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Adobe Constructions – Colonial Chilean House

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Abstract
This article presents part of the doctoral research carried out on raw earth constructions in the central zone of Chile between the 16th and 19th centuries, especifically in the so-called Chilean Colonial House, or Casa Patronal. The origin of this building typology is attributed to construction models and systems from Spain, such as the case of the Andalusian House, which was inserted in the construction culture of Chile since the foundation of the first cities of the country. Thus, the cities were continously evolving, firstly characterized by a large number of constructions of defense, but later after, diverse types of constructions were introduced, such as houses, churches and enclosure walls. Currently, more than fifty of these houses are preserved, which have resisted the historical seismic action recorded since the 16th Century, and whose last major event occurred on February 27, 2010, magnitude of 8.8 Mw, which revealed the precariousness and abandonment of the country's built heritage, especially of these types constructions. The methodology used for the study includes four stages. Firstly, the research and bibliographic review; secondly, field researches and collection of records in various Houses in the central zone of Chile; thirdly, the Systemic Method was applied in order to develop a diagnosis of the current situation of the case studies. This stage includes the application of the Chilean regulation for Constructions of Raw Earth NCh3332 of the year 2013. Finally, the fourth stage is focused on the analysis and discussion of the results, including conclusions regarding this matter. This document includes the progress of the study carried out up to the third stage of the doctoral research, which is the first part of the "Initial cycle of knowledge of buildings." This study aimes to provide and expand the range of tools for the diagnosis of the current situation of buildings, based on the analyses performed in three cases studies.

Keywords: *raw earth; heritage; earth architecture; adobe masonry.*

1. Introduction

Construction with raw earth in Chile dates back to periods long before the arrival of the Spaniards to the country. Evidences of construction in the so-called "Great North" has been found, which includes the current regions of Arica and Parinacota, Tarapacá, and Antofagasta, by the 1000 BC – 500 AD (Jorquera Silva, 2020), regions where mud or raw earth was worked manually.

By the 100 AD, settlements in the north of Chile are identified, such as the Ramaditas and the Guata-con-do (Urbina A. et al., 2012). This constructive culture based on raw earth is extended and consolidated throughout the north and center of the country, up to the current Region of Ñuble, adapting its structures to vegetation and climate diversity, very variable throughout Chile.

During the first half of the 16th Century, the arrival and first settlements of the Spanish in Chile took place, whom doubted to set permanently due to the lack of gold, the most desired metal by that time. During the Conquest of America (Lacoste et al., 2014), conquerors decided to built precarious constructions characterized by straw and mud huts, following the typology given by the struc-

tures of the indigenous people who already inhabited the place. The city of Santiago (Santiago del Nuevo Extremo) was founded in February 12th, 1541, in the Central Valley of the country, aside of the Mapocho River. By Septembre of the same year, the city suffered its first devastation, which was caused by the uprising of the indigenous people who destroyed the city's main buildings (Lacoste et al., 2014). A struggle for survival and a permanent war began that accompanied the Spanish conquerors in their efforts to conquer this territory. As an answer, they built the first forts with adobe bricks and thick walls.

The factors that explain the success of this construction system based on adobe bricks were: (i) the abundance and availability of the raw earth, (ii) the knowledge of techniques linked with it, (iii) and the strength performed by the structures in comparison to other methods such as straw or mud, delivering then a higher level of protection and security.

From the consolidation of settlements and a way of life based on the rural economy of this new country, the Hacienda was arised, an economic and familiar system formed by a Main House, "Casa Patronal," which was surrounded by service spaces and the so-called "Tenant Houses" (Benavides C., 1981).

A significant group of colonial or patron houses, nearly a hundred, were conserved until the 1980s, whose record is presented in the book "Patron Houses: rural architectural ensembles v.2" (Benavides Courtois et al., 1981).

Four years later, on March 3, 1985, an earthquake of 7.5 Ms in the country's central zone destroyed a large part of the heritage built in adobe preserved until that date.

Finally, the last great seismic event in the country occurred on February 27, 2010. An earthquake of Magnitude 8.8 Mw, acording to the information registered by the National Seismological Center of Chile (www.csn.uchile.cl), severely affected the central-southe area of the country and caused serious damage to a great number of the constructions with historical value (Consejo de Monumentos Nacionales & Corporación Patrimonio Cultural de Chile, 2010), particularly the adobe masonry constructions.

After the damages that occurred in the adobe constructions during this last earthquake, the need to evaluate and structurally analyze its state of architectural-structural conservation were arised with the view to take appropriate repair and reinforcement actions for this type of construction. In this sense, the Government of Chile has implemented action mechanisms through public investment to develop restoration projects for a series of heritage buildings. Aditionally, the development of regulations at the national level provides evaluation mechanisms and structural analysis for this type of construction.

From the implementation of this regulatory framework given by the NCh3332 of 2013 and the severe damages observed in adobe constructions, this doctoral research was arised. The Systemic Method is applied to deliver a diagnosis of the current situation. The method is based on the knowledge of the building, its environment, and history, which allow characterization and subsequent valorization to achieve the architectural-structural diagnosis of existing buildings.

2. Methodology

The methodology consists in four stages. Firstly, research and review of national bibliographic references about adobe's history and its use as constructive material for housing. Review and research of international literature in regards of adobe as main construction's material for historic houses.

The second stage consists in the compilation of constructive information about existing mansions, which are currently preserved and worked in the professional practice for some years.

The third stage with the collected information and data from the first two stages, the first part of the systemic method of existing constructions will be

applied for making a diagnosis of current conditions, focusing on the status of houses' structural condition. Structural analysis using the Chilean standard NCh3332, modeling and structural analysis using computer programs will be used as tools. Finally, the fourth stage consists in doing a comparison between the structural results' analysis versus the existing condition at the time of the inspection of the houses studied, allowing the existence of areas with greater or lesser vulnerability to seismic action, among other aspects of the construction system, to be contrasted.

3. Development

This section presents the typological model under investigation and the evaluation methodology applied to three case studies, which correspond to houses in the central zone of Chile.

3.1 Chilean Colonial House

3.1.1 Origin

The house model was imported from the Iberian Peninsula by the Spanish con-querors, particularly from the region of Andalusia, whose house model with a patio "Casa Andaluza o Hispana" (Irarrázabal, 2012), comes from the Roman House and the Greek House. Although the model of the patio house, corral house, and Sevillian house originally had more than one level, the model was adapted to the construction of one level with thick walls of adobe bricks and roofs of logs of wood. Initially, the roofs were built with tied timbers covered with straw, but later by the mid-eighteenth Century this model evolved into trusses covered with clay tiles (Yantorno & Pasmiño, n.d.).

The seismicity of the country guides the evolution of the model. During the first 100 years of the Captaincy of Chile, the consequences of large earth-quakes were suffered. The following table shows those that stand out (Centro Sismológico Nacional & Universidad de Chile, 2022).

Fecha	Ciudad	Magnitud
17/03/1575	Santiago	7,3Ms
13/05/1647	Curicó	8,5Ms
15/03/1657	Concep.	8,0Ms
12/07/1687	Los Andes	7,3Ms
08/07/1730	Valparaíso	8,7Ms

Table 1. Registro grandes sismos siglos XVI a inicios siglo XVIII (Record of large earthquakes from the 16th century to the beginning of the 18th century.) Source: http://www.csn.uchile.cl/sismologia/grandes-terremotos-en-chile/

The earthquake that impulsed one of the most significant changes in the way of building in adobe was the so-called "Great Earthquake" or "Earthquake of May" on May 13, 1647 (Amunátegui, 1882), which almost destroyed Santiago, with the exception of two buildings: the Church and the Convent of San Francisco, which are preserved to the present day. This fact drives new constructions to the increasing the width of walls and decreasing their height.

3.1.2 Characteristics and evolution

The first models were given by rectangular floors with three patios and the main entrance hall.

Three significant periods of evolution of the Chilean Colonial House are distinguished. The first, from the mid-16th to the 18th century, where the widths of the walls were increased, and wooden reinforcement pieces, called chains, were included, particularly where the walls meet and areas with span openings. These strategies were consequence of the earthquakes that had destroyed the first constructions and which led to continuously improve these structures during reconstruction processes of the cities.

In the second period, from the end of the 18th Century to the beginning of the 19th Century, the interior corridors were included in the model as well as a second level in the whole volume of the

main façade, which in the previous period only had a mezzanine to high-light the entrance, and in some rare cases covered the entire façade.

Finally, the third period covered until the second half of the 19th Century. In this period is where the most critical changes to the model of the house were took place. Among the main alterations are the changing of use of the first patio, which passes to the particular use of families and not for public service. Aditionally, the corridors were built on all four sides of the inner courtyards and, in some cases, the patios were roofed with skylights. Similarly, the second floor was extended in a U-shape along with the first patio (Secchi & Salas, 1952).

3.1.3 Main construction elements

Walls

The adobe masonry walls were built with bricks arranged with rope or head; the approximate dimension of this bricks is 60 cm long, 30 cm wide, and 7 to 10 cm high. However, walls of 100 to 120 cm wide have been found. Clay mortar and two layers of clay coating, a thick inner layer with a high level of vegetable fibers, and a thin outer layer. The walls are connected perpendicularly with the lock of their bricks and with ladders or wooden chains, which are distributed to thirds of the height in the meeting of the walls, crowning the upper level of the floor. In some cases, these reinforcing elements may be found throughout the wall and not only in these meeting elements.

Fig. 1. Casona Quilapilún adobe wall. (Source: Contreras & Jofré, 2016)

Foundations

The system is given by continuous foundations under the adobe walls, built in stone with mud mortar as a joining element. In other cases the foundation were built only with rocks stacked orderly, with pieces of certain homogeneity and size.

The minimum burial depth registered is 1 metre. On the upper level, it is possible to find a few rows of rectangular-shaped stones or fired clay bricks (minimum three rows), which give a horizontal level to the base of the adobe wall and isolate it from humidity at the ground level.

The cover

The roof is made up of trusses built by a pair of wood logs with a brace at the base or halfway up, as it is illustrated in figure 2. The trusses are distributed at a maximum distance of one meter. Above the trusses are installed wooden boards, which is the surface to directly receive the clay tiles.

Fig. 2. Example of roof trusses on adobe walls. (Source: Contreras & Jofré, 2016)

Corridors and patios

The existence of corridors is a variable characteristic within the complex since they generally are located in the interior perimeter of the house, around the patios. These corridors are developed as a continuation of the main roof, extending with

ieces of wood that connect to the walls of the inner ring of the adobe walls.

Fig. 3. Example of corridors. (Source: Contreras & Jofré, 2016).

As for the patios, the model may vary. However, the most common to find is with three patios. The main uses are: (i) the first patio for private use, for owners or patrons of the house; (ii) the second patio for service, such as kitchen and other domestic uses of daily life, and (iii) the third patio, which was used for receiving cars or guests, generally aimed to the movement of floats and with services purposes (Benavides Courtois & Universidad de Chile. Departamento de Historia de la Arquitectura, 1981).

3.2 Systemic method applied to the "diagnosis of current situation"

The method is based on the knowledge of the building, its environment, and history, which allow characterization and subsequent valorization to achieve the architectural-structural diagnosis of existing buildings (González Moreno-Navarro et al., 2018).

A more precise definition of the meaning of "system" is that it can be defined or understood from the description of its composition (C), environment (E), structure (S), and mechanism (M). In this case, the tool used by the method is "Value," as they point out in their book "The Systemic Method of Interven-tion in Existing Buildings" (González Moreno-Navarro et al., 2018). In this respect, the value allows us to understand what moves a promoter to build, modify and/or rehabilitate in a building. Therefore, it helps to understand the motivation and causes of a restoration or rehabilitation process.

From this, the first part of the method will be applied, which corresponds to the Initial Knowledge Cycle of the Building and includes the following research processes for the case studies:

3.2.1 First approximation

It is defined as the first approach to the building, initial visits, and identification of spaces and the site itself.

3.2.2 Characterization

Compilation of antecedents of the construction and history of the property: history, place, promoter, function and use, classification of the building and its parts.

3.2.3 Initial valuation

- Quantifiable values: evaluation of the current architectural values, current use of the building, application of the Chilean standard for constructions of raw earth NCh3332.Of2013. Location. Ecological and economical aspects.
- Documentary values and subjective values.

Application NCh3332 Raw Earth Constructions

The NCh3332 standard, "Structures - Intervention of heritage constructions of raw earth - Structural project requirements," came into force in 2013, being the first regulation at the national level in the field of heritage constructions (NCh3332 - Estructuras -Intervención de Construcciones Patrimoniales de Tierra Cruda - Requisitos Del Proyecto Estructural, 2013).

Structural analysis

This regulatory framework provides the guidelines for evaluating the current state and the design of the intervention project, considering structural and patrimonial criteria.

The patrimonial criteria include the com-patibility of materials, reversibility, and case-by-case evaluation. The structural criteria are based on maintaining or restoring the resistant capacity. Aditionally, it is also considered the structural performance of the structure in previous earthquakes in order to avoid collapse elements and to develop minimal intervention proposals, compatible and reversible with the original materials.

In this respect, the standar points out actions of critical importance to carry out an adequate intervention, such as:

- Critical survey of the existing construction.
- Diagnosis of the current state of conservation.
- Structural analysis in the current condition, which considers structural modeling, design, and geometric verifications. Aditionally, in the case of calculating the basal shear stress, it considers three main factors: the previous performance of the structure (k1), the building occupancy (k2) and floor type (k3). Finally, for the seismic demand coefficient, C gives us a value for this type of material, particularly C=0.1.

In conjunction with the evaluation and knowledge of the building, this structural analysis allows to obtain a diagnosis of the current state of conservation focused on the structural and architectural perform of each the cases study.

The cases of study are:

- Casona Quilapilún
- Casa de los Diez
- Casa Piñera

Fig. 4. Casona Quilapilún, tower inside view. (Source: Contreras & Jofré, 2016)

Fig. 5. Casa de los Diez main façade. (Source: Jofré, 2019)

Fig. 6. Casa Piñera main façade. (Source: Sáez 2013)

4. Results and Conclusions

4.1 Results

Although the investigation is still ongoing, the evaluation carried out preliminarily with the NCh3332 standard indicates that the adobe masonry walls, which are preserved to date, can resist the requesting shear forces and mainly comply with the geometric re-quirements of the regulations.

The results of the structural and normative analysis carried out in the mansions located in the Central region of Chile indicate that there is a relationship between the results obtained with the geometric verification proposed by the standard, which considers the dimension and location of openings, the slenderness of walls, dis-tance between bracing walls, among oth-er considerations, and the most vulnerable sectors that show more significant deterioration in spans and walls.

The vulnerability of elements or areas where regulatory requirements are not met, is confirmed by registering areas with current damage or those that has been repaired and newly damaged due to the last major earthquake.

Despite of the apparent level of deterioration, the studies carried out tells us why these constructions have been preserved up to date, even when have been through major seismic events throughout more than 100 years. Thus, its resistance is given by its solid construction and its original design, which typological model of building was constinously evolving, undergoing improvements over time. Among these improvements can be mentioned the increase in the thickness and height of the walls, the rectangular geometry of enclosures, and patios, and the reinforcements of wood in meeting elementes, as well as the size of the intersection of partitions.

The resistance values of the adobe proposed by the regulatory framework for the resistant capacity of the adobe to compression and shear, although conservative, are presented in the field of structural safety of the evaluated constructions.

On the other hand, a significant difference is observed between those cases studies that have historically carried out adequate maintenance, with an active and permanent operation. Although these cases may present punctual damages, they are preserved in an excellent structural condition due to the conservation actions carried out permanently. In constrast, there are others constructions that have been left in a state of abandonment from the moment they were declared uninhabitable due to damages caused by previous seismic events, in many cases, after inadequate or inexistent protection strategies.

4.2 Future lines of research

- It is proposed to carry out mechanical tests on bricks and adobe walls from different country areas. Since Chile is a country of more than 4000 km in length and the inhabited areas are mainly distributed in the first 3000 km, we can find adobe constructions with a diversity of climates, which go from the desert in the north to a richer biodiversity in the central valley areas. This situation produces different types and qualities of adobe. In this sense, at least three zones of mechanical characterization of adobe has to be proposed: large north zone, small north zone, and central zone.

- Full-scale compression test campaigns for walls, which will provide actual ca-pacities for existing constructions, and background for the future of new build-ings in this material.

- Design a maintenance and conservation plan for projects to rehabilitate adobe buildings, which focuses on eliminating the risks and factors that cause damage in adobe constructions.

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