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# REVIEW OF "LIGHTENED SLIPSTRAW CEILINGS" AS A CULTURAL PRACTICE IN THE VERNACULAR ROOFING OF AYMARA HOUSES IN ARICA AND PARINACOTA, CHILE[1]

# RELEVAMIENTO DEL USO DEL "CIELO DE BARRO Y PAJA ALIVIANADO" COMO PRÁCTICA CULTURAL EN LA TECHUMBRE VERNACULAR DE LA VIVIENDA AYMARA DE ARICA Y PARINACOTA, CHILE

# PESQUISA SOBRE O USO DO "TETO DE BARRO E PALHA ALIVIADO" COMO PRÁTICA CULTURAL NO TELHADO VERNACULAR DAS RESIDÊNCIAS AIMARÁS EM ARICA E PARINACOTA, CHILE

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# RESUMEN

Este artículo trata acerca de la caracterización de la tecnología de un cielo raso de paja y barro denominada en lengua aymara como "caruna". El estudio se realizó en viviendas Aymaras a más de 4.000 metros sobre el nivel del mar en la localidad de Tacora, en la región de Arica y Parinacota, Chile. El estudio forma parte del proyecto 49204 financiado por el Servicio Nacional del Patrimonio Cultural. Su objetivo es rescatar esta técnica vernácula como alternativa a los materiales industrializados que han modificado la vivienda andina y la calidad de vida en climas extremos durante los últimos 25 años. Se recogieron muestras de los materiales utilizados en esta técnica, reproducida por un cultor local, y se analizaron en laboratorio para determinar sus propiedades térmicas y de trabajabilidad. Además, se monitoreó el desempeño energético de tres viviendas en el poblado de Tacora para comparar los resultados obtenidos con los de los laboratorios. Los hallazgos revelaron que la matriz de barro utilizada en esta técnica de encielado es predominantemente arcillosa con mediana compresibilidad y baja conductividad térmica, lo que la hace adecuada como aislante en climas desérticos fríos. El cielo de barro y paja alivianado se destacó por su presencia en la cultura local, la disponibilidad de recursos materiales y su facilidad de instalación. Este estudio subraya la importancia de preservar el conocimiento tradicional, respetando los saberes ancestrales y mejorando el desempeño térmico de las viviendas en la cordillera norte de Chile, Perú y Bolivia, destacando su relevancia para el desarrollo de soluciones habitacionales sostenibles y culturalmente pertinentes.


Palabras clave
construcción en tierra, arquitectura vernácula, fibras naturales, aislación térmica, Ichu.


# ABSTRACT

This article reviews the slipstraw ceiling technology known in the Aymara language as "caruna." The study was made in Aymara homes at more than 4,000 meters above sea level in the town of Tacora, in the region of Arica and Parinacota, Chile, as part of project 49204, financed by the National Cultural Heritage Service. It aims to recover this vernacular technique as an alternative to industrialized materials that have modified Andean housing and the quality of life in extreme climates over the last 25 years. Samples of materials used in this technique, reproduced by a local craftsman, were collected and analyzed in the laboratory to determine their thermal properties and workability. The energy performance of three homes in Tacora was also monitored to compare the results obtained with those of the laboratories. The findings revealed that the mud mold used in this ceiling technique is predominantly made from clay with medium compressibility and low thermal conductivity, which makes it apt for insulation in cold desert climates. Lightened clay and straw ceilings stand out in the local culture thanks to the availability of material resources and ease of installation. This study highlights the importance of preserving traditional knowledge, respecting ancestral knowledge, and improving the thermal performance of homes in the northern mountain range of Chile, Peru, and Bolivia, highlighting its relevance for developing sustainable and culturally relevant housing solutions.


Keywords
earth construction, vernacular architecture, natural fibers, thermal insulation, Ichu.


# RESUMO

Este artigo trata da caracterização da tecnologia de um teto feito de palha e barro, conhecido na língua aimará como "caruna". O estudo foi realizado em habitações aimarás a mais de 4.000 metros acima do nível do mar na cidade de Tacora, na região de Arica e Parinacota, Chile. O estudo faz parte do projeto 49204, financiado pelo Serviço Nacional de Patrimônio Cultural. Seu objetivo é resgatar essa técnica vernacular como uma alternativa aos materiais industrializados que modificaram as moradias andinas e a qualidade de vida em climas extremos nos últimos 25 anos. Amostras dos materiais usados nessa técnica, que foi reproduzida por um cultor local, foram coletadas e analisadas em laboratório para determinar suas propriedades térmicas e de trabalhabilidade. Além disso, o desempenho energético de três casas no vilarejo de Tacora foi monitorado para comparar os resultados obtidos com os dos laboratórios. As descobertas revelaram que a matriz de barro usada nessa técnica é predominantemente argilosa, com compressibilidade média e baixa condutividade térmica, o que faz com que seja adequada como isolante em climas desérticos frios. O telhado de palha e barro destacou-se por sua presença na cultura local, pela disponibilidade de recursos materiais e pela facilidade de instalação. Este estudo ressalta a importância de preservar o conhecimento tradicional, respeitar o conhecimento ancestral e melhorar o desempenho térmico das habitações na cordilheira norte do Chile, Peru e Bolívia, destacando sua relevância para o desenvolvimento de soluções habitacionais sustentáveis e culturalmente relevantes.


Palavras-chave:
construção em terra, arquitetura vernacular, fibras naturais, isolamento térmico, Ichu.

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# INTRODUCTION

A revision of the Population and Housing censuses of the Region of Arica and Parinacota in the last 25 years demonstrates the existence of a substantial change in the composition of the materials used in the roofs of the Aymara vernacular dwellings (Figure 1), which, in turn, could have carried out a process of change in their efficiency and effectiveness in the face of the extreme climate where they are located.

Several investigations in cultural anthropology between 1968 and 1969 in Enquelga (Chile) found evidence of the use of mud and straw in the ceilings of Aymara houses. In this ethnographic record, 90 dwellings were identified where the use of the local technique called "[...] Caruna" or "Karuna" (Šolc, 2011; Weber et al., 1998), or also "takta" (Figure 2 and Figure 3), which was the traditional way used to put on a roof in the Andean highland villages in northern Chile (Šolc, 2011).

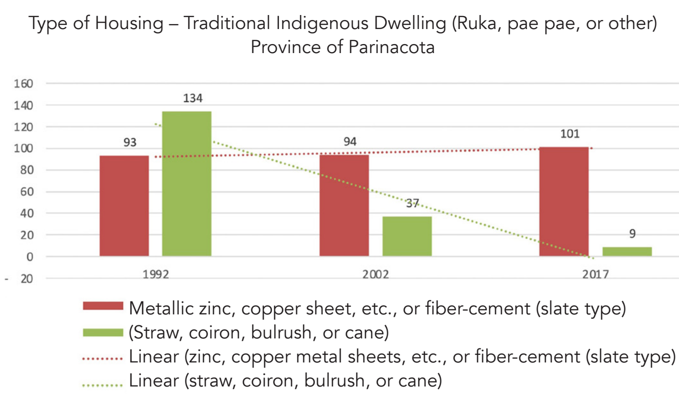
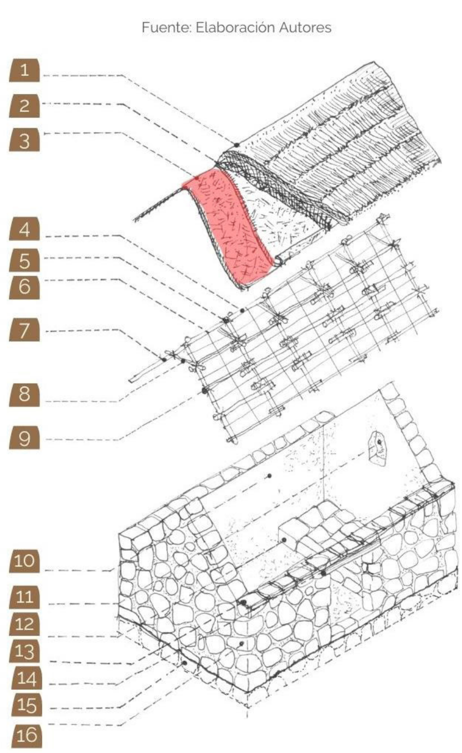



Figure 1. Analysis of the material substitution between vegetation-based roofing to zinc plates or fiber cement, "traditional indigenous" housing, Province of Parinacota, intercensal periods 1992-2002-2017. Source: Preparation by the authors

Figure 2. A ceiling of a traditional house in Guallatire, "caruna" or "takta," the material under study is white; photograph from 2022. Source: Preparation by the authors




Elements and parts of Traditional Andean housing found above 4,000 m.a.s.l, case of Guallatire, Arica and Parinacota, Chile

1. Outdoor roof, reed grass, mud-plastered, 10 to 15 cm, built with a 'fort' and 'fish-scale' perimeter protective eave.
2. Intermediate loose reed grass layer, with a regular 20 cm thickness
3. Indoor ceiling (Caruna, Karuna, takta, píra, tíli, slipstaw, 1 to 2 cm.
4. Ridge beam – Unworked queñoa wood, app. diam- 7 cm
5. Secured in an "x" shape called "correhuela," by damp llama leather
6. Sub-structure – llama leather straps – 1 cm
7. Truss structure – unworked Queñoa wood, app. diam. 7 cm
8. Knuckle or latch – unworked Queñoa wood, app. diam. 5 cm
9. Girts or "quiras" - unworked Queñoa wood, app. diam. 7 cm
10. Wall coating: sandy clay, possibly including lime.
11. Niche for bedhead wall, also called "phutu", Pre-Incan origin
12. Laminated above ground, allows placing a bed
13. Flagstone struts with volcanic, ignimbrite, or similar rocks
14. Sawn wood lintel
15. Continuous foundation on large sized stone, that jut 0.15 to 0.20 cm out of the ground, high density rocks, igneous type.
16. Quarried cyclopean corner rock blocks. The wall in general is built with two faces, with rocks split with their smooth or quarried face facing outwards. The wall is 35 to 40 cm thick.

Figure 3. Traditional housing in Guallatire incorporating the use of "Caruna or Takta". Source: Preparation by the authors

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Figure 4. Plan of Tacora, August 2022, overview of the village, walls, and ceilings of houses considered for the indoor climate study. Source: Preparation by the authors

This constructive system reveals social, cultural, and ritual implications in establishing an adaptive strategy to the physical-climatic environment of living at altitude. The last time this constructive system was mentioned was in the '70s, thanks to the research made by Dr. Václav Šolc in the town of Enquelga.

The presence of mud and straw ceilings has been mentioned recently in the context of ethnobotany studies. In this field, when considering that Aymara architecture is an adaptive response to the extreme environment, many authors have risked characterizing Andean housing as "[...] one that has common characteristics and repetitive typological patterns throughout the Andean macrozone, which have been widely described by numerous architects, anthropologists, and architectural historians" (Jorquera, 2014).

In 2018, after the restoration of the town of Tacora, this technique was reintroduced, although this time incorporating industrialized, standardized materials and combined with the vernacular technique. This phenomenon constitutes the case study discussed in this article (Figure 4 and Figure 5).

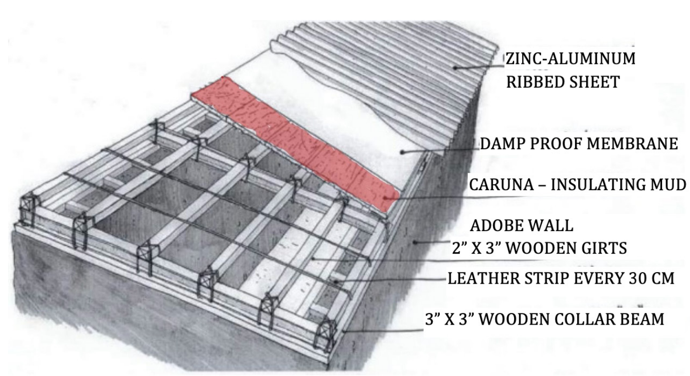


Figure 5. Construction isometrics for a house restored in Tacora in 2018. Source: adapted by the authors from Fundación Altiplano

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## POTENTIAL OF THE "CARUNA" CONSTRUCTIVE TECHNIQUE

The Aymara "Caruna" or "Takta" construction technique uses a lightened 1 to 2-cm thick clay and straw sheet, sized into 50-cm wide strips, which are placed, slightly overlapping, on a reed lattice, with a smooth inner surface. Its preparation is done on-site, with fine straw and mud rammed under a cloth to compress it (Directorate of Architecture, Ministry of Public Works, 2016).

The combination of mud and straw, called "lightened earth," has been linked to mixed systems of load-bearing wooden structures. In some European countries, such as Germany or France, these have been used for a long time in a modern way, in compliance with regulations, achieving a good thermal and acoustic performance (Meli et al., 2019). However, their seismic behavior still needs to be evaluated.

From a more ecological point of view, making clay and straw sheets for roofing is related to the cycle of the Andean pastures. The houses' roofs are constructed before flowering, as the Andean grass species with which the lightened clay and straw are made have better performance and durability when harvested at this stage. The grass species used for straw include reed grass and Peruvian feathergrass, commonly used in the ceilings and roofs of houses in the Andean sector (García et al., 2018).

On the other hand, diverse research on the effect of artificial and natural fibers on soil behavior has reported that these fibers are efficient and low-cost soil-stabilizing materials. It has also been found that the fibers' tensile strength and elongation are greater when wet (Charca et al., 2015).

## THERMAL AND MECHANICAL PROPERTIES

The "Caruna," as a mixed construction system, has interesting thermal and mechanical properties for current construction. Some research, such as that conducted by Weiser et al. (2020), Volhard (2016), and Vinceslas et al. (2019), has established that the thermal properties of mixed lightened mud and straw construction systems have great potential as an insulator, coating or filling in wall partitions or roofing. As for their thermal performance, this largely depends on the density of the mud and straw mix. However, the possibility has been raised that, with densities over 1200 kg/m$^3$, thermal yields close to 0.150 W/mK can be obtained (Meli et al., 2019).

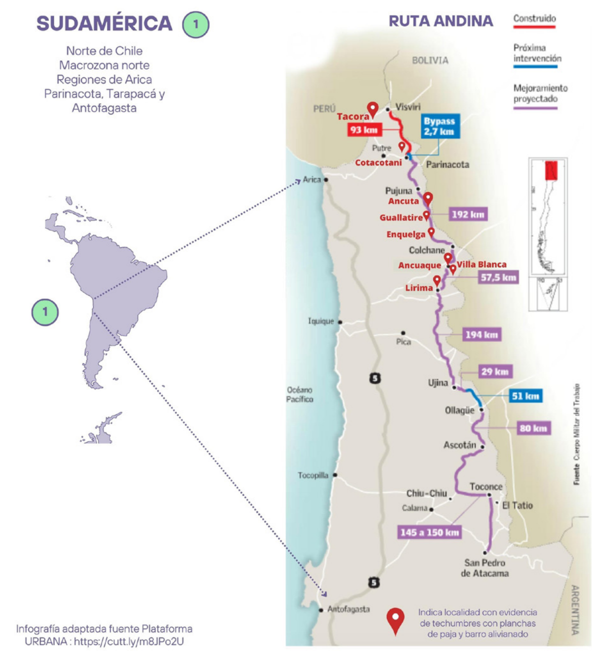


Figure 6. Case study location. The cases from Tacora to Guallatire are found along the A-23, 11, A-211, and A-235 routes of the Province of Parinacota. Source: Adaptation by the authors of the urban platform infographic.

Finally, regarding mechanical strength properties, it has been shown that both the selection and arrangement of the straw fibers improve the material's mechanical strength within the mud mix (Noaman et al., 2020).

## RESEARCH FRAMEWORK AND CASE STUDY

This article is part of the actions undertaken in the research project called "Caruna: Technological Rescue of Sustainable Vernacular Knowledge for Thermal Insulation in the Andean Architecture of Arica and Parinacota," made thanks to obtaining the 2021 Cultural Heritage Fund in the sub-modality of cultural heritage research, registration, and review.

The general goal of the research project was to expand the knowledge to safeguard "Caruna" as ancestral knowledge and the material expression of the constructive practice of the Andean world, which currently has no official identification and is in danger of disappearing from the constructive repertoire of the communities and the vernacular architecture of the Arica and Parinacota region.

The study area is located in the high Andean zone of the Arica and Parinacota Region, at more than 4000 m.a.s.l., specifically in the towns of Tacora, Guallatire, Ancuta, Chua, and Misitune, which are

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part of the General Lagos and Putre commune and are located immediately to the west of the Andes Mountain Range (Figure 6). In this area, the climate is that of the typical high-altitude marginal desert, classified as BWk in the Köppen-Geiger taxonomy (Peel et al., 2007), where the temperature can reach minimums of -15 °C and maximums of 25 °C, with very high levels of solar radiation (more than 1000 W/m$^2$ at noon for almost the whole year) and rainfall concentrated in January and February (Figure 7 and Figure 8).

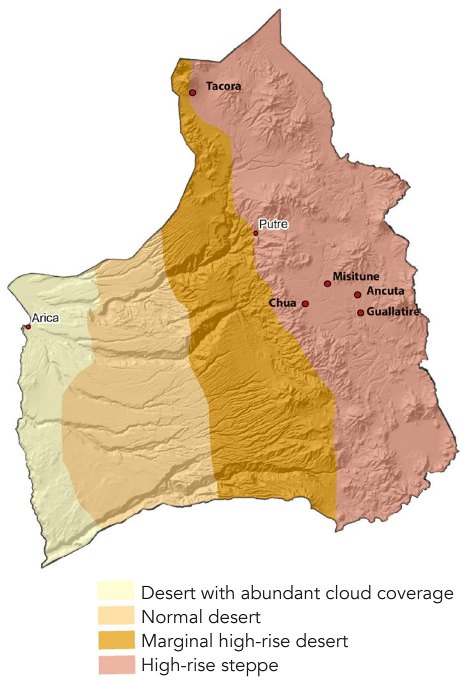


Figure 7. Climatic characterization - High Andean, Arica and Parinacota Region. Source: Base map http://www.gep.uchile.cl

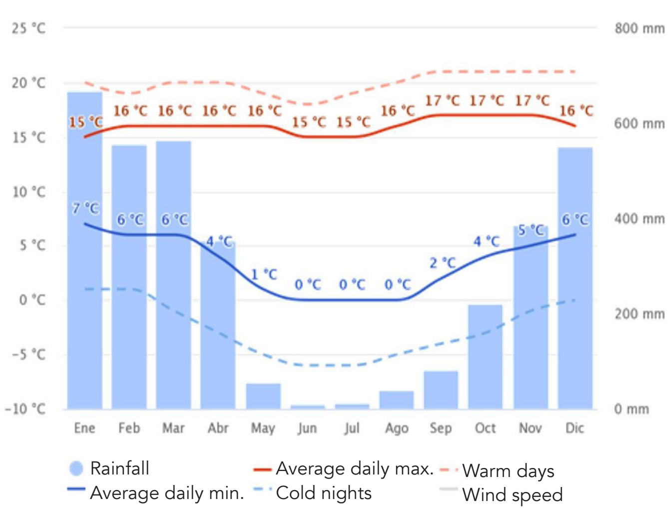


Figure 8. Average temperatures and rainfall. Historical climate and weather data of Tacora. Source: Meteoblue

The case study is located in the town of Tacora, which gets its name from the volcano on whose slopes it sits, which borders with Peru. This sector is characterized by an extraordinary natural and cultural landscape marked by the conditions of a high-altitude desert. Its origin dates back to the Inca colonial formations that took place during the 16th century in response to the advance of the Spanish crown within the territory, giving rise to the homesteads of Ancomarca, Cosapilla, and Tacora. It received influence from the Silver Route and, more recently, in the 19th century, it had its economic heyday linked to sulfur extraction and the connection with the Arica to La Paz railway. From 1967, the extraction of the mineral ceased, and migration to the nearest urban center of Arica began, which continues to this day. Tacora has a permanent population of 4 people, and many others move from the city to the village to celebrate the patron saint festivities of the Virgen del Carmen (Pereira & Yuste, 2019).

# METHODOLOGY

The methodology applied for this study can be divided into four stages. The first is related to making a bibliographic study and a review of information to confirm the presence of different roofing materials in homes in the area of interest. Then, in the second stage, surveys were made to establish the degree of knowledge transferred between generations of residents in the province of Parinacota regarding the construction techniques associated with vernacular roofs. In the third stage, samples of material identified as "Caruna" were obtained, and microscopic characterization and thermal behavior tests were performed on them. Finally, in the fourth stage, studies were made to monitor the thermal behavior of two houses with different insulation materials.

## STUDY METHODOLOGY STAGES

### First Stage: Confirmation of Roofing Materials

The first stage consisted of making a 25-year longitudinal study on replacing roofing materials in rural areas of the province of Parinacota. To do this, the data obtained from the Population and Housing Censuses of 1992, 2002, and 2017 were analyzed, focusing on two categories: a) Housing identification typologies used by the INE (National Statistics Institute), and b) material typologies that make up the different parts of the house.

The analysis consisted of reviewing each of the intercensal periods and then cross-checking

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information based on specific types of materials such as "straw," "coiron," "bulrush," and "sugar cane."

### Second Stage: Knowledge Transfer between Generations

To clarify the effectiveness of knowledge transfer between generations, the first task was to contact the locally schooled young population to determine their knowledge regarding the traditional way of making the "lightened slip-straw ceiling." For this work, the (intentional) sample chosen was 32 students aged 16-17 from the Agrícola Granderos de Putre Technical High School.

This is because strong state policies, instilled in the last two decades to promote the recognition of indigenous peoples, have resulted in a tendency among young people to affirm ethnic identities, which leads to valuing the past, recovering rituals, and resignifying them in urban spaces (Gavilán & Vigueras, 2020; Yáñez & Capella, 2021).

The methodology included, first of all, a theoretical presentation of the material's characteristics, its relevance, and the description of the research (Figure 9). Secondly, to determine the constructive knowledge among the Andean youth, a survey was used considering ten questions divided into two dimensions (Table 1). The first dimension identified previous knowledge about the construction technique, which adopts different names depending on the village's location. These names were obtained from an earlier literature review. The second dimension aimed to clarify the motivation and interest of perpetuating the constructive tradition. In this case, the assertions had a binary answer choice (yes-no).

Figure 9: Milestone of the Launch of the project in the town of Putre, August 2022, application of measuring instrument on constructive knowledge. Source: Preparation by the authors

Table 1: Dimensions of the survey that asks about previous knowledge and the projection of perpetuation of knowledge by the young people of the town of Putre. Source: Preparation by the authors

| Dimension 1: Identification of Prior Knowledge. | Dimension 2: Motivation and Interest to Perpetuate the Constructive Tradition. |
|---|---|
| 1. I have heard the term "caruna" before. | 6. There is a lot of talk about this type of roofing in my family. |
| 2. I have heard the term "tacta" before. | 7. I know other typical construction methods for making roofs. |
| 3. I have heard the term "p'ira" before. | 8. I value constructive knowledge that is typical of the local culture. |
| 4. I have heard the term "t'ili" before. | 9. I would be interested in learning about these construction methods. |
| 5. I know that any of these terms ("caruna," "tacta," "p'ira," "t'ili") are part of some traditional customs. | 10. I would be interested in knowing more about Andean architecture. |

### Third Stage: Determination of Thermal Properties of the "Caruna"

To obtain samples of "Caruna," a mason from the village of Visviri was contacted (Figure 10), who recovered this knowledge from his personal experience and allowed this technique to be incorporated into the restoration of the village of Tacora in 2018. A first-source account was obtained from him about his perspective and assessment of this constructive knowledge, and he also made two "caruna" samples. These samples were subsequently tested in the CITEC laboratory under the NCH 850 Standard Of 2008.

According to the laboratory report, the samples analyzed were defined as a natural material made using slipstraw, referred to by the customer as "Caruna," sized 30cm x 30cm x 0.5 cm, with an apparent dry density of 1252 kg/$m^3$. On the other hand, to obtain the transmittance and resistivity values of the constructive solution, the guard ring method was used according to the procedure described in the same Standard.

The standardized test consists of a central metal plate (hot plate) provided with electric heating. This plate is surrounded by a frame (guard ring), which can be heated independently. The samples

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Figure 10: Aymara mason preparing the samples to be sent to the laboratory. Source: Preparation by the authors

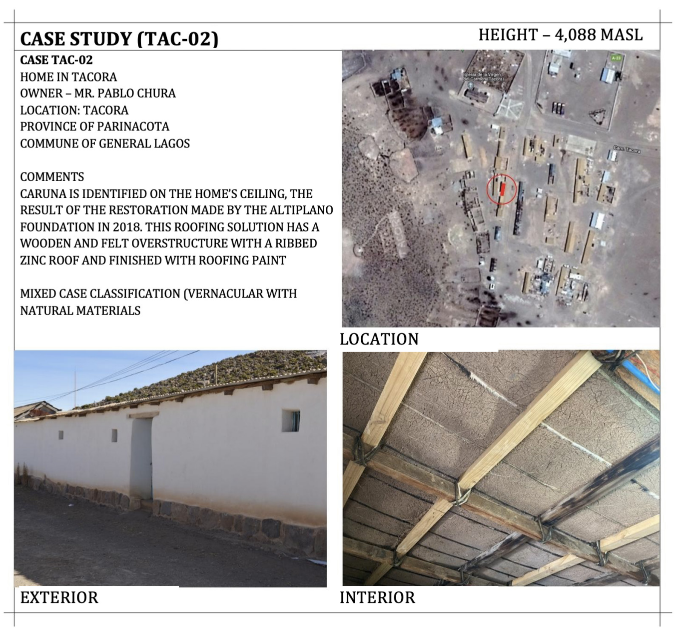


Figure 11. Houses restored with a slip-straw ceiling, Tacora, 2022. Source: Preparation by the authors

(2) are arranged on both sides of the plates, of equal dimension, and with parallel flat faces. The respective water-cooled metal plates (cold plates), whose shape is similar to that of a sandwich, are located adjusted to the samples.

**Fourth Stage: Monitoring the Hygrothermal Behavior**

As mentioned above, this study was carried out in the town of Tacora since, on the one hand, there was a contemporary and recent intervention in the use of the caruna in the restoration of the village in 2018. On the other hand, in this village, it was


Figure 12. Houses restored with a bulrush ceiling, Tacora, 2022. Source: Preparation by the authors

possible to have a contrast material that is also used in the ceiling because it is considered a good thermal insulator, known as "Totora" or bulrush (Aza-Medina et al., 2023; Hidalgo-Cordero et al., 2023).

Four houses were initially chosen to make this contrast: two with a "slip-straw" ceiling and two with a "bulrush" ceiling. Then, a new selection was made, choosing one of each to be monitored (Figure 11 and Figure 12). This process was oriented, first of all, to obtain environmental comfort parameters and data using temperature and humidity variables of the indoor-outdoor climate of the houses that use bulrush, to subsequently compare them with environmental comfort simulations of the houses from the obtaining normalized thermal transmittance data of the "slip-straw" material.

## DATA COLLECTION

As for collecting climate data, these were obtained through a planned field campaign to measure the indoor and outdoor environmental behavior of homes accurately. This campaign identified the points of interest and the tools and equipment needed to collect the information inside and outside the homes.

Inside the four houses chosen, temperature and humidity measuring equipment (Datalogger) were installed and positioned at a roof level. The equipment installed comprises small registration

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thermographs that allow storing a large amount of data for extended periods. The equipment was configured for this research to obtain information every 15 minutes for 5 months (July-November). A comfort measuring station (Testo 400) was also used, which included:

- a globe thermometer for measuring the average radiant temperature
- a hot-wire anemometer for measuring air velocity
- a thermometer for measuring room temperature
- a hygrometer for the measurement of relative humidity
- a processor recorder for the calculation of the expected mean vote

The process to determine the location of the equipment consisted, first of all, of measuring the enclosure where the equipment would be located with a laser meter. This measurement included the area of the room, the windows and doors, and the height of the dwelling. The position where the Datalogger would be located was determined from the information obtained. An attempt was made to keep the equipment focused on the room and away from any source of heat and humidity that could alter the general data. It was fastened with ropes to the roof beams for its installation, and the start of the data reading was inspected. Finally, the equipment code and its position in the room were recorded. On the other hand, for installing the TESTO 400 equipment, it was determined to consider five established measurement points and two registration heights at each point because the indoor environment was not homogeneous.

A digital weather station with a base station and sensors was installed outside the houses to obtain the measurement values. These sensors were located at a measuring point on a mast at a height of four meters. The information obtained by the sensors was sent to the base station through a display console located inside the house, and from there, a real-time reading was obtained through the Wi-fi signal. In addition, the connection of the weather station with one of the team's mobile devices was established to monitor the correct operation of the station and preview the data stored by the sensors. This made it possible to make a first approximation of the recorded meteorological fluctuation.

Table 2 summarizes the technical specifications of each piece of equipment used to measure temperature, humidity, and comfort inside and outside the monitored homes.

Table 2. Detail of the instruments used in the housing monitoring phase. Source: Preparation by the authors

| Equipment | Technical specifications |
|---|---|
| Datalogger Temperature (t°) and Humidity (H%) Elitehc | T° measuring range: +60°C ~30°C (Internal sensor) -40°C~+85°C (external)<br>H% range: 10% - 99%<br>Accuracy: ± 0.5°C<br>Resolution: 0.1°C<br>Size: 84mm x 44mm x 120mm |
| Testo 400 set comfort multifunction instrument | Digital CO2 probe<br>-Digital turbulence degree probe<br>-150 mm globe probe, TP type K, for measuring radiant heat |
| Wireless Communication Weather Station 111-METWIFI | Indoor t° range: 0°C to 50°C<br>Outdoor t° range: -30°C to 65°C<br>H% range: 1% – 99% RH<br>Anemometer wind speed: 0-50 m/s<br>Rain gauge: 0 - 9,999 mm<br>Brightness range: 0-400,000Lux<br>Pressure: 300 – 1100 hPa |

# RESULTS AND DISCUSSION

## LIST OF MATERIALS USED IN ROOFS

The analysis of census data from the 1992-2017 period on the materiality of housing focused on the province of Parinacota and showed a decrease in the presence of plant materials as insulators in the roofs of housing. This statement is reflected in Table 3, which shows that out of a total of 180 homes surveyed between 1992 and 2017 and classified as "indigenous housing," in 1992, there were 134 homes (74% of the total sample analyzed) that used this type of insulating material. In 2002, this number was reduced to 37 homes (20.5%), and in 2017, only nine houses had vegetable insulation on their roofs, representing 5% of the total.

The analysis also determined an inversely proportional relationship between using plant materials and the roofing materiality coated with metal or composite sheets (zinc, copper, fiber cement). This type of roofing is initially and primarily related to the kind of housing classified as a "house" and, to a lesser extent, with "traditional indigenous housing." However, in 25 years (1992 – 2017), the total number of homes with a roof made of zinc plates and fiber cement reached 929, showing a progressive increase in the presence of these materials in the highland areas (Table 4).

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Table 3. Roofing material: Straw, coiron, bulrush, or cane, Province of Parinacota, (Rural) - Population and housing census data for 1992, 2002, and 2017. Source: Preparation by the authors

| Presence of vegetation-based roofing in different types of housing | 1992 | 2002 | 2017 |
|---|---|---|---|
| Other types of private housing | 0 | 0 | 0 |
| Single-slope roof, improvement, ranch, or pent-roof | 1 | 0 | 0 |
| Room in an old house or tenement | 0 | 0 | 0 |
| Indigenous Housing (Ruka, pae pae, or other) | 134 | 37 | 9 |
| House | 23 | 0 | 0 |

Table 4. Roofing material: zinc plates, copper, fiber cement, etc. Province of Parinacota (Rural) Data Population and Housing Censuses for 1992, 2002, 2017. Source: Preparation by the authors

| Presence of zinc plates, copper, fiber cement, etc., in different types of housing | 1992 | 2002 | 2017 |
|---|---|---|---|
| Other types of private housing | 2 | 3 | 3 |
| Single-slope roof, improvement, ranch, or pent-roof | 2 | 32 | 11 |
| Room in an old house or tenement | 1 | 16 | 2 |
| Indigenous Housing (Ruka, pae pae, or other) | 93 | 94 | 101 |
| House | 314 | 378 | 237 |

Regarding the materiality of the exterior walls, 36.36% are brick houses, 27.27% are stone and clay, and the remaining 36.36% are adobe. Compared with the data provided by the INE regarding the roofing material composition, this sample indicates that even though the leading roofing material is zinc sheeting, the ceilings of traditional homes have a high percentage of straw and mud.

## TRANSMISSION OF KNOWLEDGE BETWEEN GENERATIONS

Analyzing the data obtained through the surveys, it can be confirmed that the students are mostly unaware of this constructive technique. For example, the question about whether they know the term "t'ili" obtained 24% recognition, this being the most well-known technique. On the other hand, the question about the association of any of these terms ("caruna," "tacta," "p'ira," "t'ili") with roofs, obtained 67% of mentions (Figure 13).

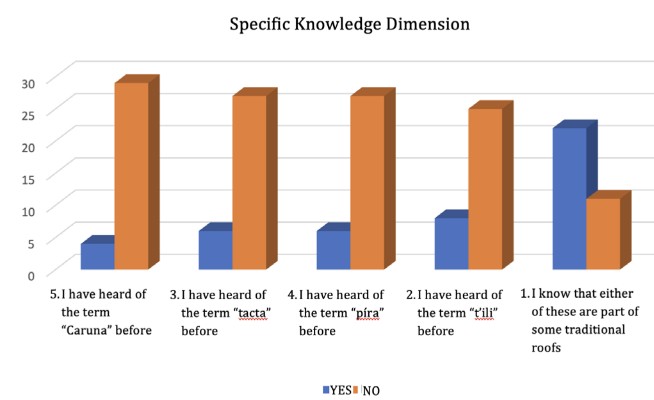


Figure 13. Association between the name of the construction system and the local names of the "lightened slip-straw" technique among Putre's younger population. Source: Preparation by the authors

Regarding the second dimension, a lack of knowledge of the caruna and the other general typical construction techniques can be identified, as, in both points, more than half of the surveyed population refers to not knowing about them (67% and 55%, respectively). This situation contrasts with 97% who find value in this knowledge and 85% who directly express interest in learning about this and other traditional Andean construction techniques (Figure 14).

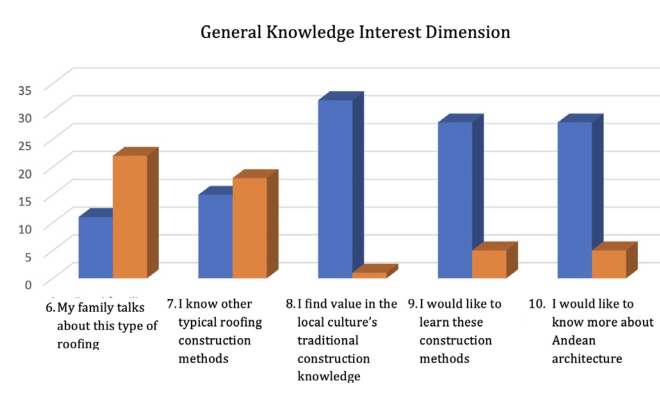


Figure 14. The number of responses from students regarding the assessment of typical local culture constructive systems. Source: Preparation by the authors

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# RESULTS

## THE TESTS AND MONITORING WORK

To determine the thermal behavior of a composite material, as in this case, a laboratory test result is needed that can be used in the construction permit procedures, as indicated by current regulations (MINVU, 2006).

For the case of "caruna", the sample tested in the laboratory consisted of a natural material made from mud straw, 30 cm x 30 cm x 0.5 cm in size, with an apparent dry density of 1252 kg/m³. The laboratory test was run following the NCh 851 standard. In this, the sample reached a linear thermal conductivity value of 0.1477 W/mK. Regarding its apparent density (Table 5) and characterization as a lightened material, the reference value obtained is above 52 gr., as Wieser et al. (2020) pointed out.

Table 5. NCh 851 Linear thermal conductivity test results - "Caruna" (mud-straw) test piece. Source: Preparation by the authors

| Linear thermal resistance (r) | 0,0359 | (m K/ W) |
|---|---|---|
| Thermal conductivity (λ) | 0,1477 | (W/ m K) |
| Dry material density (δ) | 1252 | (Kg/m 3) |
| Material humidity (H) | 22,32 | (%) |

Table 6 shows the linear thermal conductivity reference values. According to the results obtained through laboratory testing, the data on the value result for the "caruna" test piece is located within the range of materials with available standardized information. The table's data indicate for the transmittance values that the greater the magnitude, the lower the insulating capacity the material has. An enclosure with a good insulating material (5-8 cm) reaches transmittance values of around 0.6-0.4 W/m² K.

The roofing enclosures commonly used in Andean dwellings are lightweight zinc, clay tile, or wooden roofs. In some cases, the use of concrete slabs in recently built housing is observed. The lightweight roof used by caruna achieves a better thermal performance than uninsulated slabs and is comparable with earthen or wooden roofs. As for sheet metal roofs, the advantage is even more significant, improving the value of the thermal wave lag, which is an indicator of the thermal inertia of

Table 6. Reference values of transmittance and thermal lag for roofs. Source: Preparation by the authors

| Material | Thickness (cm) | Transmittance (W/m2 K) | Time Lag |
|---|---|---|---|
| Caruna 5 mm + fieltro 1 mm + zinc 2 mm | 0,8 | 5,75 | 30 min |
| Caruna 10 mm + fieltro 1 mm + zinc 2 mm | 1,3 | 4,76 | 40 min |
| Caruna 20 mm + fieltro 1 mm + zinc 2 mm | 2,3 | 3,63 | 1 h 30 min |
| Cement roof | 15 | 4,48 | 2 h 50 min |
| Zinc roof | 0,2 | 7,14 | 1 min |
| Earth roof | 7 | 3,6 | 1 h 11 min |
| Wooden roof | 5 | 2,56 | 1 h 30 min |

the roof. This result is aligned with the results obtained by other similar studies (Palme et al., 2012; Palme et al., 2014) that show that, by increasing the thickness of the caruna, the thermal performance can improve proportionally, being able to reach and exceed the thermal resistance values typically offered by wooden roofs or with other natural insulators such as, for example, cork.

Figure 15, on the other hand, shows the monitoring results for a typical day in July, with indoor temperature oscillations between 1 and 22 degrees, both for the "caruna" roof and the bulrush roof. Although this result shows a certain degree of night cooling below levels considered acceptable to being in comfort, it evidences that the thermal insulation offered by the caruna is similar to that provided by other materials traditionally used in housing roofs of the high Andean areas.

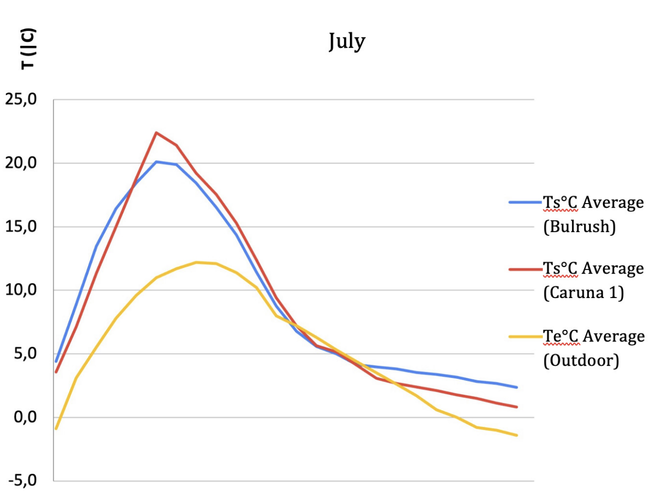


Figure 15. Performance monitoring chart, a typical day in July. Source: Preparation by the authors.

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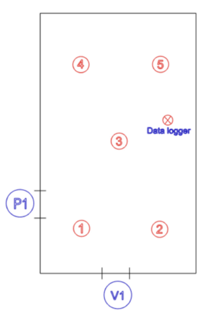
Regarding comfort monitoring, Figure 16 and Figure 17 show the results obtained in the measurements carried out in July 2022 with the TESTO 400 equipment. In these, values of 70 W/m² were used as metabolic activity and 1 CLO as thermal resistance of clothes to estimate the predicted mean vote (PMV), the standard measurement of the degree of comfort in indoor spaces (Fanger, 1973). Despite a time lag in the data collection, the results show a somewhat better thermal behavior for the "caruna" roof, with radiant average temperatures between 18 and 20 degrees Celsius, confirmed in a PMV indication of -0.8 (slightly cool environment).

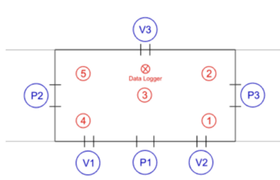
Case 1: "Bulrush" ceiling (natural fiber)




| | | INICIO MEDICIÓN: | | 10:10 am | | |
|---|---|---|---|---|---|---|
| PUNTO DE MEDICIÓN | | Ta (ºC) | TMR (ºC) | HR (%) | v (m/s) | PMV |
| INFERIOR | P1 | 12,8 | 15,9 | 33 | 0,1 | -1,63 |
| | P2 | 11 | 15,8 | 36 | 0,1 | -1,82 |
| | P3 | 11,3 | 14 | 33 | 0,1 | -1,98 |
| | P4 | 11,4 | 14,8 | 34 | 0,1 | -1,89 |
| | P5 | 11,5 | 15,2 | 33 | 0,1 | -1,84 |
| SUPERIOR | P6 | 10,8 | 15,9 | 34 | 0,1 | -1,84 |
| | P7 | 11,1 | 15,8 | 37 | 0,1 | -1,81 |
| | P8 | 11,4 | 14,4 | 32 | 0,1 | -1,93 |
| | P9 | 11,5 | 15 | 39 | 0,1 | -1,84 |
| | P10 | 11,5 | 15,3 | 36 | 0,1 | -1,82 |

Figure 16. Floor plan of the house with "bulrush" ceiling indicating data collection points. Source: Preparation by the authors.

Case 2: "Caruna" ceiling (lightened slip-straw)




| | | INICIO MEDICIÓN: | | 12:00 pm | | |
|---|---|---|---|---|---|---|
| PUNTO DE MEDICIÓN | | Ta (ºC) | TMR (ºC) | HR (%) | v (m/s) | PMV |
| INFERIOR | P1 | 17,7 | 20,6 | 29 | 0,1 | -0,65 |
| | P2 | 17,3 | 19,9 | 26 | 0,1 | -0,79 |
| | P3 | 17 | 19,8 | 29 | 0,1 | -0,81 |
| | P4 | 16,9 | 19,9 | 28 | 0,1 | -0,81 |
| | P5 | 16,8 | 20 | 30 | 0,1 | -0,81 |
| SUPERIOR | P6 | 17,5 | 20,9 | 30 | 0,1 | -0,64 |
| | P7 | 17,1 | 19,8 | 31 | 0,1 | -0,79 |
| | P8 | 17 | 19,8 | 31 | 0,1 | -0,8 |
| | P9 | 16,8 | 20 | 33 | 0,1 | -0,79 |
| | P10 | 16,7 | 20,1 | 40 | 0,1 | -0,76 |

Figure 17. Floor plan of the house with "caruna" ceiling indicating data collection points. Source: Preparation by the authors.

# CONCLUSIONS

This research has allowed us to rediscover a constructive ancestral knowledge defined as "lightened slipstraw ceiling," which has good thermal insulation characteristics compared to other materials that fulfill a similar role. The results allow resuming the ethnographic discussion in the 1970s in the Andean highlands and link it with the revaluation and reappropriation processes of the traditional ways of living at altitude. Undoubtedly, the safeguarding and dissemination of this knowledge will allow paying attention to how to preserve a material, symbolic, and domestic tradition that has been presented as a strategy against the extreme climate of the high-altitude tundra in the context of the desert above the altitude of 4,000 m.a.s.l.

From the perspective of the technological reappropriation of ancestral knowledge, in the small sample regarding Andean youth's knowledge of these, a clear representation of the risk of losing this other knowledge due to their lack of transmission could be found. However, fortunately, young people express their willingness and interest in approaching this type of learning, opening an essential space for conserving the constructive tradition. With this, two key points can be identified that give more strength and value to the realization of this project and increase the possible positive impact on the perpetuation and safeguarding of the use and practice of the elaboration of the "caruna" or "lightened slip-straw sheeting."

The longitudinal reading of the data on the composition of roofing materials obtained from the Population and Housing Censuses of Chile, taken in 1992, 2002, and 2017 for the Province of Parinacota, has made it possible to see the impact of the technological substitution of roofing materials in the typology defined by the INE as "traditional indigenous housing." This shows a drastic drop in the use of natural materials in contrast to the increased use of industrialized materials such as zinc and other sheets no larger than 1.10 m long. Despite these results, the recurrence of lightened slip-straw sheets is also highlighted as a common practice in the definition of the Andean housing space at altitudes above 4,000 m.a.s.l.

As for the material's thermal properties, the tests carried out have shown that the resistance value of the compound to the passage of heat is more than acceptable for a natural insulator, which translates into an onsite performance similar to that of other traditional structures. The possibilities offered by Caruna regarding the sustainability of the housing construction process in high Andean villages are very high, thanks to its mixing of local mud and straw. Modern sandwich-type roofs, even if they can incorporate insulating materials, will have a higher environmental cost due to the impacts generated by manufacturing and transportation at the installation site. Even the bulrush requires material displacements of a few hundred kilometers to be installed in the towns of Tacora, Guallatire, and their surrounding areas.

Finally, it is estimated that the lightened ceiling manufacturing processes can be gradually transformed into more consolidated processes so the ancestral knowledge of craft techniques can be incorporated with the most contemporary ones. However, more is needed to ensure that a highly industrialized product is reached that would significantly increase the environmental impact. On the contrary, the appropriate management of knowledge and its transfer between generations, as well as the eventual presence of some small local enterprise that is respectful of the fragile ecosystem of the Andean desert, could contribute to the consolidation of the manufacture, distribution, and use of this important material as a natural thermal insulator for constructions located in these towns and, more in general, in the entire highland macro-region.

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## BIBLIOGRAPHIC REFERENCES

Aza-Medina, L. C., Palumbo, M., Lacasta, A. M., & González-Lezcano, R. A. (2023). Characterization of the thermal behavior, mechanical resistance, and reaction to fire of Totora (Schoenoplectus Californicus (C.A. Mey.) SoJAK) panels and their potential use as a sustainable construction material. *Journal of Building Engineering*, 69, 105984. https://doi.org/10.1016/j.jobe.2023.105984

Charca, S., Noel, J., Andia, D., Flores, J., Guzman, A., Renteros, C., & Tumialan, J. (2015). Assessment of Ichu fibers as non-expensive thermal insulation system for the Andean regions. *Energy and Buildings*, 108, 55-60. https://doi.org/10.1016/j.enbuild.2015.08.053

DIRECCIÓN DE ARQUITECTURA, MINISTERIO DE OBRAS PÚBLICAS. (2016). *Guía de Diseño Arquitectónico AYMARA para edificios y Espacios públicos*. https://repositoriodirplan.mop.gob.cl/biblioteca/server/api/core/bitstreams/cd7a8ae4-2abf-4b46-95f7-1edbf9e69f73/content

Fanger, O. P. (1973). *Thermal Comfort: Analysis and Applications in Environmental Engineering*. Danish Technical Press.

García M., Castro, V., Belmonte, E., Muñoz, T., Santoro, C., & Echeverría, J. (2018): Etnobotánica y territorio en el pastal de Mulluri (Norte de Chile). Las enseñanzas del pastoreo Aymara. *Latin American and Caribbean Bulletin of Medicinal and Aromatic Plants*, *17*(5), 522-540. https://blacpma.ms-editions.cl/index.php/blacpma/article/view/135

Gavilán, V. & Vigueras, P. (2020). Embodied temporalities and memories in aymara rituals in northern Chile. *Cultura y religión*, *14*(2), 100-127. https://dx.doi.org/10.4067/S0718-47272020000200107

Hidalgo-Cordero, J. F., & Aza-Medina, L. C. (2023). Analysis of the thermal performance of elements made with totora using different production processes. *Journal of Building Engineering*, *65*, 105777. https://doi.org/10.1016/j.jobe.2022.105777

Jorquera, N. (2014). Culturas sísmicas: estrategias vernaculares de sismorresistencia del patrimonio arquitectónico chileno. *Arquitectura del Sur* 32(46), 18–29. http://revistas.ubiobio.cl/index.php/AS/article/view/739

Meli G., Onnis S., & Wieser M. (2019). Introducción en el contexto peruano de un nuevo sistema constructivo con madera y tierra alivianada. Seminario Iberoamericano de Arquitectura y Construcción con Tierra, 19. FUNDASAL / PROTERRA. p. 604-613, https://repositorio.pucp.edu.pe/index/handle/123456789/187747

MINVU. (2006). *Manual de aplicación de reglamentación térmica (Ordenanza General de Urbanismo y Construcciones)*. https://es.scribd.com/document/50958657/Manual-de-Aplicacion-de-la-Reglamentacion-Termica-Chile-Parte1

Noaman, M. F., Khan, M. A., & Ali, K. (2022). Effect of artificial and natural fibers on behavior of soil. *Materials Today: Proceedings*, *64*, 481-487 https://doi.org/10.1016/j.matpr.2022.04.954

Palme, M., Guerra, J., & Alfaro, S. (2012). Earth of the Andes Comparing techniques and materials used in houses in San Pedro de Atacama. *En PLEA 2012 - 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture*. https://www.researchgate.net/publication/250917170_Earth_of_the_Andes_Comparing_techniques_and_materials_used_in_houses_in_San_Pedro_de_Atacama

Palme, M., Guerra, J., & Alfaro, S. (2014). Thermal Performance of Traditional and New Concept Houses in the Ancient Village of San Pedro De Atacama and Surroundings. *Sustainability* *6*(6), 3321-3337. https://doi.org/10.3390/su6063321

Peel, M. C., Finlayson, L., & Mcmahon, T. A. (2007). Updated World Map of the Köppen-Geiger Climate Classification. *Hydrology and Earth System Sciences*, *11*(5), 1633-1644. https://doi.org/10.5194/hess-11-1633-2007

Pereira, M. & Yuste, B. (2019). *El último Mallku. Paisaje cultural de Tacora*. Fundación Altiplano. https://issuu.com/fundacionaltiplano/docs/el_u_ltimo_mallku._paisaje_cultural_de_tacora

Šolc, V. (2011). Casa Aymara en Enquelga. *Chungara*, *43*(1), 89-111. https://doi.org/10.4067/s0717-73562011000100006

Vinceslas, T., Colinart, T., Hamard, E., Menibus, A.H., Lecompte, T., & Lenormand, H. (2019). Light Earth Performances for Thermal Insulation: Application to Earth–Hemp. *Earthen Dwellings and Structures*, 357-367. https://doi.org/10.1007/978-981-13-5883-8_31

Volhard, F. (2016). *Light earth building: A handbook for building with wood and earth*. Birkhäuser. https://doi.org/10.1515/9783035606454

Weber, D.J., Zambrano, F.C., Villar, T.C., & Dávila, M.B. (1998). *Rimaycuna Quechua de Huánuco: Diccionario del Quechua del Huallaga con Índice Inglés (Serie Lingüística Peruana)*. Instituto Lingüística de Verano.(pp. 126)

Wieser, M., Onnis, S., & Meli, G. (2020). Desempeño térmico de cerramientos de tierra alivianada : posibilidades de aplicación en el territorio peruano. *Revista de Arquitectura*, *22*(1), 164–174. https://doi.org/10.14718/RevArq.2020.2633

Yáñez, C. A., & Capella, C. (2021). Construcción de identidad personal en niños y niñas aymara residentes en Chile. *Revista De Psicología*, *30*(2). https://doi.org/10.5354/0719-0581.2021.60644