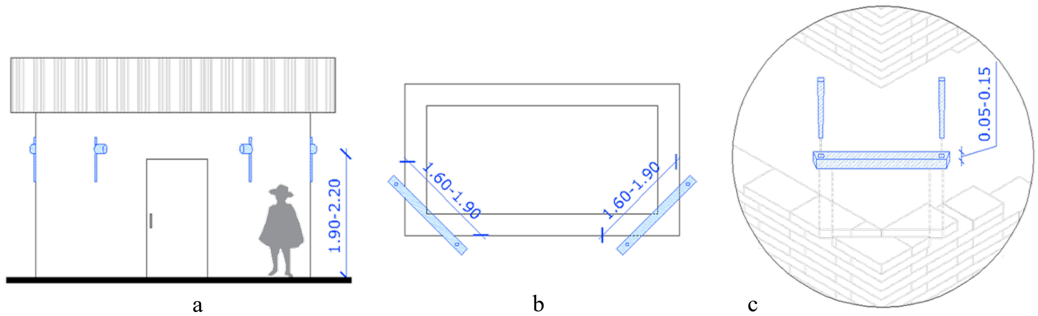

Figure 7. Drawings of the Diagonal Corner device (credits: Jaime Ortega, 2024).

Device Wall Tie.
A third device present in most traditional adobe buildings in Tulahuén is the wall tie (Fig. 8), referred to as "candados" (padlock) by the local inhabitants. The purpose of this device is to enhance the connection between the horizontal structural elements (roof and floor) and the adobe walls. The device consists of two parts: a beam and a stake perpendicular to it, which appears as a vertical element protruding from the facades of many buildings (Fig. 9), serving as a distinctive feature of Tulahuén's vernacular architecture.

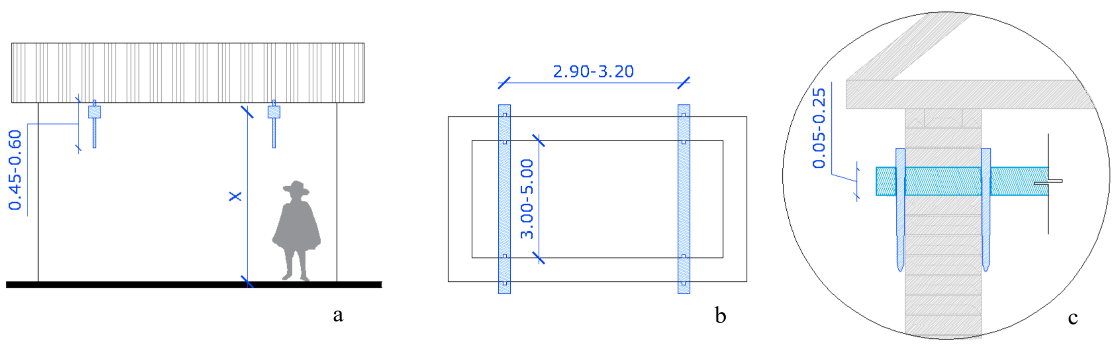

Figure 9. Typical facade with "candados" (credits: authors).

The three types of devices have proven to be very effective, both in improving the connections between the different construction parts and in preventing the tipping of the adobe walls. However, devices made from Poplar wood have encountered issues in recent years; being a softwood, it has become the preferred food for termites, leading to a decrease in its load-bearing section and, consequently, its effectiveness. This local pathology affecting the wood has left buildings in a vulnerable situation, and damages resulting from seismic action have begun to manifest, particularly the separation of the perpendicular adobe walls at their junction, threatening future tipping. This problem has not arisen in devices made from the local woods of Algarrobo and Cypress, which, being more durable, are not subject to attack by wood-destroying insects. This highlights how the use of endemic resources as construction materials is always the best response for a local environment, being one of the essential characteristics of vernacular architecture

Conclusions

Earthquakes, which in the past were faced with knowledge by local communities, have increasingly become more severe disasters due to the loss of traditional seismic cultures. This not only threatens the safety of the population but also the architectural heritage. Recovering this knowledge is essential for any seismic region in the world.

The study and understanding of local seismic cultures constitute an essential tool for generating guidelines that promote appropriate interventions in architectural heritage. These guidelines should rescue and refine the strategies that have allowed for the conservation of historical buildings in areas of high seismic activity, while avoiding incorrect solutions that compromise their durability and authenticity.

The seismic culture of Tulahuén is an outstanding example of how a community has developed a cultural and constructive response to the threat of earthquakes, in a context of extremely vulnerable architecture due to its geometric characteristics. Like other vernacular architectures, the seismic-resistant devices of Tulahuén emerged from a process of trial and error, where the damage caused by earthquakes allowed for the observation of adobe structures behavior and the development of preventive measures.

Despite the effectiveness of wooden reinforcements, constructions using poplar wood present problems due to termite attacks, which weaken the structure. This underscores the importance of using local materials adapted to the environment, ensuring the durability and resilience of vernacular buildings. Local species are more resistant to pests, contributing to the preservation of the structural integrity of seismic-resistant devices.

The researches underpinning this article emphasize the importance of preserving these devices as a fundamental part of local architectural heritage, considering them unique attributes that must be conserved and restored in the event of deterioration. Furthermore, the seismic-resistant devices of Tulahuén can serve as a source of inspiration for other vernacular architectures with similar characteristics.

Finally, one of the most valuable contributions of this research has been to help the inhabitants of Tulahuén recognize the heritage value of these constructive elements. Although residents understood the role of the devices in improving the seismic performance of their buildings, they had not fully realized their importance for heritage conservation or considered them in new constructions.

Acknowledgments

The project that gave rise to this article has been financed by the National Fund for Cultural Development and the Arts-FONDART, a national funding area, Convocatoria 2024, of the Chilean Ministry de las Culturas, Las Artes y el Patrimonio, folio nº 750219.

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