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Artículo científico

Straw and lightened mud ceiling: adaptive response to extreme climate in Andean homes

Cielo raso de paja y barro aligerado: respuesta adaptativa al clima extremo en viviendas andinas

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Abstract:
The clay and lightened straw ceiling is a construction practice that Andean communities have traditionally used in their homes. Depending on its geographical location, it is called by different names such as "caruna, takta, t'atja, tacta, and in the Chipaya language "wara", p'ira, t'llli" and uses the earth and straw of its highland environment in its preparation. It is currently at risk of disappearing as a result of the sociocultural processes experienced in the territory over the last 50 years. This article describes the rescue actions and enhancement of the system through a technological research project with field and laboratory methodology in the region of Arica and Parinacota, northern Chile. The results obtained through this research have allowed the system to be mechanically and physically characterized; the findings have been contrasted with the safeguarding principles to evaluate its potential for recognition in the national Intangible Heritage safeguarding system.

Keywords: earth construction, vernacular architecture, natural fibers, Aymara roof, thermal insulation.

Resumen:
El cielo raso de barro y paja aligerado es una práctica constructiva que las comunidades andinas han empleado tradicionalmente en sus viviendas. Según su ubicación geográfica se denomina con distintos nombres como "caruna, takta, t'ajta, tacta, y en lengua chipaya "wara", p'ira, t'illi" y emplea en su elaboración la tierra y paja de su entorno altiplánico. Actualmente sufre el riesgo de desaparición, producto de los procesos socioculturales vividos en el territorio durante los últimos 50 años. Este artículo describe las acciones de rescate y puesta en valor del sistema, a través de un proyecto de investigación tecnológica con metodología de campo y laboratorio en la región de Arica y Parinacota, al norte de Chile. Los resultados obtenidos a través de esta investigación han permitido caracterizar mecánica y físicamente el sistema, los hallazgos se han contrastado con los principios de salvaguardia para evaluar su potencialidad de reconocimiento en el sistema nacional de salvaguarda de Patrimonio Inmaterial.

Palabras clave: construcción en tierra, arquitectura vernácula, fibras naturales, techumbre aymara, aislación térmica.

1. Introduction

Local building cultures have their origins in vernacular architecture. The word "vernacular" derives from the Latin "vernacŭlus" and refers to something "domestic, native, of one's own home or country." In architecture, it relates to the traditional construction of specific local communities and their relationship with sustainability. This concept has been developed since the 1950s, highlighting the importance of considering factors such as site-climate, materials, and the relationship between architecture and the natural environment. Various authors have contributed to the definition of this type of architecture, taking as their central axis the adaptation of architecture to the climate and the environment. Sibyl Moholy points out that "[...] every foot of land, every stone, brick or piece of wood, every proportion, opening and angle of a wall is coordinated to respond to particular challenges, never entirely duplicated, of place and gravity, of climate and human comfort."(Moholy, 1957, p.33). Rafael Serra, in the Spanish edition of Architecture and Climate, emphasizes that Olgyay "[...] had already delved into the interaction between a building and the natural environment that surrounds it, postulating in his writings how the relationship between 'architecture' and 'place' is and should be, between 'form' and 'climate', or between 'urbanism' and 'regionalism', drastically contradicting the implicit and apparent laws of 'official' architecture in the middle decades of our century. (Olgyay, 1998, p.1)

Rudofsky (1965) enriches the vision of the vernacular by incorporating anthropological aspects into the reflection, "[...] In contrast to the aspirations of vernacular studies from other disciplines such as anthropology, he clarifies the need to incorporate what has been learned from these anonymous architectures into contemporary architecture." (Loren-Méndez, 2018, p. 121); and in 1969, Rapoport subsequently examined the factors that influence vernacular architecture, such as economics, religion, site, materials, and climate, but considered that "[...] The element that has the most significant effect on man-made forms would be climate. (Rapoport, 1969, p. 111)

All these theorists have advocated incorporating elements of vernacular architecture into contemporary architecture, emphasizing the influence of climate on architectural forms. In addition, they have proposed terms related to sustainable architecture that share principles with vernacular architecture, such as the use of local materials and techniques and energy efficiency. More recently, Mileto and Vegas (2014) "[...] present several terms related to sustainable architecture: kilometre zero, low tech, bioclimatic architecture, passive architecture, green architecture, and bioarchitecture (or bioconstruction)" (Torres & Jaramillo, 2019, p. 49).

In Latin America, Cordero Gulá and García Navarro (2015) & Toumi et al. (2017) highlighted that sustainability focuses on the socioeconomic dimension due to inequality and poverty in the region. Finally, Santacana and Mensa (2022) proposed categories for classifying architecture according to its climate management, seeking to redefine the relationship between architecture and climate.

These construction techniques in vernacular architecture reduce the environmental impact of construction. We find examples in studies based on the use of land as a material, which have advantages over industrial construction: "[...] it does not require transportation or exploitation of geological resources through quarries or deposits, which makes construction cheaper. It also has a low ecological and sustainable environmental impact, is 100% recyclable, and therefore has low energy costs. It absorbs pollutants and, as it is considered a healthy material, allows the creation of other materials that are harmless to humans and do not generate environmental impact."(Zabala, 2023, p.20), and "[...] the use of natural materials in the country's contemporary architecture responds, first and foremost, to the social and economic needs of the population, and secondly, to environmental needs." (Torres and Jaramillo, 2019, p. 52).

The protection of intangible heritage is constantly evolving in terms of defining the scope of the concept of cultural heritage. The most recent perspective considers people and their creations, not only the physical or material aspects of heritage but also living expressions. Its management involves ethics and highlights the fundamental processes for continuity, rooted in ancestral knowledge, as pointed out by UNESCO in 2021. Intergenerational transmission is sometimes interrupted, giving rise to new actors and processes that enable lost or endangered traditions to be recovered or revisited. Strategies exist to recover knowledge, including authentic expressions of local cultures, such as traditional craft techniques (MINCAP, 2019).

In the Parinacota Commune, near the tripartite border between Chile, Peru, and Bolivia, lies the village of Tacora (see Figure 1). A roof restoration project revealed the drastic transformation that has taken place over the last 25 years in the material used to construct high Andean dwellings to protect them from the weather. A review of the Population and Housing Censuses of the Arica and Parinacota Region (INE, 1992; 2002; 2017) showed that the composition of the roofing materials of vernacular Aymara dwellings has changed substantially. These transformations may have altered the efficiency and effectiveness of the roofs in the extreme climate where they are located.

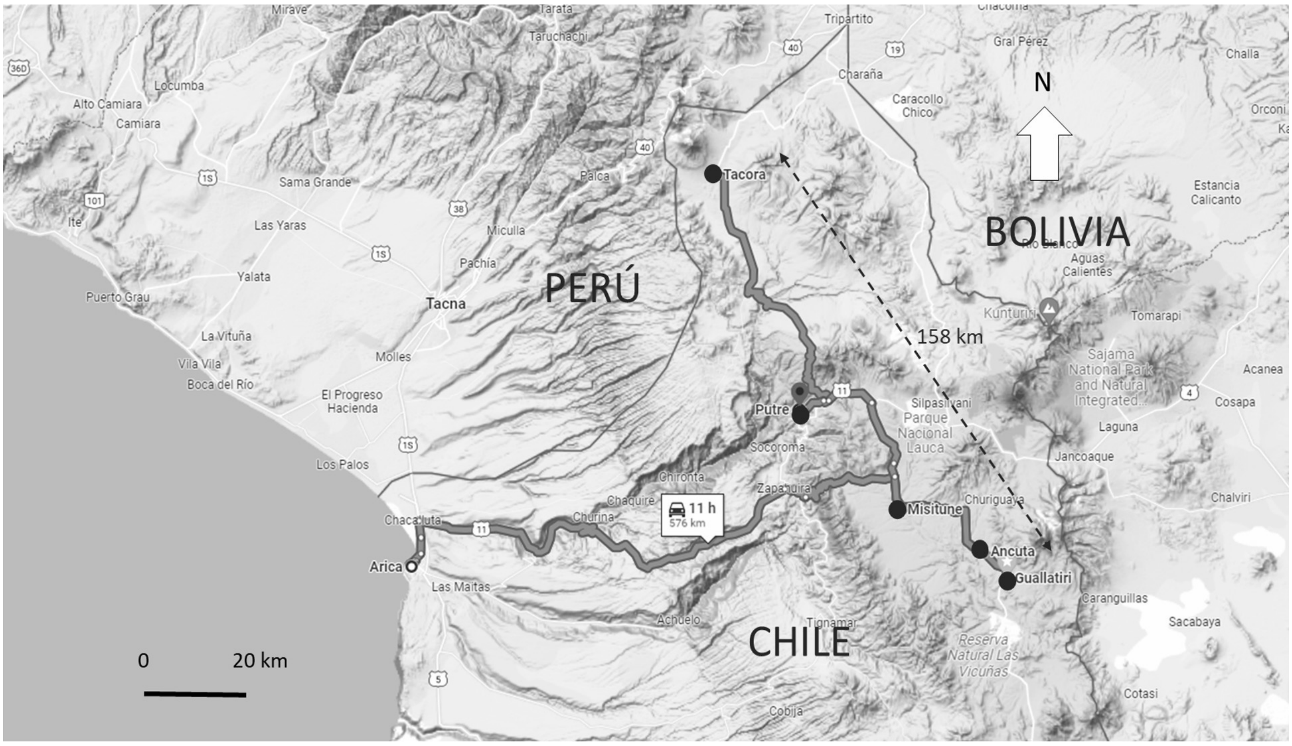

Figure 1. Route and location of the villages visited during the research in the Arica and Parinacota region
Source: Prepared by the author

Cultural anthropological research conducted between 1968 and 1969 in Enquelga, Chile, has reported the use of mud and straw in the ceilings of Aymara dwellings. This ethnographic record identified 90 dwellings, where the use of the local technique known as "p'ira," "caruna," or "takta" was described. This was the traditional way of covering roofs (Šolc, 2011 [1975]) in the Andean highland villages of northern Chile.

The closest case referred to in the literature describing this construction technique is found in Bolivia. It corresponds to a type of traditional construction of the Uru Chipayas culture, an ethnic group that forms part of the Uru Puquina nation, "[...] The same origin must have identified the Urus and the Puquinas. The Urus settlement extended across the central highlands, that is, the department of Oruro and the entire coast to the Pacific Ocean in the west (according to Max Uhle), to the north to the northern shore of Lake Titicaca and the Arequipa Valley, to the south with the upper part of the Loa River, to Lípez and Chichas, that is, covering the entire province of Tarapacá, to the east with the Cotagaita River." (De la Zerda, 1993, p. 94). This spatial distribution refers to the spatial expansion of this culture over the current Chilean territory of Arica and Tarapacá, where evidence of this construction technique has been found.

The most detailed study of this technique in Bolivia is the work documented by Bolivian architect Jorge de la Zerda in 1993 in his book Los Chipayas, modeladores del espacio (The Chipayas, Shapers of Space), which provides a graphic and written description of the process used to construct this sheet of The mud that is placed on the ceiling of the circular dwellings known as "Wallichi Koya," referring to how the tacta is constructed, indicates that "[...] It is then covered with a 'sheet' of clay and straw, called 'tacta' in Aymara and 'wara' in Chipaya, which is made on the ground beforehand. This sheet is circular and, to facilitate its transfer to the roof, is cut into trapezoidal pieces. Rough straw is placed on top of the wara to protect it from rainwater. The straw is held in place with a "chipa" or net woven from the same material, tough straw, as a precaution against strong winds. (De la Zerda, 1993, pp. 75-78).

The technical solution of suspended ceilings made from straw and mud, although very limited to the specific southern Andean area, can be found in other similar contexts involving straw and mud roofs in cold climates, such as the traditional straw-roofed houses of northwestern Spain, where it is noted that "[...] The construction methods of the palloza, as traditional architecture based on trial and error, are currently considered valid, offering professionals criteria for designing and building dwellings using sustainable, locally sourced, and low-environmental-cost materials." (Molina and Fernández 2013, pp. 213-214). The study of this case, together with others closer to the Andean area for rural dwellings in the Colca Valley, refers to the importance of roof insulation and provides data on the percentage reduction in energy demand: "[...] It is concluded that interior roof insulation has a greater impact on thermal performance, reducing energy demand by 23%; and by implementing all scenarios, a 29% reduction is achieved." (Iruri et. al, 2023, p.1).

It could be argued that Aymara architecture could be considered an adaptive response to the extreme environment. Many authors have ventured to characterize

Andean housing as "[...] that which possesses common characteristics and repetitive typological patterns throughout the Andean macrozone, which have been widely described by numerous architects, anthropologists, and architectural historians." (Jorquera, 2021). This technique, which can be defined as straw-lightened mud (see figures 2, 3, and 4), refers to "[...] a sheet of mud with straw, 1 to 2 cm thick, cut into strips 50 cm wide, which are placed on a slightly overlapping cane framework, with a smooth inner surface. It is made on site with fine straw and mud tamped under a cloth to compress it" (Directorate of Architecture, Ministry of Public Works of Chile, 2016). In 2018, following the restoration of the village of Tacora, this technique was reintroduced, incorporating standardized industrialized materials combined with the vernacular technique, which is the case study discussed in this article.

Figure 2: Caruna tied with llama leather. Queñoa wood coasters and racks.
Source: Own work

Figure 3: Caruna tied with a metal wire. Gunwales and struts made of brushed pine wood.
Source: Own work

Figure 4: Caruna tied with cowhide. Gunwales and struts made of rough pine wood.
Source: Own work

The knowledge associated with this practice is currently at risk of disappearing as a result of the sociocultural processes of uprooting and internal migration experienced by the Aymara people over the last 50 years. These phenomena are undoubtedly having a substantial impact on the territorial space and the conservation and loss of the cultural heritage of the villages of the Chilean Altiplano. For this reason, and due to the optimal efficiency characteristics obtained under test conditions, it can be argued that this technique deserves to be known, replicated, and safeguarded as knowledge belonging to the Aymara people (see Figure 5), for which recognition as cultural evidence is sought.

The novelty of this research lies in the opportunity to carry out tests that had never before been applied to this material, such as its thermal characterization. These results will be valuable for the revision of sustainable construction standards in Chile and other countries in the Southern Cone that share cold climates at altitudes above 3,000 meters above sea level.

2. Materials and methods

To address this case of Andean heritage, research methods were used that combined architectural aspects related to construction and ethnographic aspects that delved deeper into the expressions of cultural knowledge behind these physical manifestations. These methods sought to understand and analyze the characteristics, contexts, and meanings of these traditional constructions in order to draw conclusions that would validate or refute the hypothesis of the continued validity of this ancestral knowledge in non-urban Andean communities. The study was divided into three stages.

First stage: collection of information ex situ. A bibliographic and census review was carried out, followed by a field survey to confirm the presence of the technique in one case. concrete and verification of different roofing materials in dwellings in the area of interest. Next, surveys

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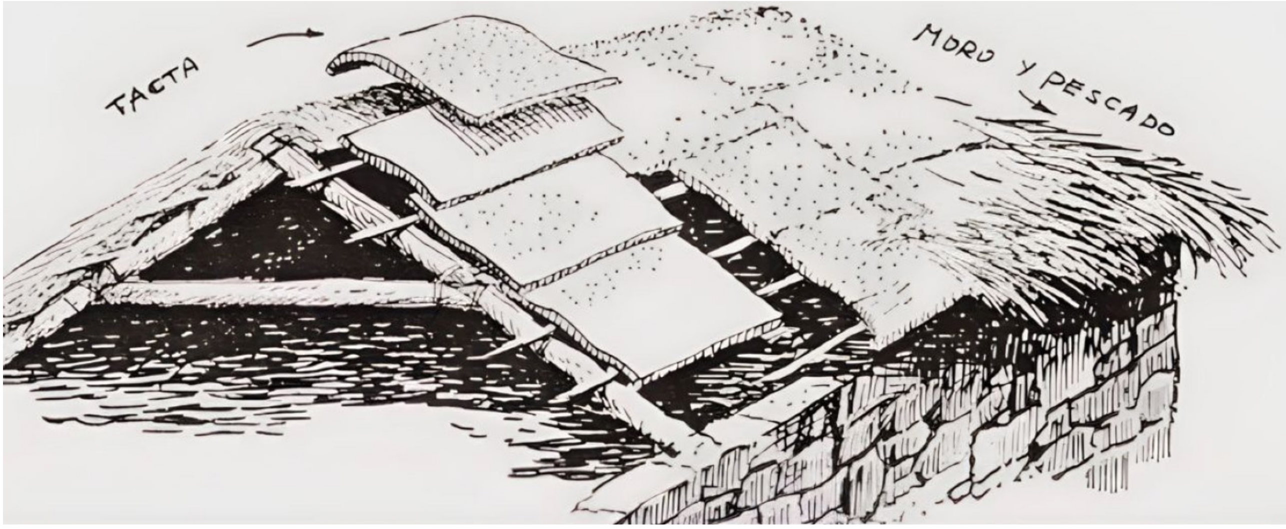

Figure 5: Sketch of the construction elements of the lightweight mud ceiling (Contreras Álvarez, 1974)

were conducted with key informants to establish the degree of knowledge about the technique under investigation.

In this phase of the research, a 25-year longitudinal study was conducted on the replacement of roofing materials in rural areas of the province of Parinacota. Data from the Chilean Population and Housing Censuses conducted by the National Institute of Statistics (INE) in 1992, 2002, and 2017 were reviewed. The data was limited to the province of Parinacota in the Arica and Parinacota Region of Chile, and two categories of information were analyzed: a) Types of housing identification used by the INE, b) Types of materials used in different parts of the dwelling. This data was analyzed for each of the intercensal periods and cross-referenced based on specific types of materials such as "straw," "coirón," "totora," and "caña."

Second stage: collection of information in situ. Test samples of material identified as "Caruna," composed of mud and lightened straw, were prepared and subjected to microscopic characterization and thermal behavior tests. Finally, studies were carried out to monitor the hygrothermal behavior and climate variables of two houses with different insulation materials located in the town of Tacora, Chile.

To obtain samples of the material used to make the "Caruna" test tubes, a farmer and bricklayer from the village of Visviri was contacted, who rescued this knowledge from his personal experience and allowed this technique to be incorporated into the restoration of the village of Tacora in 2018. This key informant provided a first-hand account of the perspective and value of this construction knowledge and also made two "caruna" test tubes, which were subsequently tested in the laboratory under NCh 850.

The soil samples obtained from the test tube preparation process were subjected to consistency limit determination (NCh 1517/1, NCh 1517/2 Of. 1979). Test (1) corresponds to the determination of the liquid limit, while test (2) corresponds to the plastic limit.

In addition, a test was carried out to obtain the sand equivalent, by the Chilean standard (NCh 1325:2010). The consistency limit was tested for both soil samples, 25313-1, which corresponded to a mixture of fine soils with a clay content to be determined, and sample 25313-2, composed mainly of sand added to the kneading process during the preparation of the "Caruna" in situ.

The third stage involved integrating the results obtained and drawing conclusions from a cultural and environmental perspective.

To clarify the effectiveness of knowledge transfer between generations, the first task was to make contact with the local school-age population to determine their level of knowledge regarding the traditional method of making "cielo de barro y paja alivianado" (lightweight mud and straw roof), as proposed by Gavilán and Vigueras (2020), as a result of strong state policies for the recognition of indigenous peoples in the last two decades, "[...] young people tend to affirm ethnic identities by valuing the past, recovering rituals and re-signifying them in urban spaces," according to Yáñez and Capella (2021). Therefore, the sample selected is intentional and corresponds to 32 students aged 16-17 from the Liceo Técnico Agrícola Granaderos de Putre.

The methodology of the meeting included a theoretical presentation of the characteristics of the material, its relevance, and a description of the research. A brief survey of 10 dichotomous qualitative questions in two dimensions was also administered. The first was aimed at identifying prior knowledge about the construction technique, which takes on different names depending on The town where it is found, and the second aimed at elucidating the motivation and interest in perpetuating the construction tradition.

In this last stage, data were obtained from monitoring the hygrothermal behavior of the case studies. The study was conducted in the town of Tacora, Chile, based on the initial considerations that there had been a recent intervention involving the use of caruna for the restoration of the town in 2018. The second reason was the possibility of having a contrasting material, also considered a good thermal insulator, in the wall covering of the houses, which was made using totora (Aza-Medina et al., 2023; Hidalgo-Cordero & Aza-Medina, 2023). To this end, four houses were initially selected, two with "mud and straw" ceilings and two with "totora" ceilings, and two of them were then monitored. The purpose of this study was to obtain environmental comfort parameters and data through indoor and outdoor temperature and humidity variables in the houses, and then compare them with environmental comfort simulations of the houses based on standardized thermal transmittance data for "mud and straw" material.

Climate data was collected through a field measurement campaign to determine the indoor and outdoor environmental performance of the homes. For indoor measurements, temperature and humidity measurement devices (Dataloggers) were installed at roof level in each of the four prototype homes mentioned above. The installed equipment consists of small recording thermographs capable of storing large amounts of data over extended periods. For this research, the equipment was configured to collect data every 15 minutes over five months (July to November).

3. Results

3.1. Cultural aspects related to the use of material resources

About the materiality of the roof in the indigenous housing category, which is similar to the concepts of ruka, pae pae, and others, the presence of plant materials in the roof showed a decline in 1990. Of the total number of cases surveyed in that year, which corresponded to 180 dwellings, it reached 134, representing 74% compared to 2002. Homes with this type of material only reached 37 homes, representing 20.5% of the total, while in 2017, only nine homes were counted, representing 5% of the total. This indicates that there was a 93.24% reduction in the proportion of homes with roofs made of plant materials.

The analysis of census data also showed the presence of substitute materials, such as metal sheets or materials such as zinc, copper, or fiber cement. This type of roof is mainly associated with the architectural typology referred to as "house" by the INE and, to a lesser extent, with "traditional indigenous housing." However, in 25 years, the total number of dwellings with zinc and fiber cement roofs reached 929, showing a progressive increase in the presence of these materials in the highland areas.

Based on the cases observed during the field campaign, which visited the towns of Tacora, Misitune, Ancuta, and Guallatire over a distance of 150 kilometers, it was found that zinc sheets were present in 81.82% of cases, compared to mud-covered straw roofs. However, when comparing the type of ceiling in these cases, 72.73% had "mud and straw" ceilings and only 18.18% had "reed" ceilings, while 9% could not be identified.

About the material used for exterior walls, 36.36% were mud-brick houses, 27.27% were stone and mud, and the remaining 36.36% were adobe houses. Compared to data provided by the Chilean National Institute of Statistics (INE) on the material composition of roofs, this sample indicates that even though zinc sheet metal is the most common roofing material, the roofs of traditional dwellings have a high percentage of straw and mud.

Regarding knowledge transfer, our analysis of the survey data reveals that, in the first dimension, most students are unfamiliar with this construction technique, with "t'ili" being the most recognized term, at 24% of those surveyed. However, 67% say they associate some of these terms with roofs. About the second dimension, the information gathered shows that there is a lack of knowledge about both this specific technique and other typical construction techniques, since in both areas more than half of the population surveyed said they did not know of them (67% and 55%, respectively).

This situation contrasts with the 97% who find value in this knowledge and the 85% who directly express an interest in learning about this and other traditional Andean construction techniques. The term "t'ili" stands out, and they also recognize that the terms used to identify the system are part of traditional roofing.

3.2 Physical characterization of the materials used in the manufacture of the clay and lightened straw panels

The method used for the physical characterization and composition of the samples was carried out through observation and analysis with field emission scanning electron microscopy (FESEM) at the Major Equipment Unit (MAINI UCN).

"[...] The scanning electron microscope, better known by its acronym SEM, uses a beam of relatively low-energy electrons as an electron probe that is scanned regularly over the sample. (Metalinspec 2023) The action of the electron beam stimulates the emission of high-energy scattered electrons and low-energy secondary electrons from the sample surface.

The scanning electron microscope uses emitted electrons and works on the principle of applying kinetic energy to produce signals about the interaction of the electrons. These electrons are secondary electrons, backscattered, and backscattered diffracted electrons that are used to view crystallized elements and photons. Thanks to the narrow electron beam, SEM micrographs have a considerable depth of field that provides a 3D appearance, allowing for a perfect understanding of the sample's surface structure. In summary, the signals used by a scanning electron microscope to produce an image are the result of interactions between the electron beam and atoms at different depths within the sample.

Sample preparation: Sample preparation is relatively easy since most SEM equipment only requires that samples be conductive.SEM equipment only requires that they be conductive. In other words, the sample must generally be coated with a layer of carbon or a thin layer of a metal such as gold to give it the conductive properties required by the sample, and then scanned with the accelerated electrons. (Metalinspec 2023).

The observation method consisted of extracting a small 10 x 10 mm portion from each of the material samples. The samples were placed on a support that allowed them to be exposed to the electron microscope, which is subjected to an electron bombardment process, allowing observation through the monitor, as shown in (Figure 6), which allows observation of the molecular composition of the compounds as well as the surface structure of the different materials that make up the sample. The procedure allowed portions of the sample to be observed on the lower and upper sides of the test tube, as shown in Figures 7 and 8, where it can be seen that the test tube of the material has a different distribution of straw on the upper and lower sides.

It should be noted that the technique used for these analyses effectively identifies and quantifies elements heavier than sodium (Na), so the absence of lighter elements does not indicate that they are not present, but rather that the technique did not identify them.

The soils analyzed contained rock fragments ranging in size from 60 to more than 500 microns, mostly silicate minerals, possibly quartz, feldspars, and some clay minerals. To a lesser extent, some minerals composed of Fe, Ti, and O were identified. Based on the morphology of the rock fragments, it could be assumed that they had been transported from their source, possibly volcanic, as indicated in the laboratory report.

The results corresponding to the plasticity index in the clays and the percentage limit of sand were obtained from the material used to make the "caruna" test tubes. These samples were characterized as a natural material made from soil and straw, measuring 30 cm x 30 cm x 0.5 cm and with an apparent dry density of 1252 kg m-3. This sample had only 1% sand equivalent, indicating that it was predominantly clayey, composed essentially of 99% clay. It is important to note that the sand fraction used in the soil mixture added to the base material corresponded to 0.473 liters, which was only 5% of the dry volume.

Regarding the apparent density of the tested material and its characterization as a lightweight material, the reference value obtained was 52 kg m-3, denser than the density limit established for a clay and straw matrix considered lightweight, whose density is 1200 kg m-3, as indicated by Wieser et al. (2020). Meanwhile, the interpretation of the results for the liquid limit test according to Casagrande (1932) indicates that soils with a liquid limit greater than 50% (LL>50%) are highly plastic, while soils with a liquid limit less than 50% are defined as low plasticity.

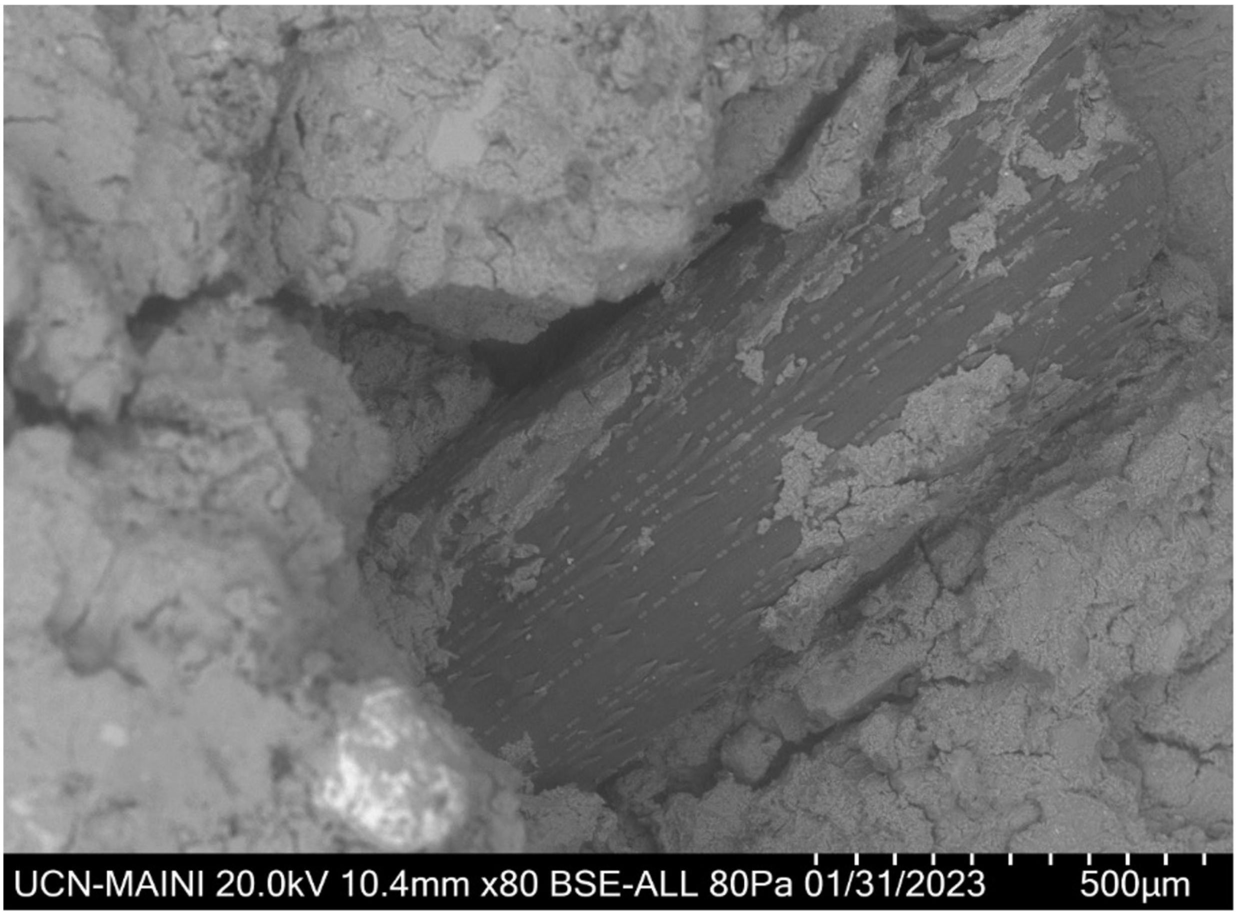

Figure 6: Image of the monitor showing the mud matrix next to the "Ichu" straw fiber. The reading indicates that the fiber is 100% carbon. (MAINI, 2023)

The results obtained place the material used to make the "caruna" close to the high plasticity limit.

The plasticity of the samples tested refers to their ability to deform without breaking when subjected to changes in pressure or humidity. A soil with high plasticity can withstand considerable deformation without cracking, which can be beneficial in conditions of environmental or load changes. The plasticity index obtained from the tests reached 21%, indicating that the tested material exhibited high plasticity and medium compressibility, which could influence cracking, as shown in Figures 7 and 8.

3.3. Results of the visual analysis of the fibers

This allowed the orientation and distribution of the straw to be identified by observing the front and back surfaces of the test piece. This examination established, using the counting method, that: on the lower face, 79 fibers were identified, which, compared to the upper face, represent 59% of the total fibers on both surfaces. In this count, 47 fibers were identified, representing 40.5%, which run from the edges to the interior of the test piece and are much longer than the interior fibers, while the short fibers that do not touch the edges of the test piece numbered 32. The fibers on the upper side are much finer and longer.

Figura 7: Comparativa de agrietamiento en la cara inferior
Fuente: Elaboración propia

Figura 8: Comparativa de agrietamiento en la cara superior.
Fuente: Elaboración propia

A total of 54 fibers were identified on the upper face (Figure 8), which, compared to the lower face (Figure 9), represent 41% of the total for both surfaces. Twenty-three fibers, representing 42.59%, run from the edges to the interior, while the short fibers that do not touch the edges of the test piece accounted for 31 fibers, representing 57.40%. Compared to the lower surface, the fibers on this surface are wider and fewer in number than on the lower surface.

There are notable differences between the lower and upper sides of the test tube in terms of the quantity and characteristics of the straw fibers. The lower side has more fibers than the upper side, and these represent a significantly higher percentage of the total fibers. About fiber lengths, it was found that the longest fibers are located on the outside of the probe, extending from the edges to the interior. The shortest fibers are found in the center and do not touch the edges of the test tube. This could indicate a specific stratified arrangement of the fibers based on their length and alignment.

These counts would have implications when considering the flexural strength factors of the sheet once it is deposited on the roof structure and the sheet begins the drying process, and thus analyze the cracking factor about the effects of clay shrinkage when water is removed from the mixture and the drying and consolidation process of the material begins.

By depositing the fibers in successive layers in multiple directions, combined with the compression exerted by the foot to allow the mud matrix to penetrate between the fiber layers, the fibers are concentrated in the lower part of the board, thus achieving better performance under tensile and flexural stresses in the caruncle blanket.

The concentration of fibers in the lower part of the plate can have several implications for its structural behavior, improving tensile and flexural strength: when aligned and evenly distributed, fibers can provide considerable tensile and flexural strength. This property is accentuated when the fibers are concentrated in the lower part of the sheet, where tensile stresses are usually higher in a cantilevered structure. In this case, the bending moment generates tensile stresses in the upper fibers, such as the ceiling of a house.

The higher concentration of fibers at the bottom of the board would help prevent or limit the formation of cracks, providing additional protection against them. The fibers act as a reinforcement, distributing stresses and helping to maintain the integrity of the board even when movements or loads occur.

3.4 Resistivity and monitoring test results

In the case of the material known as "caruna," the sample tested in the laboratory by NCh 851 achieveda linear thermal conductivity value of 0.1477 W m-1 K-1. The guard ring method was used in the procedure described in NCh 850 Of . 2008.

The apparatus used consisted of a central metal plate (hot plate) equipped with electric heating. This plate is surrounded by a frame (guard ring) that can be heated independently. On both sides of the plates, test tubes (2) of equal size and with flat parallel faces are arranged. Water-cooled metal plates (cold plates) are placed against the test tubes. The entire assembly thus formed constitutes a sandwich in close contact. (Figure 9).

Comparing this result with others obtained from the specialized literature (Ashour et al., 2015; Zeghari et al., 2021) indicates that the higher the transmittance values, the lower the insulating capacity of the material. An enclosure with good insulating material (5-8 cm) achieves transmittance values of around 0.6-0.4 W m-2 K-1.

The roof enclosures commonly used in contemporary Andean villages are lightweight zinc roofs, mud cake roofs, or wooden roofs. In some cases, concrete slabs are used in recently constructed dwellings.

The lightweight roof used in the system, known as "caruna," achieves better thermal performance than uninsulated slabs and is comparable to mud or wooden roofs. Compared to metal sheet roofs, the advantage is even greater, also improving the heat wave delay value, an indicator of the thermal inertia of the roof.

This result is in line with the results obtained by other studies (Palme et al., 2014; Palme et al., 2012). By increasing the thickness of the caruna, thermal performance can improve proportionally, reaching and exceeding the thermal resistance values typically offered by wooden roofs or other natural insulators such as cork.

3.5. Thermal characterization

About thermal properties, several studies have established a baseline for understanding the properties of mixed construction systems that use soil and lightened straw as insulation, cladding, or infill in wall partitions or roofs. In this regard, it is important to highlight the previous research by Weiser et al. (2020), Volhard (2016), and Vinceslas et al. (2019).

Monitoring results were obtained for a typical day in July, with indoor temperature fluctuations between 1°C and 22°C, both for the caruna roof and the totora roof. Although this result shows a certain degree of nighttime cooling below levels considered acceptable for comfort, it demonstrates that the thermal insulation provided by caruna is similar to that provided by other materials traditionally used in housing roofs in the high Andean regions.

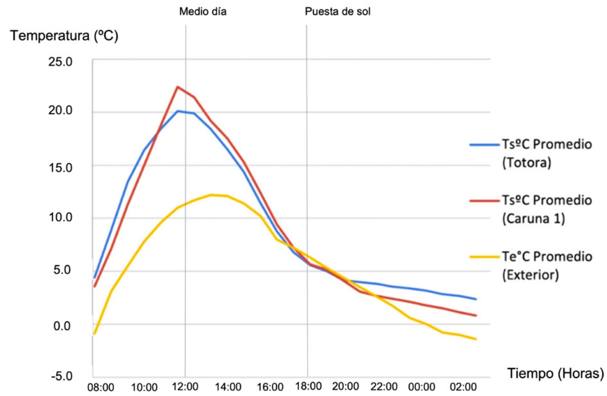

Figure 10: Performance monitoring on a typical day in July.
Source: Own elaboration

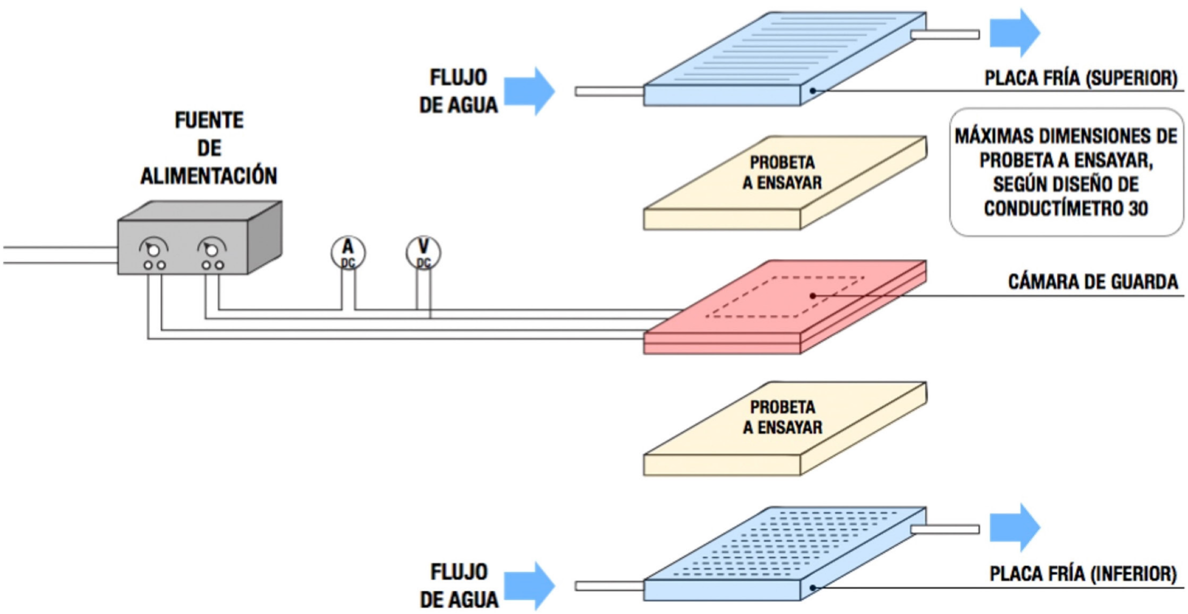

Figure 9: Thermal conductivity test method NCh 851 test (CITEC UBB 2022)

According to the data obtained from the monitoring measurements carried out from July to November in Tacora, the data corresponding to the most unfavorable winter situation, which corresponded to July 2022, were isolated. The graph (see Figure 10) shows the average temperature values reached by the different materials tested in the field, compared with the maximum and minimum outdoor temperatures for that month. It can be seen that the average highest outdoor temperature reached 12°C, while the average minimum outdoor temperature reached -2°C. The highest indoor temperature reached by the caruna was around 23°C, while the highest average temperature reached by the totora ceiling was 20°C, and the lowest minimum temperature was reached by

The totora at around 3°C, while the minimum indoor temperature reached by the caruna ranged between 1°C and 2°C.

4. Discussion

Lightweight earth has usually been associated with mixed systems of load-bearing timber structures, which "[...] use a mixture of mud and fibers to fill the walls [...]. In some European countries (Germany, France), they have been used for some time in a modern way and by national regulations, achieving good thermal and acoustic performance [...], but this should also be evaluated from the point of view of seismic performance" (Meli et al., 2019, p.605).

In the Leicht Lehmbau (lightweight earth) construction system, made from a high proportion of fibers bonded together with clay, the density is essentially between 500 and 800 kg m-2. This density is achieved by adding a larger amount of plant stabilizer; in some cases, wheat straw (Pereira, 2003). The results obtained from the test specimens showed an apparent density of 6.5% above the reference value, as indicated by Wieser et al. (2020). In this sense, despite this slight variation, the mud and straw ceiling could be considered a lightweight system as it is close to the above range.

About thermal properties, several studies have established a baseline for understanding the properties of mixed construction systems that use "soil and lightened straw" as insulation, cladding, or infill in wall partitions or roofs. In this regard, it is necessary to highlight the previous research by Weiser et al. (2020), Volhard (2016), and Vinceslas et al. (2019). Thermal performance depends mainly on the density of the clay and straw matrix; however, it is possible to argue that at densities above 1200 kg m-3, thermal performance close to the values of 0.150 W m-1 K-1 (Meli et al., 2019).

Research conducted on the effect of artificial and natural fibers on soil behavior has reported that these are efficient and low-cost soil stabilizing materials. It has also been proven that the tensile strength and elongation of fibers are greater when wet (Charca et al., 2015). In terms of mechanical resistance properties, there is also evidence indicating improved performance of this combination of materials about the selection of fiber sections and their arrangement within the clay matrix. In this regard, Noaman et al. (2020) provide data that allow the combination of variables to be parameterized and adjusted to obtain better mechanical performance from the material.

Regarding the distribution and density of the fibers present in the test tube analyzed, it can be concluded that, concerning the tensile stresses to which a flexible blanket-shaped insulation is subjected, it is possible to argue that, according to the data obtained, in general, a notable variation was observed between the lower and upper sides of the sample in terms of fiber density and characteristics, aspects that prove that the non-oriented distribution of the fiber and the compression action when stepping on the fibers against the ground would cause a distribution that helps improve the mechanical properties of the material against tensile stresses.

From a more ecological perspective, the manufacture of mud and straw boards for wattle and daub is related to the cycle of Andean grasses, the construction of house roofs before flowering, as pointed out by researchers Villagrán and Castro (2004), who identified the Andean grass species used to make the mud and straw boards: "[...] Generic categories were recorded according to growth forms (such as champeal grasses, straws or wichu, t'olas, montes, rain grasses, and others), as well as nomenclatures by species that refer to vernacular names that, in most cases, had already been recorded in other Andean communities." (García et al., 2018)

5. Conclusions

By the guidelines established by UNESCO and the Chilean Ministry of Culture, Arts, and Heritage (MINCAP 2019), the recognition of intangible heritage is based on a series of criteria that a cultural expression must meet in order to be included in the national catalog of cultural expressions through a safeguarding process.

About intangible heritage, these criteria refer to validity, nature and collective identity, relevance, and responsibility. In this context, this article seeks to demonstrate how, in light of the research evidence to date, lightweight straw and mud roofs constitute a valid case for recognition as intangible heritage belonging to the Aymara world.

"Validity" corresponds to ancestral traditions, including the contemporary uses of various cultural groups. According to this principle, the system of lightweight mud and straw roofing, known as "Caruna," "Tacta," "T'ajta," Tacta, and in the Chipaya language "wara," "Píra," or "T'íli," has proven to be a technique used in the recent past in the Andean highlands, with documentary evidence from research carried out in the town of Enquelga since the 1970s. Its use continues today, as documented in the restoration of the roofs of the village of Tacora in 2018, located in the Arica and Parinacota region of Chile. Audiovisual records from 2018 show its community and family use in the town of Chua, a cattle ranch, and in Ancuta, both locations near the town of Guallatire, where there is also evidence of the existence of this construction system in old houses.

This cultural heritage is widely distributed across the region and is associated not only with Aymara communities in Arica and Parinacota, but is also recognized in Bolivian border towns such as Cosapa, near Putre, and Santiago de Machaca, near the border with Visviri. These references were obtained through interviews with young students at the Granaderos Agricultural Technical High School in Putre. There is also evidence of its use in transregional locations within Chile.

"Nature and collective identity" is a principle that states that "intangible heritage" must be linked to specific social groups and transmitted in a participatory and inclusive manner. Its recognition and validity depend on the consent of the communities, groups, and individuals involved, without allowing exclusive appropriation or decision-making without their consent. The mud slab with lightened straw is part of the building practices passed down from generation to generation in traditional Aymara dwellings. This building practice is associated with family formation rites and the construction of the roof as a constructive and symbolic act. In the area near the border with Peru and Bolivia, this technique is known as "caruna" or "karuna," which means "blanket" in Quechua (David et al., 1998, p. 126) and (Aninat et al., 2019, p. 133). Towards the south of the Altiplano, it is called "takta" or "torta" (Villagrán & Castro, 2004), (DA.MOP., 2016, p. 156), and (García et al., 2018, p. 529). In the Tarapacá region, it is called "pira" or "tili" (Šolc, 2011 [1975]; Contreras, 1974).

The construction is carried out collectively and is associated with a symbolic and social dimension of mutual aid called Ayni, which represents community collaboration to help build homes when a member of the community needs it. Both men and women participate in this work, each with specific roles.

"Relevance" must reflect the cultural and historical processes of a community and reveal a sense of belonging and identity among its members. Its value does not lie in its exclusivity or rarity, but in its ability to promote social cohesion, intergenerational dialogue, and be an expression of human creativity. The practice of roofing houses is not merely functional. However, it reveals itself as a deeply rooted ritual in the communities of the central-southern Andean highlands, covering regions of Peru, Bolivia, Argentina, and Chile. This ritual has been meticulously documented through research on regional architecture. Among the key figures who have delved into this subject, the Argentine researcher and architect Ramón Gutiérrez stands out. In his work Aspects of Popular Architecture in the Peruvian Altiplano (1978), Gutiérrez breaks down the rituals associated with house building in the 1970s in the Peruvian Altiplano.

In this web of symbols and actions, a deep link emerges between the roofing ceremony and cultural cosmogony. Over time, these traditions have persisted as a living testimony to the connection between architecture, spirituality, and the identity of communities in the highlands. The continuity of these rituals underscores the capacity of cultural practices to transcend time, transmitting deeply rooted meanings and keeping alive the interrelationship between the individual, the community, and their environment.

"Responsibility," the expression of intangible heritage, must fulfill the responsibility of not violating "human rights," fundamental or collective rights, especially those of women, children, indigenous peoples, and Afro-descendants. Furthermore, it must not compromise the health of people, the integrity of the environment, or animals, among others. About the integrity of the environment or animals: "[...] the Andean perception defines the Altiplano landscape according to its forage and ecological attributes, given that livestock management is structured around different vegetation formations; however, the concentric and altitudinal conception is constantly maintained (Villagrán and Castro 1997, Gundermann and González, 1986, p. 20).

The production of mud and straw boards contributes to collective rights of solidarity and mutual aid. About women and children, "Traditionally, any work involving the use of force or greater physical skills is considered to be the domain of adult men, while women and children are assigned to auxiliary tasks and the preparation and procurement of materials." (Carrasco Gutiérrez and Gavilán Vega, 2014, p. 45)

Women and children collect and sort the fibers, while men participate playfully in the compaction process. Men collect clay and sand, sift, supply water, prepare mixtures, measure, roll, transport, and arrange the material on the roof.

Recognized by indigenous peoples, it has ritual value through its formation in the Aymara family, promotes good health, due to the natural materials it is made of, it is a better alternative to plasterboard ceilings or other industrialized materials, it acoustically dampens rain and hail, and the lightweight mud and straw sheets can be used to combat the effects of climate change on people and camelids.

Based on the research carried out in this article, new lines of research are proposed to continue promoting this traditional technique. On the one hand, it would be possible to continue analyzing the life cycle of the technique and its contribution to the sustainability of vernacular architecture. On the other hand, it is proposed to continue the registry of traditional roofs beyond the study area in the village of Tacora and its relationship with the cultural territory shared with Peru and Bolivia.

It is estimated that the manufacturing processes of the sky-lighted roof can be gradually transformed into more consolidated processes, incorporating ancestral knowledge into more contemporary craft techniques, without becoming a highly industrialized product, which would considerably increase the environmental impact. Appropriate knowledge management and transfer between generations, as well as the eventual presence of a small local enterprise that respects the fragile ecosystem of the Andean desert, could contribute to consolidating the manufacture, distribution, and use of this important material as a natural thermal insulator in homes and buildings located in the studied localities and, more generally, throughout the high plateau macro-region.

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