FIG 1 Fotogrametría elevación poniente Iglesia y Convento San Francisco / *Photogrammetry west elevation San Francisco Church and Convent.* Escala / *Scale* 1:500. Fuente / *Source*: FONDECYT Nº 11130628

THE BASEMENT OF THE SAN FRANCISCO CHURCH:

AN EARTHQUAKE-RESISTANT FOUNDATION ON A PREHISPANIC LAYER?

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**How has a four-century old church managed to stand on its feet, resisting more than 15 earthquakes of magnitude over 7?
Starting from this question, this research examines the church's subsoil to suggest that its foundations, built in 1586, perhaps would be one of the first earthquake-resistant structures in Chile.**

KEYWORDS · soil, ground, foundations, heritage, seismic resistance

The San Francisco Church and Convent in Santiago comprise both the capital's and the country's oldest built complex (FIG. 1),[1] being "the only authentic sixteenth-century architectural testimony preserved in Chile" (Benavides, 1988:128). The building, which has undergone numerous alterations, still preserves its original Latin-cross shaped stone structure (FIG. 2), an element that today constitutes the church's central nave and transept (FIG. 3).

Several authors state that it was in 1572 when the church's first stone was laid, but the fact remains that this was only the beginning of "early 'adobe brick and mud' walls [that] were hit 'by three fires' and an earthquake, which on August 7th, 1583 toppled the building" (Archivo Nacional Real Audiencia 1594, cited in Pereira Salas, 1953:5). It is unknown whether part of this first building –or its foundations– were reused for the stone church that stands up to this day and which allegedly begun construction, according to Montandón and Pirotte (1998), would have begun in 1586. It was not until 1618 that "the church with Latin-cross shaped plan and stone walls" was completed (Rovegno, 2009:20). Today the temple is the only example of Santiago's initial architecture, which along with its prime location on the capital's main artery, makes it an iconic, historical and traditional landmark. Thus, in 1951, it was declared Historical Monument and subsequently included in the list of assets that could apply for the World Heritage status granted by UNESCO (Consejo de Monumentos Nacionales, 1998). In

1 It is the oldest building whose construction date is known. While many sources consider the San Francisco de Chiu-chiu church located in Antofagasta region the eldest Chilean building, it was built in the "mid-17th century" (Consejo de Monumentos Nacionales, undated), while San Francisco Church in Santiago was completed in 1618.

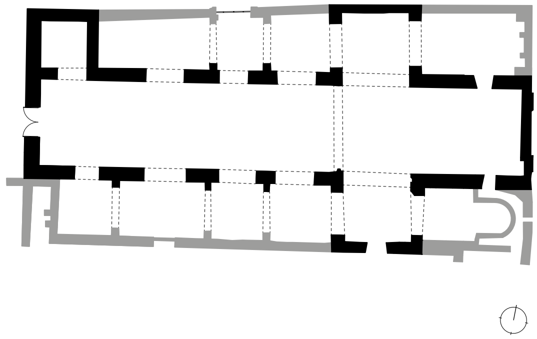


FIG 2 Planta actual iglesia San Francisco. En negro se destaca la planta de la iglesia original de piedra, estructura que permanece hasta nuestros días / *San Francisco Church current plan. Highlighted in black the original stone church plan, a structure that remains up to this day.* Escala / *Scale* 1: 1.000. Fuente / *Source*: FONDECYT Nº 11130628

addition to these recognized historical and urban values, a key aspect should be considered: being the capital's oldest building it is also the one that more earthquakes has endured.

The church has withstood about 15 earthquakes of magnitude over 7,[2] and it is the only building that survived Santiago's 1647 'magnum earthquake' which, with a magnitude of 8.5, was the most destructive of the colonial period because "almost all temples were completely ruined, except for the San Francisco Church and Convent" (De Ramón, 2000:62). After the earthquake, the building only lost its original tower and the choir, which was dragged down by the collapse of the former. Successively, the church survived the 1730 earthquake –the second most destructive of the colonial period– the one on 1751 and the "great earthquake of April 2, 1851 [in which it] only suffered the fall of its external cornices" (De Ramón, 2000:150). Being a very slender appendix, only the tower has been damaged by earthquakes and replaced three times –the current one, built in 1856 by Fermín Vivaceta, is the fourth tower (Peña, 1969). Other transformations –the 18th century construction of the side aisles that gave it its current rectangular plan and the three façade changes– are due to expansions derived from usage requirements or restyling and not from post-earthquake restorations.

Thus, although the church has been modified and shows partial damage of seismic origin, these have been minor. This, despite the apparent fragility of the constructive systems employed, consisting of stone masonry in the original nave and brick masonry in the aisles (FIG. 4); basically, systems with low capacity to resist horizontal forces.

Then, what is the church's seismic resistance based on? Several authors have claimed that the temple owes its

2 Earthquakes that have affected Santiago: 1575, 1647, 1690, 1730, 1751, 1822, 1850, 1851, 1906, 1909, 1927, 1965, 1971, 1985, 2010 (FONDECYT 11130628, based on the historical record of the Centro Sismológico Nacional and Lomnitz, 2004).

FIG 3 Corte fotogramétrico longitudinal iglesia San Francisco. Nave central original. / *Photogrammetric longitudinal section San Francisco Church. Original central nave.* Escala / *Scale* 1:500. Fuente / *Source*: FONDECYT Nº 11130628

endurance to its 1.7 m thick walls and the fact "of having such a brave timberwork, of very thick and close together woods with beams and joists that embrace it embedded to the same walls" (Rosales, 1674, cited in Benavides, 1988:129).

The second phase of this FONDECYT project confirms these hypotheses, but also reveals new information on the subject: through several studies[3] and thanks to the contribution of academic specialists in seismic analysis of historical buildings,[4] it was determined that both the roof and its diaphragm have contributed to tying together the church's walls, preventing them from falling and improving their seismic performance. In addition, the brick construction of the aisles has positively influenced the overall performance of the property, but has paradoxically increased the seismic vulnerability of specific elements (the upper part of the façade, the tympanum behind the altar and both transepts), which could cause local failures (Jorquera, Palazzi, Rovero and Tonietti, 2016).

3 Structural and constructive characteristics survey; cracking pattern analysis; vulnerability assessment of macro-elements; linear and nonlinear local kinematic analysis; overall modal dynamic analysis using a 3D FEM model with Straus7 software.

4 The seismic analysis was conducted by Italian architect and professor Ugo Tonietti, coordinator of the Doctorate Program in Structures and Architectural and Cultural Heritage Conservation of the University of Florence, together with Luisa Rovero, Doctorate and architect as well as professor on the same program, and Doctorate student Nuria Palazzi, all permanent collaborators of the FONDECYT Initiation project Nº 11130628.

FIG 4a Detalle mampostería de piedra original / *Original stone masonry detail.* Fuente / *Source*: FONDECYT N° 11130628

FIG 4b Detalle albañilería de ladrillo de las naves laterales, de construcción posterior / *Masonry brick detail in side aisles, of later construction.* Fuente / *Source*: FONDECYT N° 11130628

Complementing these analyzes, and advised by an archeology team,[5] in January 2016 a survey was performed adjacent to the oldest walls of the church to inspect their foundations –a key element in the transmission of seismic forces– about which neither literature nor books on historical works have information. Along this, a number of material remains were rescued, which are a testimony of the site's occupational history.

THE GROUND OF SAN FRANCISCO: FROM GEOTECHNICS TO ARCHAEOLOGICAL EXCAVATION

Despite its early construction in the Conquest period (1541-1598), the San Francisco Church and Convent are located outside the foundational triangle's grid plan, at the time limited by the two branches of the Mapocho river (FIG. 5), The soil of this site belongs to the Unit II type defined by Leyton et al (2011), composed of sandy gravels from the Mapocho. In addition, it is part of the seismic zone A, "where less damage from earthquakes is expected" (Leyton et al. 2011).

With these preliminary data on the soil –subsequently verified by measuring the velocity profile of Vs30 waves through the use of a geophone[6]– the archaeological excavation proceeded,[7] being the first examination of the building's subsoil throughout its history. The main goal was to observe and characterize the church's foundations. Thus, a 2 × 1 m polygon –adjacent to the south wall of the transept– was defined as

5 Led by Universidad de Chile archaeologist and Master of Fine Arts, Catalina Soto Rodríguez and a multidisciplinary team: the archeologist specialized in historical archeology Dafna Goldschmidt; the physical anthropologists Iván Arregui; the Doctorate student Verónica Silva; the art historian and heritage expert Lorena Villablanca; the social anthropologist and advanced archeology student Texia San Martín; and the archeology student Iván Bravo.

6 Instrument by which it is possible to make a geophysical non-invasive survey, using the measurement of shear wave velocity profiles that allow the primary evaluation of a site's dynamic response (Tokimatsu, 1997, in Pereda, 2011).

7 Autorization N° 003964/15, Consejo de Monumentos Nacionales.

FIG 5 Plano de Santiago, 1600. En rojo se destaca la iglesia y convento de San Francisco / *Plan of Santiago, 1600. Highlighted in red San Francisco Church and Convent.* Fuente: Imagen reelaborada a partir del croquis original de Tomas Thayer Ojeda, 1600. / *Source: Image developed from Tomas Thayer Ojeda original sketch, 1600.* Colección Biblioteca Nacional.

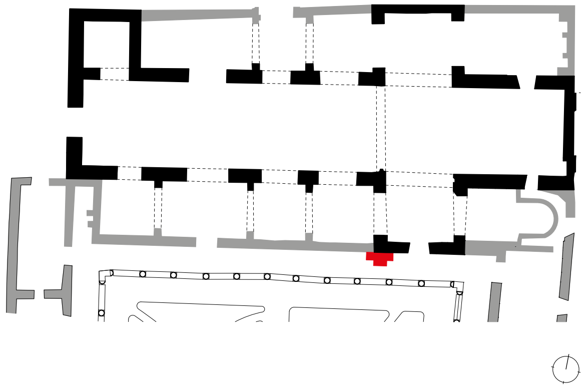


FIG 6 Planta con la ubicación de la excavación / *Plan showing the excavation's location*. Escala / *Scale* 1:1.000. Fuente / *Source*: FONDECYT N° 11130628

excavation area (FIG. 6), a place where the church's southwest corner used to be and where the San Francisco Colonial Art Museum's corridor is today (FIG. 7). This specific location was chosen considering that the transept corresponds to the church's original stage and that it has never collapsed with earthquakes or been modified; therefore, the foundations to be found here could be representative of the church's entire first phase. The excavation polygon was entitled Unit 1; subsequently, due to the findings –the atypical characteristics of the foundation and also human remains– it was decided to extend it to more than twice its size, about 4 linear meters by 1 meter wide and 1.5 meters in the burial area. The excavation's enlargement area was called Unit 2, while the burial area was called Burial 1 (FIG. 8).

The digging exposed a mostly untouched ground, relatively unchanged by events or removals subsequent to the construction of the original church, with a stratigraphy organized by periods ranging from pre-Hispanic times to the 19th century; consistent with the fact that the Franciscan order has been in place since the Cabildo of Santiago granted them the land in 1553. This condition is also quite unique in comparison to other areas of the city, where property disputes and successive interventions are reflected in highly altered soil stratigraphy. It should also be mentioned that the foundations were discovered only centimeters away from the floor levels registered prior to the excavation, while only a meter deep the soil lacked of cultural material, which is nothing when compared to similar explorations throughout Santiago (in the Cathedral, the Palacio Pereira, the former Hotel City, among others) that have reached nearly two meters.

Observations on the building's foundations as well as the artifacts unearthed during the excavation, which depict the historic range between the church's establishment and the 19th century, are described next.

FIG 7 Ubicación de la excavación en el actual corredor del Museo / *Location of the excavation in today's Museum's corridor*. Fotografía / *Photograph:* Claudio Zamorano. Fuente / *Source*: FONDECYT Nº 11130628

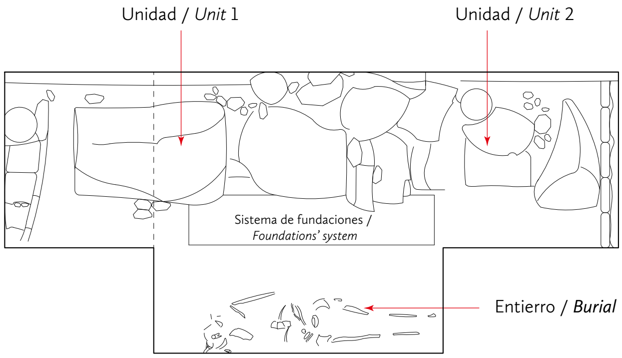


FIG 8 Planta detalle excavación / *Excavation detail plan.* Escala / *Scale* 1:50. Fuente / *Source*: FONDECYT Nº 11130628

DESCRIPTION OF THE FOUNDATIONS: SEISMIC ISOLATORS?

The foundations of the original San Francisco church constitute an atypical case and, therefore, are dissimilar from most colonial buildings in Santiago. Their structure starts 10 cm below floor level –where the 1.7 m thick stone wall ends– and is made of cobblestone ('boulders' in colloquial language), contained laterally by two megalithic stone axes. Cobblestones –likely extracted from the Mapocho river– vary in size, ranging between 10 and 30 cm, and are submerged in loose soil and sand; that is, they are not bounded by mortar and, therefore, they have no rigidity. This means that the thick wall is simply rests on a sort of mobile support. The lateral axes –of which only one was observed during the excavation– are composed of large semi-shaped stone blocks about 60 × 60 × 60 cm, parallel to the foundations and detached 20 cm from the wall, with a larger stone (90 × 60 × 60 cm) located at the corner of the transept. At the junction between the large blocks are small cobblestones and wedge-shaped stones, presumably to keep together the ensemble, transforming the axis into an immovable lateral retaining wall (FIGS. 9-10).

Given the impossibility of excavating inside the church, a georadar[8] was used to verify the existence of an identical axis on the inner side of the walls; this analysis showed an abnormality in the subsoil which could be interpreted as the inner lateral axis. This means the foundations form a 'seismic isolator' where the cobblestones can move freely during an earthquake without neither crumbling nor losing their geometry as they are contained on both sides (FIG. 11). Thus, this system partially isolates the structure from ground movements, reducing the horizontal effort that could affect the building. In all likelihood this foundation system is the

8 A georadar allows analyzing materials without the need for destructive penetration, through the transmission of electromagnetic ultra-wideband waves.

FIG 9 Vista frontal del sistema de cimientos / F*ront view of the foundation system*. Fuente / *Source*: FONDECYT Nº 11130628

FIG 10 Vista superior del muro de contención lateral del sistema de cimientos / *Top view of the foundation's retaining lateral wall.* Fuente / *Source*: FONDECYT Nº 11130628

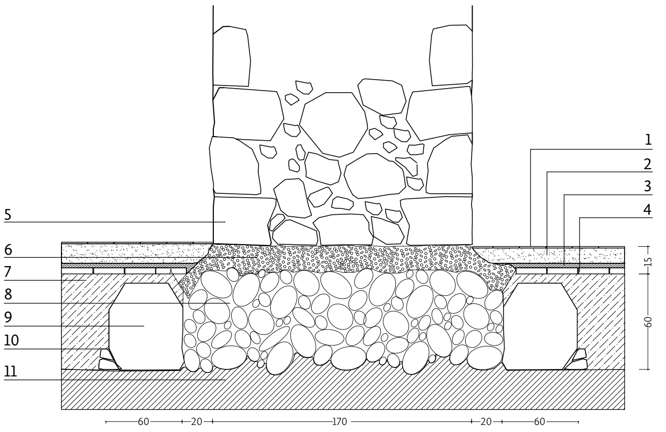
same throughout the church, but given the limitations of the excavated surface this idea will remain a hypothesis.

It is noteworthy that although the use of cobblestones in foundations was relatively common during the colonial period, these were used in the deepest part as filling material –immediately above the soil– and if they were more superficial or near the wall, they would be bound by mud or lime and sand mortar. In addition, in monumental buildings in Santiago like the Cathedral, the Real Audiencia and the Real Aduana (current Museum of Pre-Columbian Art) it is usual to find great depth and thicker-than-walls foundations, built of stone or brick and mortar (FIG.12). In other words, conventional foundations belonging to Spanish tradition.

OTHER CHRONOSTRATIGRAPHIC MATERIALS IN SAN FRANCISCO'S SUBSOIL

San Francisco's excavation allowed both to observe its foundations and to retrieve objects that provided useful information to reconstruct the site's historical occupation. The retrieval was performed following the stratigraphic units or layers, but dividing the deposit in arbitrary levels every 10 cm as a control strategy.

It was then possible to determine that the stratigraphy presents itself nearly unchanged after the first construction



LEYENDA / *LEGEND*

1. Pavimento cerámico actual / *Current ceramic tile floor*
2. Radier / *Concrete floor*
3. Capa de alquitrán / *Tar layer*
4. Pavimento colonial ladrillo panadero / *Colonial brick pavement*
5. Muro de piedra Iglesia / *Church stone wall*

Sistema de cimentación / *Foundation system :*

6. Estrato de e= 15 cm de mortero de cal con grava Ø 1 cm / *15 cm lime mortar layer with Ø 1 cm gravel*
7. Suelo de relleno muy arcilloso / *Clay filling soil*
8. Estrato de e= 55 cm (aproximado) de piedras de canto rodado, dispuestas sobre tierra suelta / *55 cm (approx.) strata of cobblestones, arranged on loose ground*
9. Eje de piedras semi-canteadas de 60 × 60 × 60 cm (aproximado) / *Semi-shaped stone axis 60 × 60 × 60 cm (approx.)*
10. *Piedras canteadas en forma de cuña / Wedge-shaped stones*
11. *Suelo natural / Ground*

FIG 11 Corte detalle del sistema de cimientos, muro y fundaciones / *Base, wall and foundation system detail section*. Escala / *Scale* 1:50. Fuente / *Source*: FONDECYT Nº 11130628

event and organized by periods, being able to clearly identify components allocable to the 16th, 17th, 18th, 19th and 20th centuries (FIG. 13). Within these components, the information provided by Layer 3 stands out, where the current corridor's floor filling is, consisting of a predominantly silty matrix combined with sand, stones and varied cultural material, indicating its deposit was made during the 17th century. Along with the previous, Layer 4 also stands out –where the building's foundation were laid upon– which corresponds to a silt-clay substrate highly compacted with few stones and a significant density of pre-Hispanic cultural material without presence of historical materials.

Among the material remains documented are fragmentary ecofacts (faunal, malacological and floral) along with ceramic, glass, metal and stone artifacts. Noteworthy are the 119 pottery fragments recovered, among which it was possible to distinguish ten decorated pre-Hispanic pieces, one of them –fragmented in two and with a clepsydra motif– clearly belongs to the Inka period (FIG. 14) as well as the presence of a high percentage of open red-slipped vessels used in rituals and funeral contexts (FIG. 15). Three majolica pottery fragments belonging to the late colonial period (18th) and five fragments of high temperature pottery (crockery) of the *Whiteware* type, attributable to the second half of the 19th century, were also found.

Regarding the lithic assemblage, some slices of different raw materials (silica and obsidian) were noted, underlining the presence of an irregular based projectile point (FIG. 16). These remains, together with the decorated ceramic fragments belonging to the late period and the Inka vessel, are unambiguous indicators of the existence of a late pre-Hispanic occupation of local groups in contact with the Inka or directly subjected to the Inka Empire (Sanchez, 2004; Uribe, 2000), on top of which San Francisco was possibly built.

Finally, the excavation exposed the burial of a young-adult female individual (± 27 years old) in poor conservation

FIG 12a Cimientos de piedra con argamasa de cal de la Catedral de Santiago / *Stone and lime-mortar foundation of Santiago's Cathedral*. Fotografía / *Photograph*: Claudia Prado. Fuente / *Source*: FONDECYT Nº 1090325

FIG 12b Cimientos de piedra con argamasa de cal del antiguo mercado de la Plaza de Armas de Santiago / *Stone and lime-mortar foundation of Santiago's ancient market at* Plaza de Armas. Fotografía / *Photograph*: Claudia Prado. Fuente / *Source*: FONDECYT Nº 1090325

FIG 12c Cimientos de piedra con argamasa de la ex Real Audiencia de Santiago. Excavaciones realizadas en el marco de la construcción de la Estación Metro Plaza de Armas / *Stone and mortar foundation of the former* Real Audiencia *in Santiago. Excavations performed during the construction of* Plaza de Armas *Subway Station*. Fotografía / *Photograph*: Claudia Prado, 1997.

Período	Capa	Nivel (cada 10cm)
S. XX (Piso actual)	1	1
S. XIX (Piso panadero)	2	2
S. XIX - XX (Desagüe)	Rasgo 1	3 - 4
S. XVI - XVII	3	3 4 5 6
S.XVI	Cimientos	3 - 4 - 5 - 6 - 7 - 8
Prehispánico tardía	4	7 8 9 10

FIG 13 Relación entre períodos y estratigrafía del suelo de la iglesia de San Francisco / *Correlation between periods and soil stratigraphy at San Francisco Church*. Fuente / *Source*: FONDECYT Nº 11130628

FIG 14a Fragmento cerámico de escudilla con motivo propio de la época *Inka*, de origen foráneo / *Ceramic bowl fragment with* Inka *motif, of foreign origin*. Fotografía / *Photograph*: Claudio Zamorano. Fuente / *Source*: FONDECYT Nº 11130628

FIG 14b Fragmento cerámico con decoración roja sobre blanco, propio de épocas tardías de presencia *Inka* en la zona / *Ceramic fragment with red on white decoration, belonging to late* Inka *presence in the area*. Fotografía / *Photograph*: Claudio Zamorano. Fuente / *Source*: FONDECYT Nº 11130628

conditions, placed in supine position and arranged parallel to the axis of the wall facing the altar. Considering these characteristics and the cultural remains on Layer 3, it is argued that this burial belongs to the early colonial period, possibly synchronous to the first stage of the church's construction.

CONCLUSIONS

To speak about the church of San Francisco is to speak about a fundamental part of Santiago's history. A history embedded in the building's walls and which today can be read in its subsoil. Undoubtedly, the survival of the church in time is due to many factors, among them, for instance, its condition of heritage

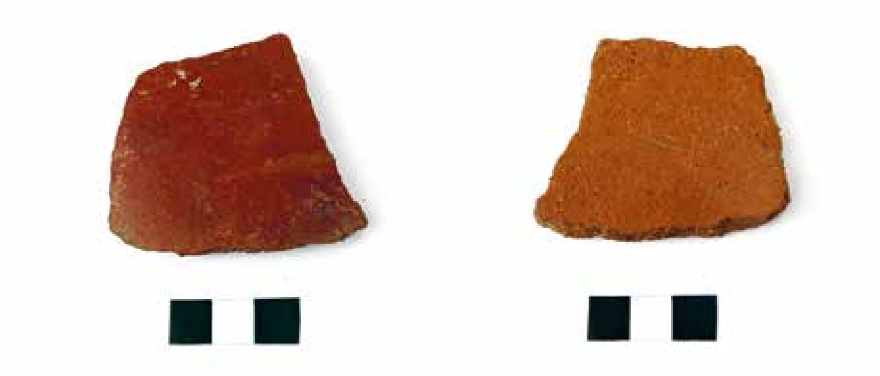


FIG 15a-15b Fragmentos rojos engobados con escobillado interior, atributo propio de los tipos prehispánicos / *Red slipped fragments with brushed interior, characteristic feature of pre-Hispanic types.* Fotografía / *Photograph*: Catalina Soto. Fuente / *Source*: FONDECYT N° 11130628

FIG 15c Fragmento de negro decolorado sobre rojo, asociado a contextos Aconcagua tardíos / *Discolored black on red fragment, associated with late Aconcagua contexts*. Fotografía / *Photograph*: Catalina Soto. Fuente / *Source*: FONDECYT N° 11130628

FIG 16 Punta de proyectil de base escotada, utilizada como pieza del conjunto arco y flecha, propia del período Intermedio Tardío y Tardío en la zona central de Chile / *Irregular based projectile point, used as part of bow and arrow set, typical of Late Intermediate and Late Period in central Chile*. Fotografía / *Photograph*: Claudio Zamorano. Fuente / *Source*: FONDECYT N° 11130628

early assigned by Santiago's society, which did not allow the replacement of the building despite the city's many transformations. Regarding its good dynamic performance in a highly seismic context such as the Chilean one, this has been certainly influenced by factors such as the building's shape, the quality of the materials employed, its construction and, undoubtedly, the soil characteristics and type of foundation found in the excavation.

On the other hand, the presence of pre-Hispanic artifacts in the church's subsoil, likely indicating that the building was built on a site of indigenous occupation, opens up an interesting research path. If, given the nature of the excavation, it is not possible to identify with certainty either the extent or the depth of the site, it is, however, possible to think that this is a place of actual symbolic value for locals hidden under a Christian building, as it has happened in other areas of America and the Peruvian-Bolivian *altiplano* (Gisbert, 1980) such as Cuzco in Peru, Copacabana in Bolivia (Ziólkowski, 1997) and even the Cathedral of Santiago (Stehberg and Sotomayor, 2012).

Undoubtedly, the archaeological work developed constitutes a significant illustration of the building's subsoil and likely of a significant portion of the Paris-Londres neighborhood in the capital's center. In this case, despite cultural materials are not numerous, they are indeed representative and a diagnosis of specific periods, which could change the history of the city's southern area. **ARQ**

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