Patrícia Marchante, Amanda Rivera Vidal

Characterization of Traditional Coatings in Earthen Vernacular Architecture in the Limarí Valley: Their Role in the Conservation of Built Heritage in Chile

Caracterización de los revestimientos tradicionales en la arquitectura vernácula de tierra del Valle del Limarí: Su papel en la conservación del patrimonio construido de Chile

Caracterização dos rebocos tradicionais da arquitetura vernácula de terra no Vale do Limarí: O seu papel na conservação do património construído do Chile

Keywords | Palabras clave | Palavras chave

Earthen heritage, Earthen renders, Preservation, Traditional finishes, Vernacular techniques

Patrimonio de tierra, Revestimientos en tierra, Conservación, Acabados tradicionales, Técnicas vernáculas

Património construído em terra, Rebocos de terra, Preservação, Acabamentos tradicionais, Técnicas vernáculas

Abstract | Resumen | Resumo

Despite its seismic activity, Chile has a large number of heritage buildings built with earth. Their conservation depends on elements such as roofing and foundations, but also on the quality of renders and finishing materials. This study seeks to identify and characterize the coating systems and materials used on the wall surfaces of earthen heritage structures in the Limarí valley, Chile, seeking to contribute to the dissemination, promotion, and preservation of these traditional renders. The case studies included are historic buildings in various Limarí valley villages. Render and plaster samples of earthen built heritage were taken for analysis from a diversity of wall structures (such as adobe, *pandereta,* or *quincha*) and finishing techniques. Despite differences, the conclusions of our fieldwork and sample observations and analysis allow us to identify effective, common coating systems and finishes.

A pesar de la actividad sísmica, Chile cuenta con un gran número de edificios patrimoniales construidos con tierra. Su conservación depende de factores tales como las cubiertas y los cimientos, pero también de la calidad de los revestimientos y de los materiales de los acabados. Este estudio pretende identificar y caracterizar los sistemas de revestimiento y los materiales utilizados en los muros de las estructuras de tierra del valle del Limarí, en Chile, para contribuir a la difusión, promoción y conservación de estos revestimientos tradicionales. Los casos estudiados incluyen edificios históricos de varios pueblos del valle del Limarí. Las muestras de revestimientos que fueron analizadas se tomaron de edificios patrimoniales construidos en tierra. Para su selección se atendió a los diversos tipos de muros (de adobe, *pandereta*, o *quincha*) y de técnicas de acabado. A pesar de las diferencias, las conclusiones del trabajo de campo y de la observación y el análisis de las muestras nos han permitido identificar sistemas de revestimiento y acabado comunes y eficaces.

Apesar da sua atividade sísmica, o Chile tem um grande número de edifícios patrimoniais de terra. A sua conservação depende de elementos como coberturas e fundações, mas também da qualidade dos rebocos e materiais de acabamento. Este estudo procura identificar e caraterizar os sistemas de revestimento e materiais utilizados nas superfícies das paredes das estruturas patrimoniais de terra no vale do Limarí, Chile, procurando contribuir para a divulgação, promoção e preservação destes rebocos tradicionais. Os estudos de caso incluídos são edifícios históricos em várias aldeias do vale do Limarí. Foram recolhidas amostras dos rebocos do património construído com terra, para a análise de uma diversidade de estruturas de parede (tais como adobe, *pandereta*, ou *quincha*), e as diferentes técnicas de acabamento. Apesar das diferenças, as conclusões do nosso trabalho de campo, e as observações e análises das amostras, permitem-nos identificar sistemas de revestimento e acabamento eficazes e comuns.

1. Introduction

In Chile, as in the whole world, earthen construction techniques have existed since ancient times, and they continue today. Thus the forms of buildings can be seen as a reflection of a knowledge that has matured over time, always adapting to local characteristics: traditions, socioeconomic organization, climate, topography, local resources, etc. (Houben and Guillaud 2006).

Despite its seismic hazards, Chile has a large number of structures built with earth, in which adobe is the best-known technique. Their conservation depends on elements such as roofing and foundations, but also on the quality of their coatings against erosion and rain infiltration, as well as for natural hygrometric control of wall interiors (Röhlen and Ziegert 2013). Moreover, finishes add a social component to structures, contributing to their image and evidencing how well they are cared for.

Wall coverings are often inappropriately reworked, in a way that can jeopardize structural integrity. Such interventions are generally linked to an ignorance of the functions of the materials and techniques used in earthen structures. In some such practices it is common to find adobe walls or wooden structures with earth filling covered with cement stucco or emulsion paint, which deteriorate over time owing to damp accumulating in the wall (Minke 2005). In addition, once these coatings are removed, the retained moisture is often found also to have compromised the structural interior.

This study is part of a larger project called "Revestimientos de Tierra" (Earthen Coverings) that started in 2015 with research on historic building renders in Santiago de Chile (Marchante and Silva 2017). In 2019[1], with the FONDART Fund, the "Coatings in the conservation of earthen heritage in Limarí" research project undertook a survey of traditional finishing systems in various villages along the Limarí river (Fig. 1) in the Coquimbo region of northern Chile (30°34'S 71°12'W). The Coquimbo region was at the center of a big 8,4 Mw earthquake in 2015 (Jorquera and Rivera 2017) and during our research major structural restorations were still in progress. This presented an opportunity to study building techniques and to take samples of finishes.

2. Contextualization: The Limarí Valley

South of the great Atacama desert is the Norte Chico area, a semi-arid territory between the river Copiapó to the north and the river Aconcagua to the south, with successive valleys connecting the Andes and the Pacific. The Limarí valley is one of these, between those formed by the rivers Elqui and Choapa.

In the early colonial period (i.e. the sixteenth century), the only major town founded here was La Serena, and the territory served mainly as an overland route to Santiago. The "Camino Real" route prompted the establishment of settlements around churches (Fig. 1), such as Barraza in 1648 and Combarbalá in 1757 (Benavides 1961). With the rise of small-scale mining and agriculture, in the

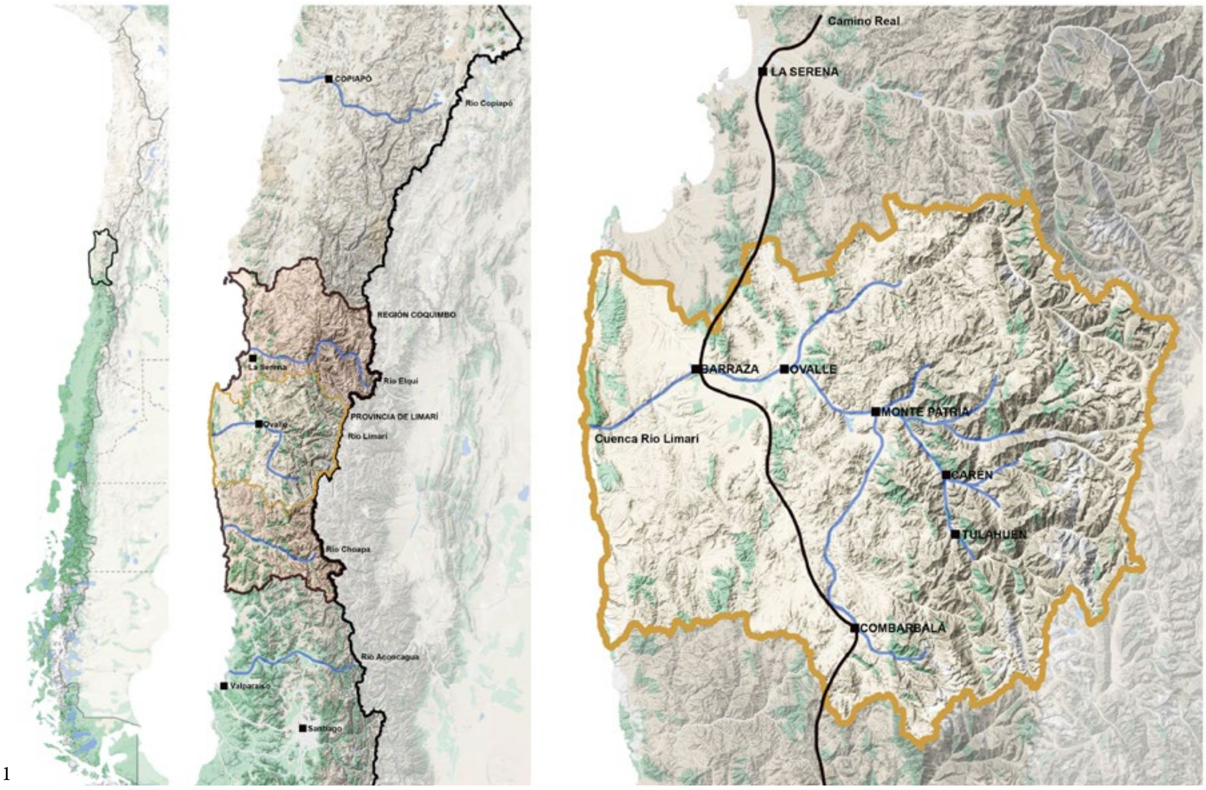

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Figure 1: The Coquimbo region in Chile | Limarí province in the Coquimbo region and the Norte Chico area | Distribution of the main settlements in the Limarí valley with the Limarí river basin and the Camino Real

Figure 2: Indoor finish sample from the Contreras family house in Carén (CAR02D). Top: whole sample (13 × 18 cm) with stratigraphic survey showing the different layers of earthen render and wallpaper. Middle and bottom: section showing 4 mm of earth and sand plaster (*enlucido*) and 30 mm of *enfoscado* plaster with earth and fiber

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seventeenth century the first churches were erected in the Limarí valley, initially associated with *hacienda* estates and later developing into towns. Most of these were built along main roads, and more were founded in the eighteenth and nineteenth centuries, such as Combarbalá and Ovalle (Segovia and Ferrada 2007).

3. Scope and Methodology

The aim of our study is to identify, characterize, and catalog the coating techniques and materials to be found on existing earthen structures in the Limarí valley, as well as to disseminate the traditional techniques and materials used in the finishes of earthen buildings.

Case studies were chosen so as to cover a diversity of architectural typologies on one hand (religious, residential, and agricultural), and of settlement context (urban or rural) on the other.

From these buildings, samples of 10 × 18 cm were taken from the walls (Fig. 2), of variable thickness depending on the coating depth, as far as the structural substrate (Fig. 3). Thirty samples were taken and thirteen cases selected from six buildings. The samples were used to identify the coating systems, from the first layer to the finish.

Earthen layers of render were characterized by observing their texture, composition, and thickness, confirmed by optical microscopy. The finishing layer of each sample was subjected to stratigraphic analysis, microscopy and physico-chemical tests (Fig. 4).

The stratigraphic analysis consisted of controlled mechanical stripping by layers – in most cases firm and well defined, though in others friable and degraded, tending to contaminate one other. Ordinary and microscopic photos of the samples were taken, allowing us to ascertain their composition. The microscopic imaging was done with digital recording equipment: Celestron 500x–1800x.

Physico-chemical and solubility tests were performed on some strata so as to define the dispersion capacity of paint layers, including polar solubility (vinyl-acrylic) or nonpolar solubility (alkyd). The TEA triangle system was used as a solubility test, with organic solvents, alcoholic ethers, aromatic hydrocarbons, benzenes, and nitrobenzenes. Alkalinity tests were also done on some samples with exposure to a solution of 25% phenol in ethanol and to a phosphoric acid solution so as to detect any lime in the composition. Activating the sample materials allowed us to observe accelerated alteration by oxidation reduction (Redox) of salts, hydroxides, and carbonates present in the agglutination of older strata, which cohere by the calcification process when calcium hydroxide is slaked.

At the end of this stage, talks were given in various towns in the Limarí valley along with a series of workshops on the earthen building systems and finishes found in the area. These were aimed both at the general public and at high-school students and their teachers. During these activities, prototypes of the local earthen building systems were made, from earthen renders to traditional finishes. A two-month exhibition was also held in the local museum including videos and the catalog of our research, also available online.

4. Traditional Earthen Structures of the Limarí Valley

In the Limarí valley we find diverse traditional construction techniques, all involving soil. Many of them use raw earth blocks (adobe), either as simple masonry or as fillers in wooden structures (Rivera 2016). It is also common to find different types of *quincha* structure[2].

4.1 Adobe Masonry

The technique found most widely is adobe masonry (Fig. 5), with cuboid blocks of unfired earth laid with a header bond, where the block length becomes the wall thickness


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Figure 3: Extraction of a sample (13 × 18 cm) from the adobe wall of a house in Carén (CAR02D)

Figure 4: Physico-chemical tests. Top right: Test with nitrobenzene (Nitro C) on the CAR02A sample, with immediate solubility confirming that the paint layer is vinyl (latex). Top right: 1000x microscopic image of a phosphoric acid test on the OVA02A sample with high oxide reaction and redox (third layer), confirming that the pigments are bonded to lime. Bottom: Solubility test on the fifth layer of the CAR02B sample, with a clear reaction to organic solvents confirming that this is vinyl latex with a high calcium carbonate content (Manuel Concha)


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Figure 5: Adobe house in Combarbalá

Figure 6: *Pandereta* hybrid wood-and-earth system with external branches and metal wire for containment, Tulahuen

Figure 7: *Quincha* hybrid wood-and-earth system infilled with branches and earth, confined with external horizontal canes, Carén

(Muñoz and Rivera 2017). Various block sizes were found, typically 55 × 30 × 10 cm, 40 × 20 × 10 cm, 60 × 40 × 10 cm or 60 × 30 × 10 cm, resulting in walls with thicknesses of 50-70 cm in smaller structures, and thicker ones in larger structures (Marchante and Rivera 2020).

4.2 Hybrid Structures: Timber Frames with Earthen Infill

Timber frameworks are infilled with adobe blocks laid on edge, locally called *adobe en pandereta* (Guzmán 1979) (Fig. 6), confined in the wall by containing elements (Rivera 2017). The *quincha* technique (Fig. 7) involves a main structure of wood, a secondary structure traditionally of plant matter, and a filling of earth and fiber. In the cases studied, willow branches were arranged vertically and contained by horizontal elements anchored to the main structure, infilled with an earth-and-fiber mixture. In both *pandereta* and *quincha* structures the external confinement elements are made of sawn wood, local cane, branches of various local trees, and metal wires.

It is common to find all these construction techniques complementing each other, with some specific variations. When these systems are found together, the perimeter walls are generally of adobe, and mixed techniques are used to delimit interior spaces, extensions, and sometimes second floors. Structures were also observed built only with hybrid timber-earth systems, either *quincha* or *pandereta*.

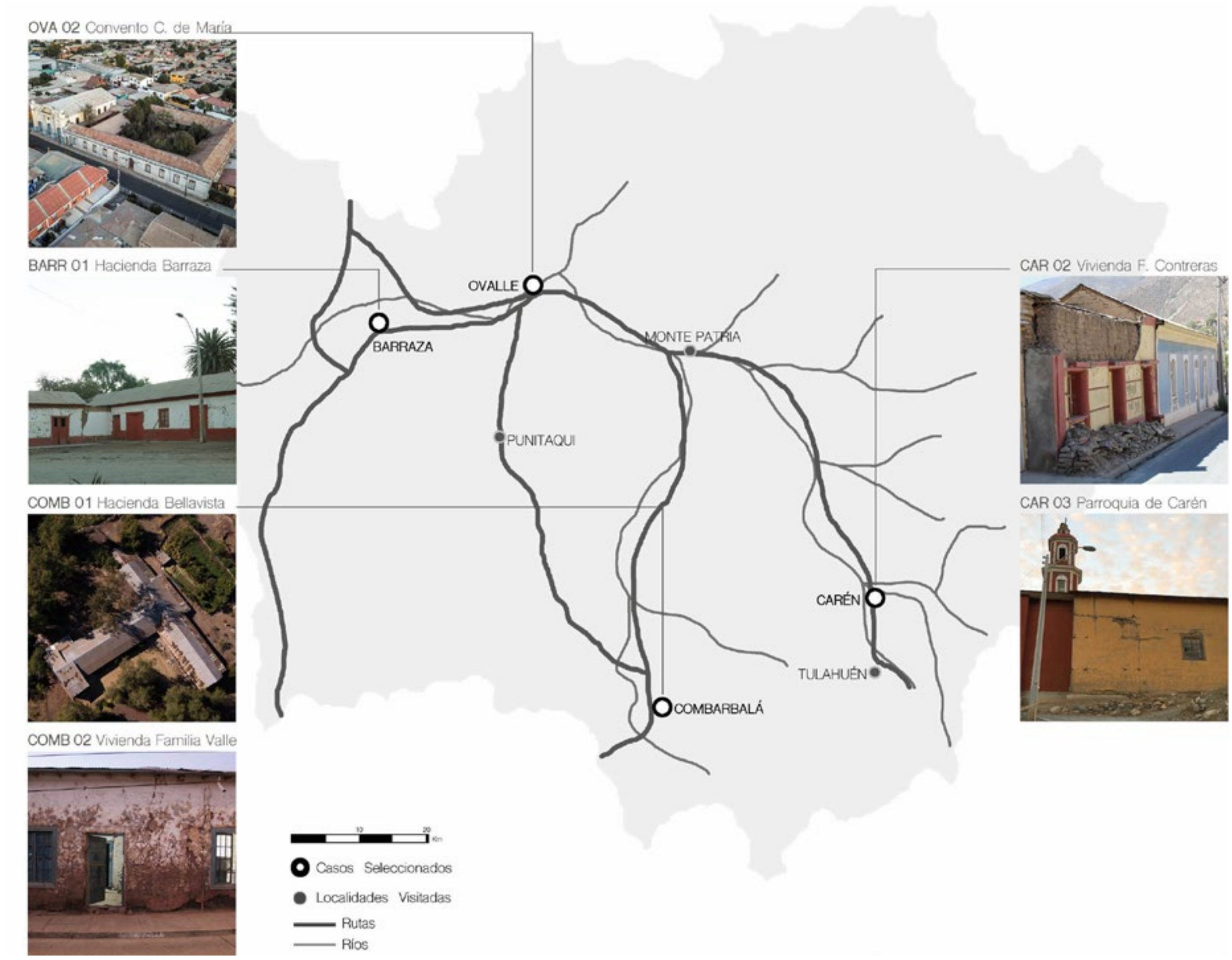


Figure 8: Map of the Limarí Valley with locations of buildings chosen for analysis of finishing layers in Ovalle OVA02 (convent), Barraza BARR01 (*hacienda*), Combarbalá COMB01/COMB02 (house and *hacienda*), and Carén CAR02/CAR03 (church and house)

5. Plasters and Renders in Historic Limarí Earthen Buildings

The coating system for the earthen structures characterizing the built landscape of the Limarí valley, and to be found in much of Chile, seems to have been used for many years, up to the present. It might be several centuries old judging by some buildings in our study, built prior to the nineteenth century. The finishing layers of this traditional system were largely transformed in the late twentieth century with the advent of synthetic materials.

5.1 Case Studies

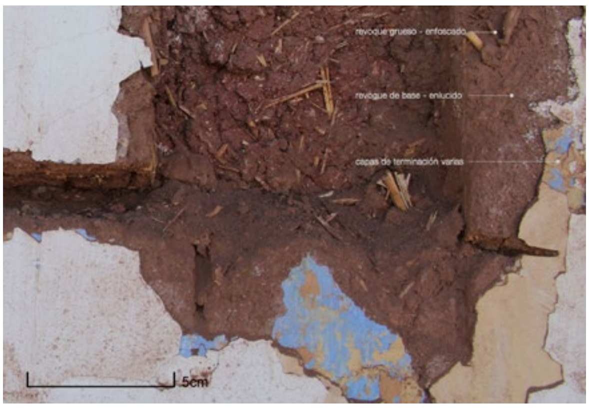
Our case studies were selected and samples were taken with an approach of investigating the valley's building culture, extending previous knowledge about local forms and construction materials, focusing on buildings under restoration or seriously damaged (Fig. 8).

Case studies were selected where original and older building coatings were present. Another criterion was the use of diverse earthen techniques with a variety of wall coverings.

5.2 Coating System

With all structural techniques, the coating system has two layers of earthen render and a finishing coat (Fig. 9). In the finishing layer, variations in materials were found by period, place, wall function, and state of upkeep.

Figure 9: Layers of the finishing system: adobe wall structure, first layer of earth and straw (*enfoscado*), second layer of an earth and sand mixture (*enlucido*), and various finishing plasters. Combarbalá, sample COMB02A



Core	Interior/Exterior wall	Wall structure	1st Earthen Layer	2nd Earthen Layer
BARR 01-B	Interior	*Adobe*	Earth and plant fiber render (30 mm)	Earth and sand render (5 mm)
OVA 02-A	Interior	*Adobe en Pandereta*	Earth and plant fiber render (35 mm)	Earth and sand render (5 mm)
OVA 02-C	Exterior	*Adobe*	Earth and plant fiber render (15 mm)	Earth and sand render (3 mm)
CAR 02-A	Interior	*Adobe en Pandereta*	Earth and plant fiber render (30 mm)	-
CAR 02-B	Interior	*Adobe en Pandereta*	Earth and plant fiber render (40 mm)	Earth and sand render (10 mm)
CAR 02-D	Interior	*Adobe*	Earth and plant fiber render (30 mm)	Earth and sand render (4 mm)
CAR 02-G	Interior	*Quincha*	Earth and plant fiber render (75 mm)	Earth and sand render (3 mm)
CAR 03-A	Exterior	*Adobe*	Earth and plant fiber render (40 mm)	-
CAR 03-B	Interior	*Adobe*	Earth and plant fiber render (60 mm)	Earth and sand render (5 mm)
COMB 01-A	Interior	*Adobe*	Earth and plant fiber render (30 mm)	Earth and sand render (5 mm)
COMB 01-B	Exterior	*Adobe*	Earth and plant fiber render (50 mm)	Earth and sand render (5-6 mm)
COMB 02-A	Exterior	*Adobe*	Earth and plant fiber render (50 mm)	Earth and sand render (2-3 mm)
COMB 02-B	Interior	*Adobe*	Earth and plant fiber render (45 mm)	Earth and sand render (5 mm)

Figure 10: Location, type of wall and composition (first and second earthen layer) of the 13 samples

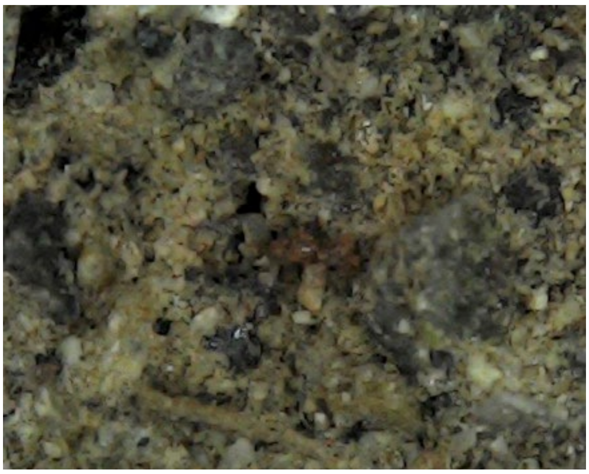
The first layer is earthen render of variable thickness, as it must cover the irregularities of the wall structure (Fig. 10). In the samples analyzed, this layer can vary between 15 and 75 mm and is made up of earth and normally also plant fibers, usually wheat straw. The second intermediate layer is a mortar of sandy earth or a blend of earth and sand. Normally no thicker than 10 mm, it makes the wall even and serves as a base for the finish.

The wheat straw fibers in the first plaster layer (Fig. 11) serve to reduce cracking (as the clayey earth tends to fissure), and is also thought to give greater resistance against horizontal and diagonal movements caused by frequent earthquakes. The fibers must also help this layer adhere to the structure (Lima and Faria 2016), which is especially important in composite structures. In this layer one also often finds pebbles and even fruit stones that may have been mixed into the mortar.

The second intermediate layer is thinner and needs to be carefully executed so as to achieve a smooth, vertical surface without cracks. It is worked with a plaster trowel, and so

Figure 11: 1000x microscopic image of the earth and fiber layer of the CAR02A sample (Manuel Concha)

Figure 12: 1000x microscopic image of the earth and sand layer of the COM02B sample, where the layer is uniform (Manuel Concha)



it contains sand but not straw (Fig. 12). The sand grains allow the surface to be worked evenly and stabilize the clayey earth, preventing fissuring. But it results in a plaster with little surface cohesion due to its low clay content, and which easily sheds sand when rubbed. The subsequent layers provide a firmer finish.

Different finishes may then be applied over this layer. On exterior walls, pigmented lime or water-based paints are often found, or on more recent walls, latex paints. The latter have problems of compatibility with older coating substrates.

Core	Interior/Exterior wall	Finishing layer (from oldest to newer)
BARR 01-B	Interior	1. Whitish wallpaper, printed and finished by hand 2. Brown and blue wallpaper, printed and finished by hand 3. White and blue printed wallpaper. 4. Thicker printed wallpaper
OVA 02-A	Interior	1. Calcium Hydroxide (lime) 2. Terracotta paint (lime paint) 3. Vinyl yellow paint on a highly degraded calcium carbonate primer 4. Calcium carbonate mortar (pasta muro) 5. Vinyl damask paint 6. Vinyl white paint
OVA 02-C	Exterior	1. Calcium Hydroxide (lime) 2. Colonial blue paint (lime paint) 3. Colonial red paint (lime paint) 4. vinyl light blue paint 5. Vinyl damask paint 6. Vinyl white paint 7. Vinyl pink white paint
CAR 02-A	Interior	1. Calcium sulfite (gypsum) 2. Ocher paint (water paint)
CAR 02-B	Interior	1. Vinyl blue paint 2. White vinyl paint 3. Vinyl pink paint 4. Vinyl damask paint
CAR 02-D	Interior	1. Wallpaper with phytomorphic motifs
CAR 02-G	Interior	1. 1st layer of printed paper on earth and sand mortar 2. 2nd layer of printed paper
CAR 03-A	Exterior	1. Yellow ferrous oxide paint
CAR 03-B	Interior	1. Textured wallpaper
COMB 01-A	Interior	1. Ecru wallpaper 2. White wallpaper 3. Vinyl binder textured paint
COMB 01-B	Exterior	1. Calcium hydroxide (lime paint) 2. 3 to 4 mm earth and sand mortar 3. Calcium hydroxide (lime paint)
COMB 02-A	Exterior	1. Blue pigment paint (water paint) 2. Ocher paint layer (water paint) 3. Calcium hydroxide (lime paint)
COMB 02-B	Interior	1. Vinyl white paint

Figure 13: Finishing layers of the 13 samples

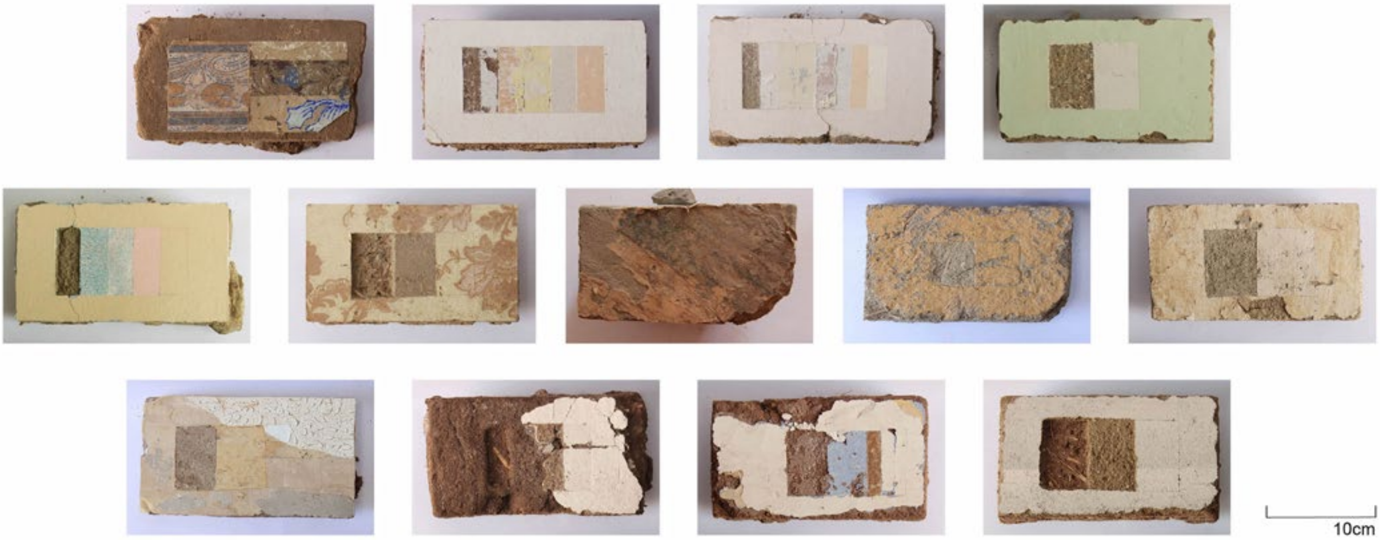


Figure 14: Stratigraphic survey of the 13 samples. From top left: BARR01B, OVA02A, OVA02C, CAR02A, CAR02B, CAR02D, CAR02G, CAR03A, CAR03B, COMB01A, COMB01B, COMB02A, COMB02B

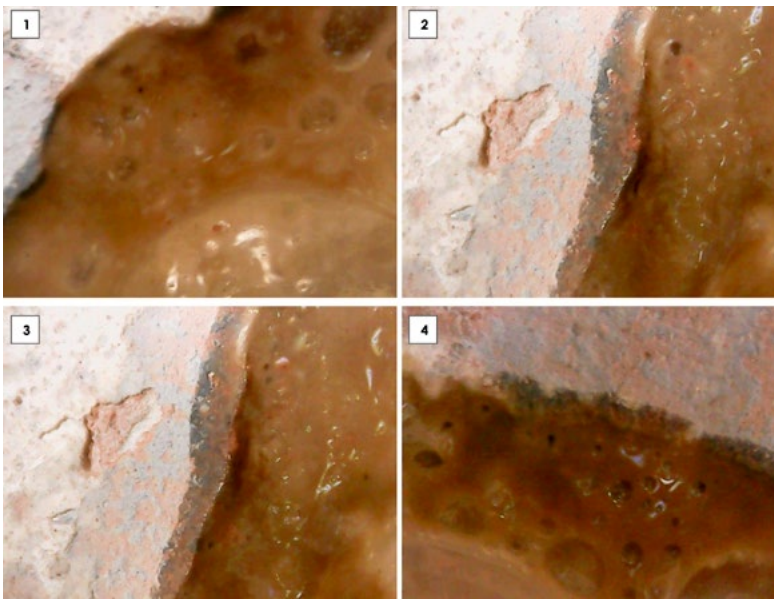
5.3 Types of Finish

Interior finishes are more varied and the older ones include lime and pigment paints as well as a range of wallpaper colors and designs (Fig. 13). Gypsum plaster, *pasta muro*,[3] and latex paints (vinyl or acrylic) are some of the materials used in interior renovations of the late twentieth century. But in areas with fewer economic resources and/or less access to industrialized materials, lime and pigments continue to be used (Fig. 14).

Lime has been employed since colonial times, both in mortars and in paints, for interior and exterior coatings (Figs. 15 and 16). This is the oldest finishing material commonly used up to the early twentieth century.

Figure 15: Indoor finish from the Corazón de María Convent in Ovalle (OVA02A). Left and top right: stratigraphic survey showing different layers of lime finishings and vinyl paints. Right center and bottom: section showing 5 mm of an earth and sand plaster (*enlucido*) and 35 mm of *enfoscado* with earth and fiber.

Figure 16: Phosphoric acid (H3PO4) test on the third and fourth strata of the OVA02C sample. The blue and colonial red paint layers show a reaction and a redox oxide product, confirming that these are pigments bonded to lime (Manuel Concha)



Enlucido: 5 mm of soil and sand plaster

Enfoscado plaster: 30mm of soil and fiber

Figure 17: Indoor finish from an abandoned *hacienda* estate in Barraza (BARR01B) with various wallpaper layers. Right from bottom: the white first paper and blue second paper are printed and hand painted from approx. 1850-1930; the third must have been manufactured around 1950. The last is a thicker stamped wallpaper. Left top: whole sample with paper finishes and stratigraphic survey. Left center and bottom: section showing 5 mm of an earth and sand plaster (*enlucido*) and 30 mm of *enfoscado* with earth and fiber

On interior walls, the use of wallpaper dates back to the early nineteenth century (Figs. 17 and 18). Wallpapers have evolved over time and their manufacturing period can be identified by the paper type and the technique applied. The oldest were made with plant fibers and could be printed and painted by hand. Industrially printed mixed-fiber papers (plant-based and synthetic) have been used since the 1950s.

Although all of these materials can still be used, since the second half of the twentieth century they have been largely replaced by cement, gypsum plasters, *pasta muro*, and synthetic paints. As to durability, there are layers of lime and pigments that are probably more than two centuries old over earthen plasters and which still adhere. In the stratigraphic survey of our samples, these layers were difficult to separate due to being quite firmly attached both to the earthen layer and to each other. Latex paints, by contrast, are often detached from the base and are easily removed (Fig. 19).

6. Conclusions

Coatings are designed to protect structures and to provide a good finish to walls, both inside and outside. In our samples a clear difference was observed between the first earthen layers and the finishing ones. Directly on the structure, these first layers of wallcovering have the function of evening out and smoothing the facing, providing a substrate for the finish. In all our case studies a layer of earth and plant fibers was found with a thickness range of 15 to 75 mm, with an average of 41 mm. Moreover, 85% of our samples had a thinner second layer of earth and sand with an average thickness of 5 mm. All our samples showed a decreasing thickness from the first layer containing fibers to the second layer containing sand. The first layer with earth and fibers is

Figure 18: 1000x microscopic images of wallpapers in the BAR01B sample, with fibers and mineral pigments agglutinated with aqueous polymer (Manuel Concha)

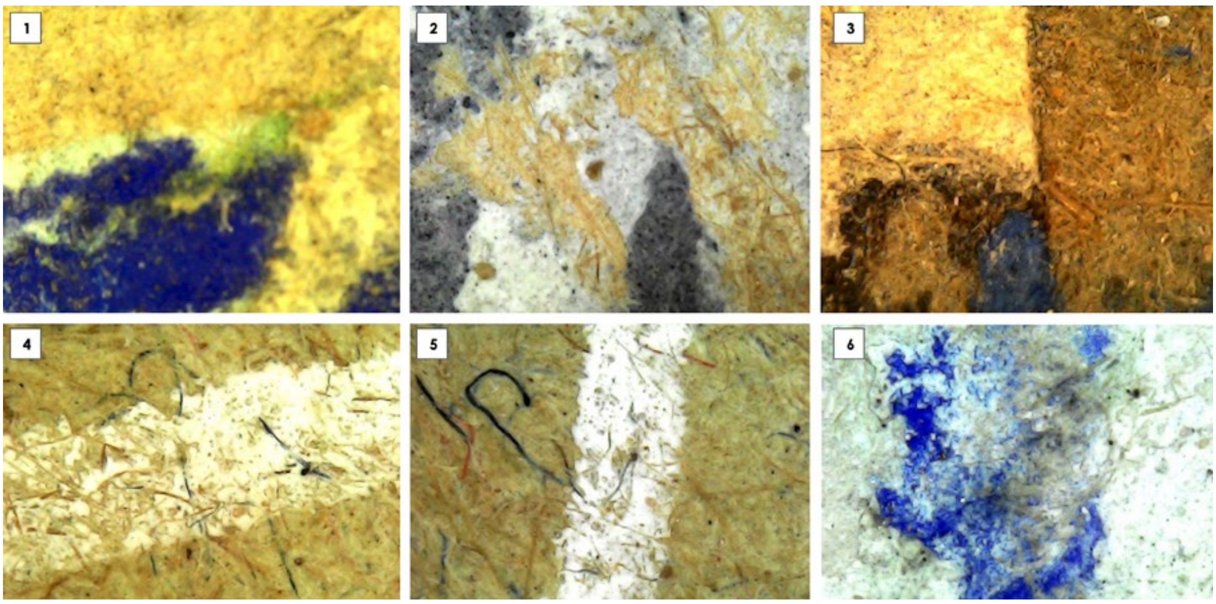


Figure 19: Detachment of synthetic paint layers due to damp retained in the wall. Pathology found in a wall at the Corazón de Maria Convent in Ovalle in 2019

assumed to have better adhesion to the substrate (Lima and Faria 2016), and has the specific function of smoothing the wall and covering its imperfections, resulting in a surface with only small cracks. The sandy layer is designed to avoid any cracking and to provide a homogeneous substrate for thinner plasters or wallpapers.

The successive layers have the function of providing a finished and decorated surface, and in the case of exterior finishes, they need to protect against rainwater. On these layers different interior finishes were observed, with lime, gypsum, paint, and wallpaper, the latter being the most common (56%). On exteriors, paint, earthen pigment and lime were found, with lime plaster being the commonest finish (50%).

Coatings must also keep walls dry, protecting mainly against surface deterioration due to rainfall, as a skin enveloping the structure but allowing it to "perspire", releasing excess moisture from the interior. The covering materials compatible with earthen structures are therefore those permeable to water vapor, mechanically equal to or less resistant than their substrate and not liable to crack (Faria Rodrigues 2005). Good execution and selection of covering materials meeting these conditions is therefore vital. It should be noted that such coverings allow early detection of damp and seepage in walls, as moisture soon becomes visible on the surface and can be repaired before the structure is permanently damaged.

Traditional materials such as lime have coexisted since ancient times with earthen buildings. Lime layers applied over mud layers effectively protect walls and show good adhesion. The replacement (Minke 2005) of these materials with cement and synthetic paint is detrimental to the appropriate maintenance of earthen structures.

Acknowledgements

We thank everyone who helped us carry out this project, particularly all the owners who allowed us to remove pieces of their historic buildings in Carén, Tulahuén, La Cisterna, Combarbalá, Ovalle, and Barraza. Thanks to Cristian Muñoz, Matilde Muñoz Rivera, and Manuel Cortés Marchante for their patience and company during field visits and the rest of the project. Manuel Concha (conservator-restorer), Sergio Peña (historian), and Cristian León (visual recorder) were also part of the project. Claudio Vega (construction engineer at La Ruta de la Tierra) took part as an external collaborator.

[1] Project funded by Fondo Nacional de Desarrollo Cultural y las Artes (FONDART) Regional Coquimbo 2019 Nº486914. Original title: "Los revestimientos en la conservación del patrimonio construido con tierra en El Limarí".

[2] *Quincha* is a native Quechua term meaning "wall", normally used to describe an earth-and-wood building technique with wattle and daub used in the southern Andes.

[3] *Pasta muro* is the trade name of a local putty made of calcium carbonate and synthetic components, such as a blend of acrylic and vinyl additives.

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Patrícia Marchante

Patrícia is a Portuguese architect devoted to earthen construction and earth-based renders and finishes. She holds an Architecture degree from the University of Oporto and a post-master's degree in Earthen Architecture from CRATerre laboratory, ENSAG, France. She is a PhD candidate at the University of Cagliari (Italy) and leader of two research projects on traditional earthen renders financed by the Chilean Ministry of Culture, Arts, and Heritage. She has taught earthen architecture and heritage at the Andrés Bello University, the University of Santiago and for the Earthen Architecture and Construction Diploma at the Catholic University of Chile. She is Vice-President of Associação Centro da Terra - CdT.

Amanda Rivera Vidal

Amanda is a Chilean architect devoted to earthen, vernacular, and historical architecture technologies. She holds a degree in Architecture from Bío-Bío University (Chile), an Earthen Architecture Post-Graduate Diploma from the CRATerre laboratory ENSAG (France), a master's degree in Cultural Heritage from the Catholic University of Chile, and she is a PhD candidate at the University of Cagliari (Italy). 2009 RIBA Norman Foster Traveling Scholarship. She teaches at the School of Architecture at the University of Talca (Chile) and for the Earthen Architecture and Construction Diploma at the Catholic University of Chile. She belongs to the PROTERRA Ibero-American network and is a member of ICOMOS-Chile, an expert member of the International Committee of Vernacular Architecture CIAV-ICOMOS, and Vice-president of the International Scientific Committee on Earthen Architectural Heritage ISCEAH-ICOMOS.