Built Heritage

RESEARCH ARTICLE

Open Access

Identifying disappeared historic buildings of port of Callao using georeferencing

Diego Javier Celis Estrada[1,2*], Francisco Felipe Quiroz Chueca[3] and Ruth Aracelis Manzanares Grados[1,2,4]

Abstract

The port of Callao is important for its varied historical and archaeological heritage, which includes several military buildings that were the main actors and witnesses of the colonial era of Peru (from the 16th century to the country's independence from Spain early in the 19th century). Despite the studies that have been carried out on the basis of documents and some eventual archaeological excavations, the port's main monument, namely, the Real Felipe Fortress, continues to hide very important information that could be used to understand the role that the fortress played in numerous historical events throughout the centuries. The main contribution of this study is the use of photogrammetry software and a Geographic Information System (GIS) to examine the Real Felipe Fortress. In this way, the nature of the atypical construction within the fortress is determined. As a result, it is possible to accurately establish the location of the defensive wall that surrounded the ancient city of Callao, as well as its first churches, whose records were lost after being destroyed by the 1746 earthquake and tsunami in Lima, the worst cataclysm registered in the history of Peru and South America. As a result, this study demonstrates that technology can be successfully used to establish and validate with great precision the existence of the location of churches that have been built in the port of Callao since the founding of Lima in the 16th century. Such identification allows architects, engineers and students who are interested in the history of monuments to discover hidden structures and buildings and carry out the necessary restoration and archaeological works, with the aim of recovering the history of the colonial architecture of Callao and other similar cities and ports worldwide.

Keywords georeferencing, Viceroyalty of Peru, church, military buildings, port of Callao, cultural heritage

1 Introduction

The Spanish conquistadors established the capital city of Peru on the coast of the Pacific Ocean. Through the port of Callao, Spanish colonialism controlled the transfer of goods, wealth and people between South America, Mexico, Europe and East Asia, i.e., the Philippines. The wealth of the silver mines located in Peru gave rise to legends about an immensely rich country, which, from the very beginning, aroused the greed of Spain's rival powers—Great Britain, France, Portugal and the Netherlands—to the point that they sent numerous privateering and navy expeditions to seize the distant colony from Spain (Suárez Espinosa 2015). Starting with Sir Francis Drake's incursion in 1579, various English corsairs tried to attack Spanish ports and merchant ships; at the beginning of the 17th century, Dutch armies tried to seize Peru on two occasions in 1615 and 1624. Ships belonging to these European powers constantly arrived at Peruvian coasts and ports with contraband merchandise.

On the other hand, in viceregal America, politics were closely linked to religion because of the need to justify

*Correspondence:
Diego Javier Celis Estrada
diego.celis@upn.edu.pe; delarq13@gmail.com
[1] Faculty of Architecture and Design, Universidad Privada del Norte, Lima, Peru
[2] Research Group GIADIPS, Faculty of Architecture and Design, Universidad Privada del Norte, Lima, Peru
[3] Department of History, Universidad Nacional Mayor de San Marcos, Lima 15081, Peru
[4] Directorate for Research, Innovation and Social Responsibility, Universidad Privada del Norte, Lima, Peru

the conversion of native peoples to the Christian faith (Mazzanti 2021). As a result, the Catholic Church and other religious orders built churches in all the cities and towns located within the colony (Hemming 1970). The port of Callao was not an exception; there were five main churches and several oratories located in hospitals and private homes built by Spanish architects (Dorta 1960; VanValkenburgh 2017).

2 The Hispanic Callao

The port city of Callao is located on the central coast of the Peruvian coast, on the shores of the Pacific Ocean, in South America (Fig. 1), approximately 11 kms west of the city of Lima, which is the capital of Peru, with which it currently forms a conurbation known as Metropolitan Lima (Distrito.Pe 2021).

The decision to designate Lima as the new capital was related to the characteristics of the port of Callao; among other attributes, the port is a wide and clean bay of low altitude, with an adequate depth of water near the shore and protection from the winds, which, mild as they are, are permitted to enter, exit and remain in the enormous bay. However, the historic city and port of Callao covered a larger territory than that by which the Constitutional Province of Callao is known today; this is because in pre-Hispanic times, the covered area included several surrounding populated centres. The new settlement comprised two well-differentiated parts, namely, the indigenous town, with ephemeral constructions of cane and mud used for its indigenous fishing ranches (Quiroz 2007), and the Spanish borough, which had permanent buildings. In both cases, the resulting urban structure differed thoroughly from the orderly model of the checkerboard or Spanish grid that was applied, for example, in the nearby city of Lima. The Spanish model followed an orientation determined by the light curve of the marine coast in an area that favoured the operations of loading and unloading to and from the ships under sail with chalupas or barges. Hence, without permanent docks or landings, the port warehouses were located side by side in a row along the coast. In other words, the configuration was similar to that of north-European ports formed by a single street extended along the sea or riverbank that in the German urban literature is called 'einstrassenwik' or 'villa of one street' (Holmberg, Sánchez Dextre y Pérez Torres Llosa 1989). In that sense, the port was located on a long street.

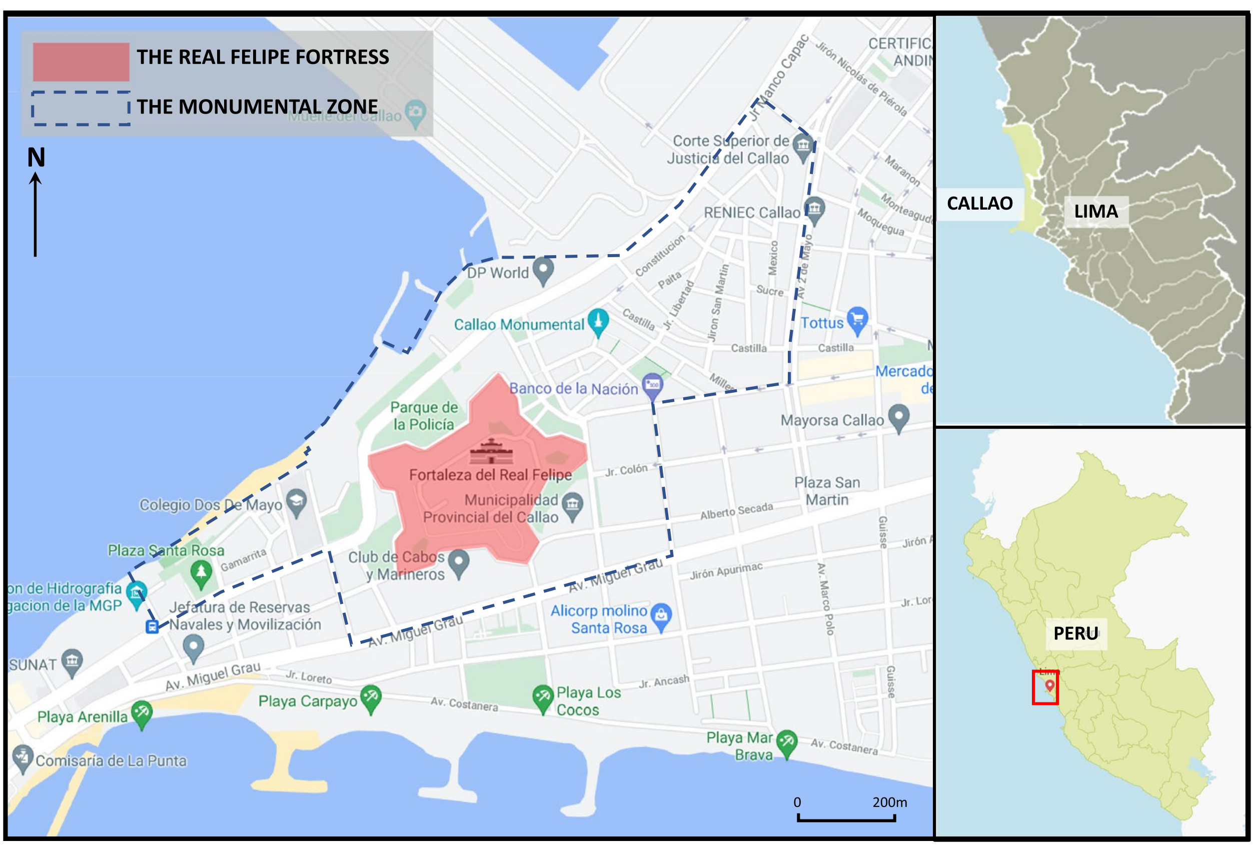

Fig. 1 Location of the port city of Callao (Source: Celis 2021)

In a short time, the port grew in size and population, as well as in urban activities such as handicrafts and other services typical of large ports. The new city saw the appearance of new buildings such as churches, convents and administrative premises.

The main church was located between the Spanish district and the indigenous district. In only a few decades, the port witnessed the rapid construction of churches belonging to religious orders. First were the Dominicans, whose church was devoted to Our Lady of Good Guidance (between 1567 and 1573); then came the Franciscans, with their convent of San Diego (1593), and the Augustinians, whose church was located near the creek of Callao (1595). The Jesuit church also occupied a place in the centre of the population. In the 1570s, the Cabildo, the prison and the butcher shop were all built on the current Santa Rosa square in the Chucuito borough. Since the end of the 16th century, the town has used the hospice of San Juan de Dios as a general hospital.

The location and orientation of the Spanish Callao was more related to its geographical features, pre-Hispanic background and trade needs than to the defence priorities of the Spanish empire. The military constructions that formed the defences of the port that served as a prelude to the capital city of the rich and extensive Viceroyalty of Peru were made without prior planning; rather, they were constructed according to the concrete needs and possibilities of the Spanish empire when its rivals challenged it in this part of the Pacific Ocean. The individual batteries that were installed after the first of the numerous attacks by corsairs and enemy fleets, such as that by the corsair Francis Drake in 1579, were eventually replaced by enormous defensive structures collectively known as the 'presidio' (De la Barra 1964). The most important challenges came from the English corsairs, Dutch naval fleets, and contrabandists from different countries (Fig. 2). Clearly, Callao needed to have a more efficient fortification for its own defence and that of the capital of the Viceroyalty of Peru, Lima.

3 The Port of Callao

The port of Callao is at a low altitude with respect to the sea. This characteristic generates the permanent risk of flooding, as seen in the events of 1746. Its urban morphology differed from that of the city of Lima. To be sure, both urban centres had reticular and aligned streets; however, the city has an orthogonal layout, while the urban blocks of the port were rectangular with variable dimensions and forms. The most important administrative and commercial buildings of Callao were the governor's house and the viceroy's palace, which were located on the shores of the sea, specifically, on two sides of a square. The parish church occupied the third side of the square, and an eight-gun battery constituted the fourth; the guard corps and the weapons room were also grouped near the viceroy's residence. On the north side of the same main street were the main stores, where the merchandise that Spanish ships imported from Chile, Mexico and different regions of the Viceroyalty of Peru were sold (Frézier [1716] 1908).

The aforementioned churches were constructed out of the same materials used in other buildings along the

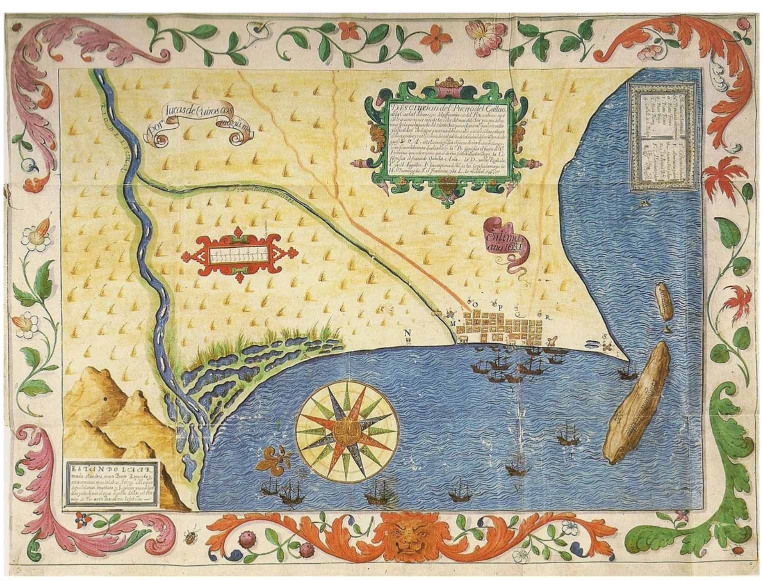

Fig. 2 Port of Callao and its fortifications in 1631, drawn by Lucas de Quiró (Source: Royal Palace Library, Madrid, adapted from Description of the port of Callao of the city of the Kings)

Peruvian coast, namely, a frame of cane reeds covered with clay or wood and then painted white. These materials abound in the examined area (Schilder Díaz 2000).

4 The Wall of Callao

The construction of the wall was mainly due to the work of Viceroy Pedro de Toledo and Leiva, Marquis of Mancera, who dedicated himself to providing effective security to the port of Callao and, consequently, to the city of Lima. The wall became a strong defensive device against enemies entering the wide bay intending to launch bombs and land. The work took seven years; the first stone was laid on November 21, 1640. Formally approved by the Council of the Indies in 1643, the work was finished in 1647 (Gálvez 1907) (Fig. 3).

The construction costs were paid by the entire population of Lima and Callao through taxes, or 'sisas', applied to sugar, wine and meat. The latter was estimated at the rate of half a real per arroba of beef and two reales per arroba of ram. The costs amounted to 876,000 pesos, not counting a series of expenses such as the stone that was obtained from the island of San Lorenzo (in front of the port), the transport of the stone by ships, and the salary of the soldiers who worked at the construction site (Lohmann 1964).

The project was designed by the engineer captain Juan de Espinosa; however, the work was directed by Francisco de Quirós and revised by the military governor of the port, Isidro Coronado, who in all actuality thoroughly changed Espinoza's original design. The plans were altered such that both the number of bastions and the dimensions of the wall were modified, and some elements were omitted, such as the water moat and the glacis, thereby making the enclosure less secure (Augustin 2011).

The resulting wall had 10 bastions on the front-facing land, which were called San Miguel, San Ignacio, Santa Cruz de la Buena Vista, Santa Catalina, Santiago, San Juan Bautista, Santo Domingo, San Felipe, San Luis and San Lorenzo el Real; they were separated from each other by a curtain or canvas wall of approximately 118 m, while the seaboard comprised five canvases and four platforms called San Antonio, San Bernardo (which was weakened by the force of the 1656 surge), San Pedro de Mancera and San Francisco de Borja or San Francisco Javier (Lohmann 1964).

The walled enclosure had two principal points of entry. One of them was oriented to the pier, and the other was oriented to the road to Lima. In addition, there were two small gates, namely, the Santiago and Mancera gates (Regal 1961), and six shutters in the port area equipped with portals for the cargo traffic (De Altolaguirre 1930). The main point of entry on the seaboard region was called Puerta de Santa María; it was located between the bastions of San Francisco and San Pedro de Mancera, and it was carved out of stone blocks. On the other extreme end of the enclosure port, the gate leading to the road to Lima was located next to the bastion of Santiago. The wall transformed the port into a fortified commercial city, which in the terminology of the time was known as a 'presidio'. Inside the presidio remained the squares, churches, houses, shops and port facilities; however, part

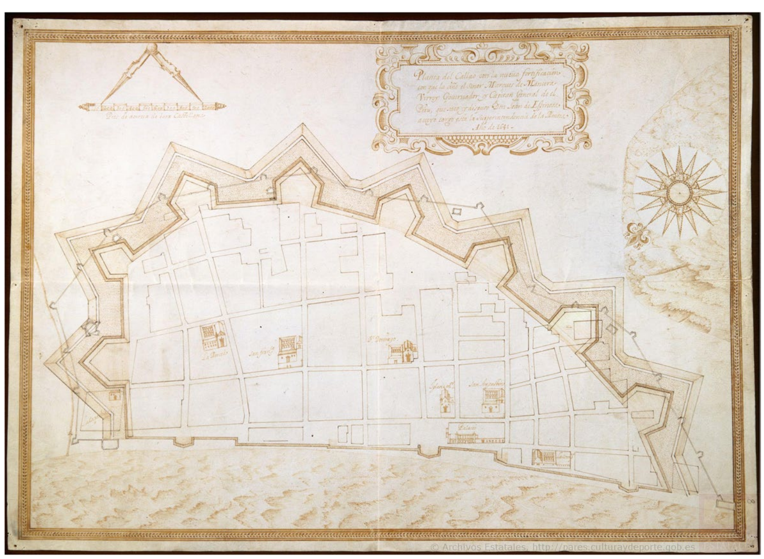

Fig. 3 Plan of the fortification project of the port of Callao, 1641, drawn by Don Joan de Espinosa who was in charge of the Superintendence of La Montea (Source: PARES, Seville. http://pares.mcu.es:80/ParesBusquedas20/catalogo/description/22484)

of the neighbourhoods and ranches belonging to the indigenous people were excluded and left outside of the walled enclosure of Callao.

Indeed, the wall directly affected the urban structure of Callao by imposing a limit on population growth and significantly restricting the beach space suitable for port activities, as the port was reduced to the shore located in front of the plaza or governorate space. In addition, the wall split the city into three parts, namely, the Spanish section and two towns or neighbourhoods inhabited by indigenous fishermen that were located at the extreme southern and northern points of the port city. These two areas were composed of ranches and lacked a conventional urban order (Lohmann 1964; Quiroz 2007).

In July 1693, the construction of the most ambitious work for the loading and unloading of the port city began, namely, the quarry dock positioned perpendicular to the coast with two steps extending towards the sea. On May 26, 1696, the work was inaugurated after having been designed by the Augustinian friar Pedro de La Madriz, who was the master supervisor of the royal factories of Callao, during the administration of Viceroy Melchor Portocarrero Lasso de la Vega, count of Monclova. The perpendicular pier soon highlighted an unintended effect, namely, it prevented the passage of the sand and stones that were normally carried away by the oblique waves; thus, in a short period of time, the stone pier rendered itself not useful because it ended up positioned in the middle of a newly formed beach. Another effect of this phenomenon was that the sea eroded the coast of the Mar Mansa at the base of the walls and forts. To solve this serious problem, during the administration of Viceroy José de Armendáriz, marquis of Castelfuerte, the main cosmographer, Pedro Peralta Barnuevo, proposed building a set of eight breakwaters that, once they gained land that extended to the sea, would form an artificial beach at the base of the wall. The construction of this system began on August 22, 1724; in only three years, the walls had 'moved away' from the shore enough to perform work on their bases. This system was adopted later on in other ports around the world (Lohmann 1964).

5 The Real Felipe Fortress

On November 10, 1746, Viceroy José Antonio Manso de Velasco, first count of Superunda, began the reconstruction of the port of Callao after the earthquake of October 28, 1746. However, instead of reproducing the old 'presidio', those in charge of the new project contemplated the idea of eliminating all of the civil activity buildings in Callao and replacing them with a modern fortress. In effect, the construction of the fortress known as the Real Felipe Fortress of Callao started almost immediately after the catastrophe, and on January 4, 1747, the French mathematician and Royal Navy pilot known as Louis Bodin was appointed the director of the most ambitious construction project Spain led in Hispanic America (Celis 2022).

According to state-of-the-art military science and engineering, the Real Felipe Fortress was constructed following an irregular pentagonal plan with masonry walls, which initially contained adobe parapets (Regal 1961) but later contained bricks, in addition to five bastions: El Rey, La Reina, San Carlos (later called El Príncipe), San Felipe (later called La Princesa) and San José (Gálvez 1907). It also had three caballeros, i.e., constructions on the embankments of the fortress, which were located in the bastions of El Rey, La Reina and San Felipe and known as the Tower of El Rey, La Reina and the Caballero of the 12 Cannons, respectively (López 1926).

6 Callao during the war of independence

During the second part of the 18th-century Peruvian War of Independence, i.e., from 1821 to 1826 (Paz Soldán, 1870), the Real Felipe Fortress was the locus of numerous military and political events of great importance. From the defence of the Spanish colony and its capital city from the first insurgent incursions in 1816 through the siege of the port by the maritime separatist expedition led by Lord Cochrane, the fate of Peru and South America was at stake in Callao. The fortress even served as a prison for the royalist and separatist forces, independent of the forces that controlled the strategic military position.

After achieving independence, on January 23, 1826, the fortress was the last Spanish colonial bastion to fall in South America (Regal 1961).

7 Georeferencing of the Port of Callao

To recognise the precise displacement of the old port of Callao, it is necessary to locate certain landmarks that still exist to this day. The old port was completely razed during the earthquake and tsunami of 1746; although there is no visible vestige remaining, there is valuable historical graphic documentation that shows the complete layout of the Real Felipe Fortress, including the disappeared glacis and the streets, main buildings and walls of the old port of Callao. For this reason, this essay uses historical graphic documentation and current photos of the fortress and the port city to establish points of reference to be able to geographically locate the old port.

The georeferencing work was supported by ArcMap software, which is a program utilised in the field of geographic information systems or GIS, management and cartographic building (GIS&Beers 2016). The software was developed by the Environmental Systems Research Institute, Inc (ESRI). The company was founded in 1969 by Jack Dangermond and Laura Dangermond and is headquartered in Redlands, California, USA (Business Wire 2018).

7.1 Selected graphic documentation

Among the selected historical graphic documentation is a geographical chart of the city of Callao before the earthquake of 1746 (Melo 1900) (Fig. 4), which is an adaptation of the ‘Plan de la Ville Du Callao’ (1717) made by the French military engineer and traveller Amédée Frézier (Frézier [1716] 1908), with a graphic scale of 300 toesas; this is an old unit of French length established in 1735 that is equivalent to 1,949 m (Centro Virtual Cervantes 2022). The chart shows the old port of Callao, including the layout of its streets, main buildings and walls, as well as its surroundings; the chart also refers to the exterior of the glacis of the Real Felipe Fortress.

There is also the ‘Map of the Real Felipe Fortress in Callao, erected by order of Don José Ramón Rodil by Professor D. Miguel Padilla de Peralta, at a time it was besieged by the enemy General Bolívar, the Year 1825’ (Zapatero 1983) (Fig. 5). This chart has a graphic scale of 300 Castilian rods, which is an old Spanish unit of length equivalent to 0.836 m (Fundación Juan March 2022); it is the most complete and detailed ancient map of the fortress showing its glacis.

Finally, there is an impressive aerial photograph of Callao with a resolution of 1694 PPI (Fig. 6) that shows the city, the port and the Real Felipe Fortress in modern times.

7.1.1 Orthophoto of the Real Felipe Fortress

In the photogrammetric survey of the Real Felipe Fortress, an RPAS DJI Mavic Pro was used to obtain aerial photographs. The flight plan was programmed using PIX4Dcapture software, performing a flight at a height of 40 m above the ground for a more detailed record and using a double grid to obtain a 3D model (Celis 2021). The photogrammetric processing of the aerial photographs was carried out using PIX4Dmapper software. A total of 3,343 georeferenced aerial photographs were used (WGS 54/UTM zone 18 s), with a median of 41,293 key points per photograph and a median of 8,679.11 matches per calibrated photograph. This resulted in an orthomosaic and a digital surface model (DSM) of the fortress, which was both georeferenced and in TIFF format, with an average sampling distance (GSD) of 1.25 cm/pixel (Fig. 7).

7.1.2 Photogrammetry of the access staircase to the underground vault

The access ladder to the underground vault and its immediate surroundings were photographically recorded with

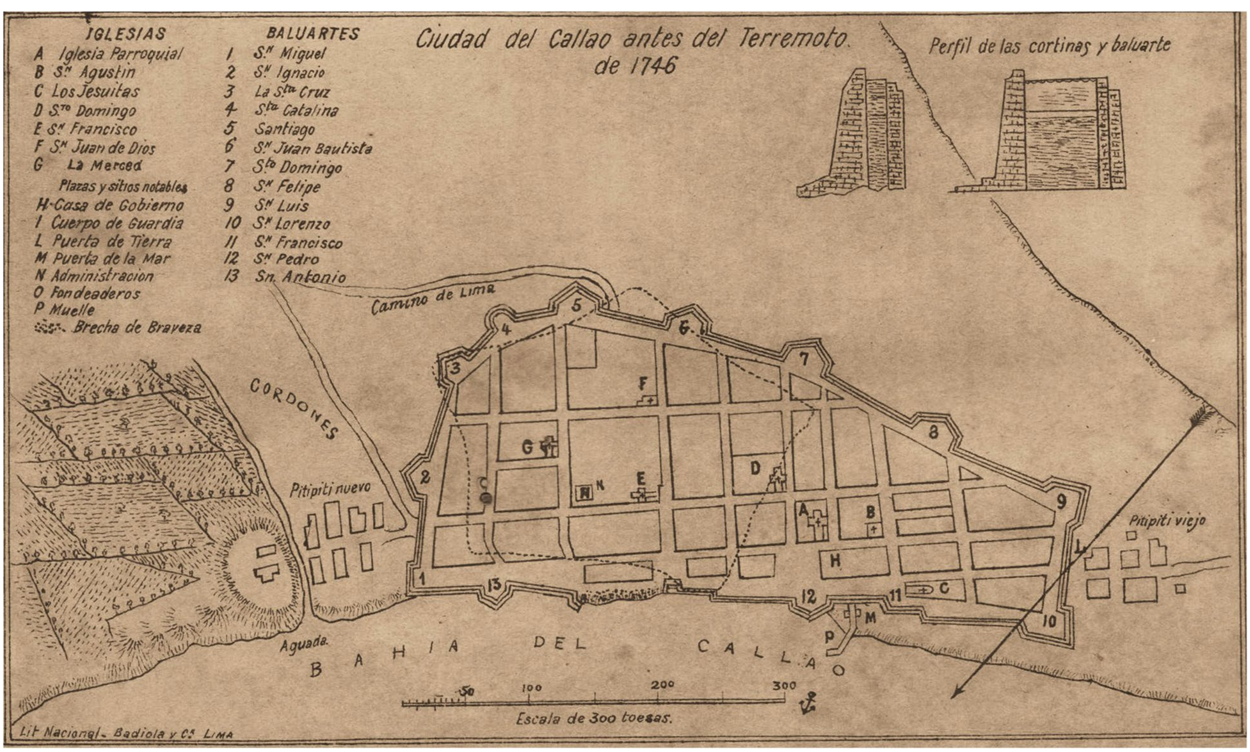

Fig. 4 City of Callao before the 1746 earthquake (Source: Melo 1900)

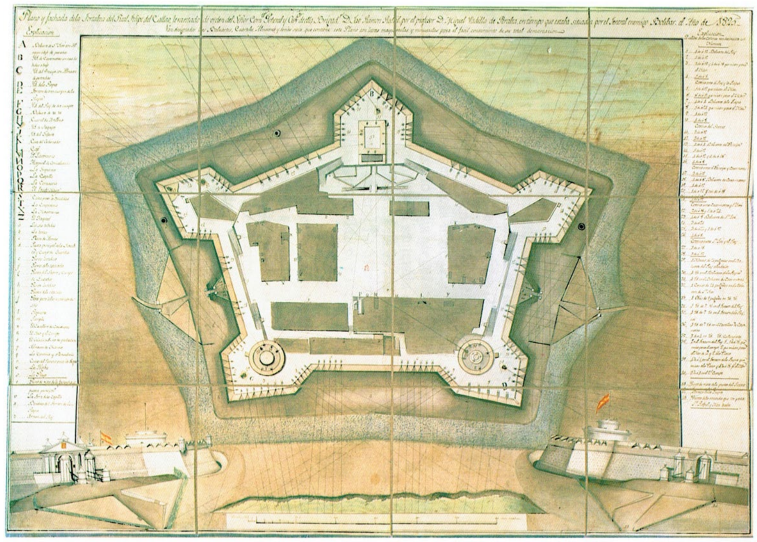

Fig. 5 The Real Felipe Fortress in 1825, it was besieged by the enemy General Bolibar, drawn by Miguel Padilla de Peralta (Source: Zapatero 1983)

Fig. 6 Aerial photograph of the port city of Callao (Source: aerial photograph of the National Aerophotographic Service, 2000)

a DJI Mavic Pro RPAS. Based on these photographs, the structure from motion virtual reconstruction methodology was used to generate a photogrammetric 3D model from a point cloud. The photogrammetric processing of the photographs was carried out using Agisoft Metashape Professional software.

Agisoft Metashape Professional is a stand-alone software product that enables the photogrammetric

Fig. 7 Orthophoto of the Real Felipe Fortress (Source: the authors)

processing of digital images, such as RGB or multispectral camera images, including those from multicamera systems. The software enables the generation of 3D spatial data, such as dense point clouds, textured polygonal models, georeferenced true orthomosaics, and DSMs/DTMs, which can be used in geographic information system (GIS) applications (AgiSoft LLC 2021). Ninety-nine photographs were used, and a dense point cloud of 81,596 points and a textured polygonal model of 2,559,492 faces and 1,283,576 vertices were obtained. Based on these results, it was possible to obtain an orthomosaic and a digital surface model (DSM) of the access staircase to the underground vault, which was both georeferenced and in TIFF format (Figs. 8 and 9).

Fig. 8 Photogrammetry of the access staircase to the underground vault and its immediate surrounding environment (Source: the authors)

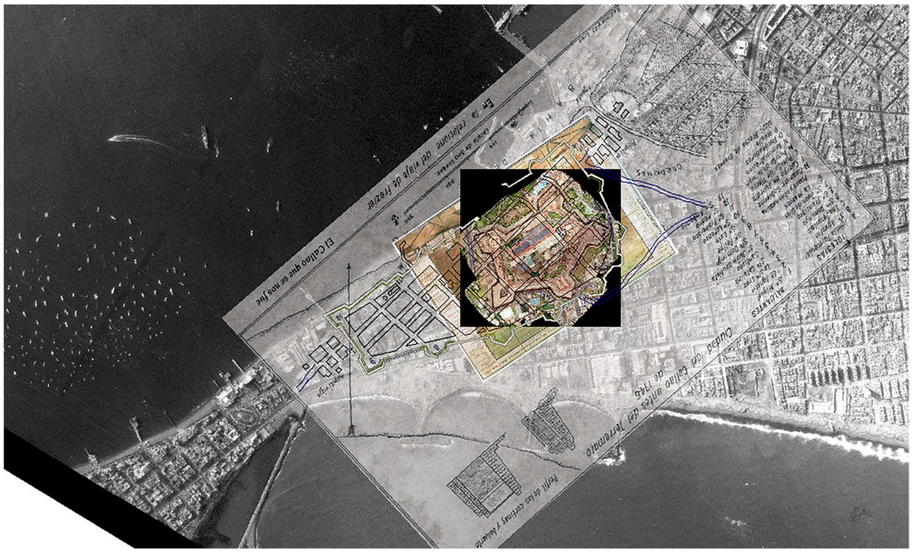

Fig. 9 Georeferencing in ArcMap 10.8 (Source: the authors, based on the aerial photograph of the National Aerophotographic Service, 2000)

It was not possible to obtain photographs with which to carry out a photogrammetric survey of the interior of the underground vault due to poor lighting. However, measurements of the underground vault were made with a Leica Disto D20 laser distance metre. Thus, it was possible to determine the dimensions and current state of the interior.

7.1.3 ArcMap

ArcMap 10.8 software, a product of the Environmental Systems Research Institute, Inc. (ESRI), was used. This geographic information system (GIS) and geodatabase management software enables map drawing and features georeferencing tools through the selection of control points to geographically locate selected graphic documents (Environmental Systems Research Institute, Inc 2023).

The orthophoto of the Real Felipe Fortress, which was obtained by photogrammetry, was georeferenced (WGS 54/UTM zone 18 s), which allowed its use not only as a geographical spatial reference but also as the source against which to georeference the remaining graphic documentation (Fig. 7).

The first georeference made using the orthophoto of the fortress was to 'Plano de la Fortaleza del Real Felipe del Callao, levantado de orden del Señor Don José Ramón Rodil por el Profesor D. Miguel Padilla de Peralta, en tiempo que estaba sitiada por el General enemigo Bolibar[sic], el Año de 1825' [Plan of the Real Felipe Fortress in Callao, erected by order of Don José Ramón Rodil by Professor D. Miguel Padilla de Peralta, at a time that was besieged by the enemy General Bolívar, the Year 1825] (Zapatero 1983) (Fig. 5). To do so, control points were added with respect to the fortress wall. In this way, it was possible to locate the original glacis of the fortress.

Then, the geographical chart 'City of Callao before the 1746 earthquake' (Melo 1900) (Fig. 4) was georeferenced by adding control points within the external original profile of the glacis. In this way, it was possible to locate the layout of the old port of Callao with respect to the Real Felipe Fortress by adding common control points. In addition, the aerial photograph of Callao was georeferenced with the orthophoto of the Real Felipe Fortress. In this way, the contemporary layout of the port city of Callao was superimposed over the georeferenced historical graphic documentation.

The abovementioned georeferencing work considered not only the graphic scales of the historical graphic documentation, each being equal to 300 units of length as either toesas or Castilian rods, but also their equivalent length in metres using the International System of Units. In this way, considering the measurement of the graphic scale of each plane and its equivalence in metres, the graphic documentation could be georeferenced, and the degree of accuracy could be confirmed (Table 1).

Notably, the degree of accuracy depends not only on the georeferencing of the graphic documentation but also on the precision with which the map of the fortress and the geographical chart of the old port of Callao were drawn.

Table 1 Georeferencing of graphical documentation

Documentary source		Year	Length unit	Equivalency	Accuracy	Figure
Base	Orthophoto of the fortress	2021	meters	1 m	1	Fig. 7
georeferenced	'Plano de la Fortaleza del Real Felipe del Callao, levantado de orden del Señor Don José Ramón Rodil por el Profesor D. Miguel Padilla de Peralta, en tiempo que estaba sitiada por el General enemigo Bolibar[sic], el Año de 1825' [Plan of the Real Felipe Fortress in Callao, erected by order of Don José Ramón Rodil by Professor D. Miguel Padilla de Peralta, at a time that was besieged by the enemy General Bolívar, the Year 1825]	1825	Castilian rod	0.835905 m	0.99	Fig. 5
	Callao city before the 1746 earthquake	1900	French toesas	1.949 m	0.97	Fig. 4
	Aerial photography of the port city of Callao	2000	meters	1 m	1	Fig. 6

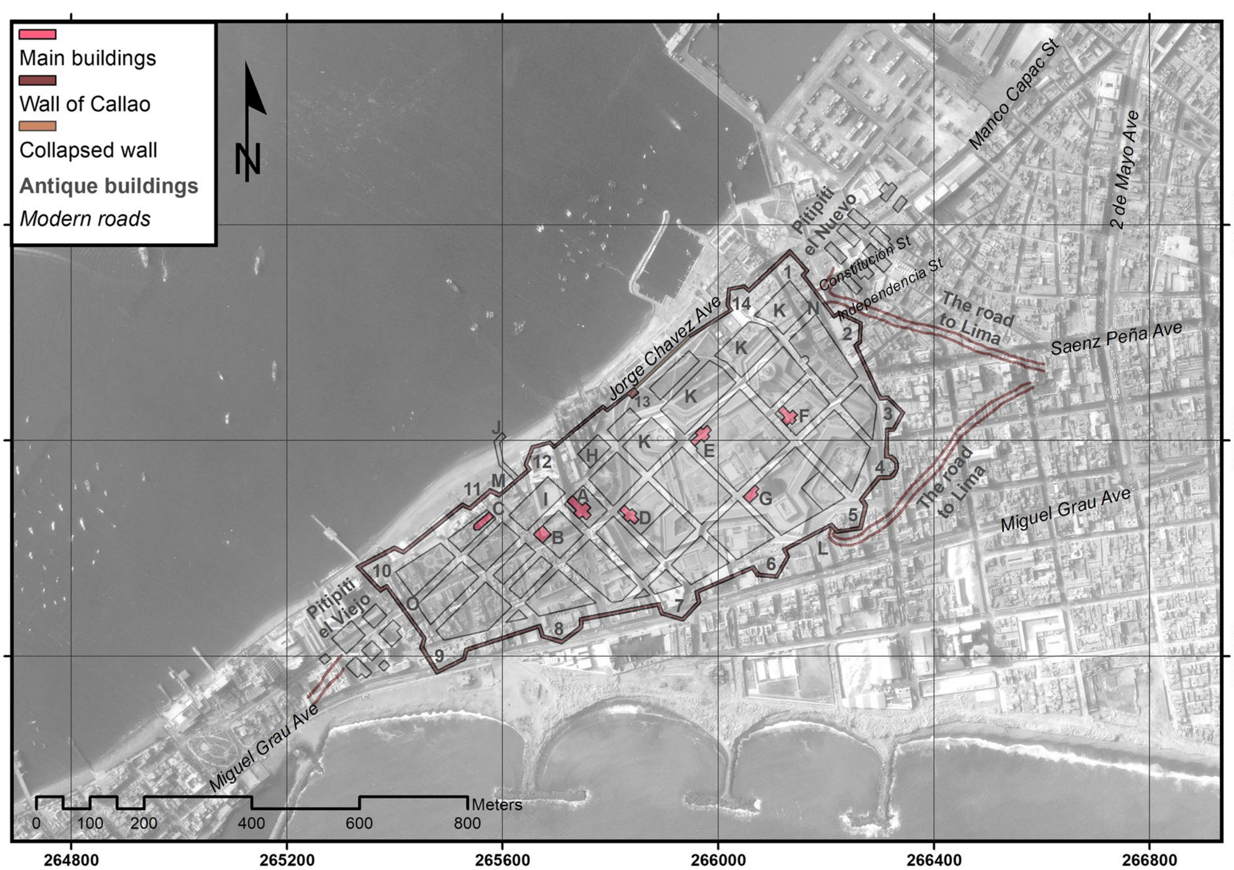

Fig. 10 Georeferenced plan of the port of Callao with respect to the current city. CHURCHES: A. Parish B. San Agustín C. Los Jesuitas D. Santo Domingo E. San Francisco F. La Merced. BUILDINGS: G. San Juan de Dios Hospital H. Governor's house I. Viceroy's palace J. Dock K. Main stores. GATES: L. to Lima M. Santa María N. Santiago O. Mancera. BASTIONS: 1. San Miguel 2. San Ignacio 3. La Santa Cruz de la Buena Vista 4. Santa Catalina 5. Santiago 6. San Juan Bautista 7. Santo Domingo 8. San Felipe 9. San Luis 10. San Lorenzo el Real 11. San Francisco de Borja/Javier 12. San Pedro de Mancera 13. San Bernardo 14. San Antonio (Source: the authors, based on the aerial photograph of the National Aerophotographic Service, 2000)

8 Georeferenced plans

8.1 Old Port of Callao

The georeferencing of the historical graphic documentation allowed us to draw a plan in which the urban distribution of the old presidio and the port of Callao overlaps with the current disposition of the port city (Fig. 10). It is noted that the old urban layout is parallel to the coastline and formed by one street that extends along the seashore, similar to that of North European ports (Holmberg, Sánchez Dextre y Pérez Torres Llosa 1989); thus, it has no relation to the current urban layout. Thanks to this procedure, it is possible to theorise about and confirm the location of the main buildings and the exact location of the old wall, all of which disappeared due to the earthquake and tsunami that occurred on October 28, 1746.

8.2 Location of the San Francisco Church

During the viceroyalty, burials used to take place in the subsoil of the temples due to the belief that one remained closer to God if one's body rested in sacred ground (Carlín 2018). For this purpose, the churches had burial vaults located under their pavement, known as catacombs (San Cristóbal 2011).

The georeferenced orthomosaic of the access stairway to the underground vault allowed its use as a geographical spatial reference. The digital surface model (DSM) helped to generate a profile graph of the access to the underground vault, which was complemented with the measurements taken of the underground vault. In this way, it was possible to make drawings of sections of the underground vault.

The orientation of the underground vault, known as the ossuary in the Real Felipe Fortress, is not related to the layout of the wall of the monument since it is neither perpendicular nor forms specific angles with the wall. Rather, its location, according to the georeferencing of the graphic documentation, coincides with the location of the San Francisco Church of the old port of Callao. In addition, the underground vault has two ventilation holes that do not coincide with the exterior but rather with the solid interior of the fortress wall. Therefore, it is concluded that this vault predates the construction of the fortress and served as the catacomb area of the San Francisco Church located in the old city of the port of Callao.

The remaining catacomb area is rectangular, and its dimensions are approximately 4.20 m wide, 6.00 m long and 2.55 m high; furthermore, it is approximately 2.95 m below ground level. The floor is made of stone, the walls of the vault are made of stone masonry with lime mortar (calicanto), and the vault is made of bricks with lime mortar. The inner wall has a niche and two ventilation holes on both sides. The staircase of access to the catacomb has a width of approximately 0.93 m and 15 steps of variable dimensions.

The underground vault has undergone structural reinforcement to prevent its collapse. The base of the walls has been thickened with stone and cement. In addition, two concrete columns with metal beams have been put in place to shore up the interior of the vault.

In addition, near the access to the catacomb, to the southeast and at a distance of approximately 2.65 m, there are two graves that have been excavated above ground level. Both pits have brick walls with lime mortar. The graves are placed parallel to each other and spaced at approximately 1.40 m. Their dimensions are approximately 2.00 m long, 0.90 m wide and 2.15 m deep. It can also be seen that the graves have the same orientation as the catacomb. In turn, both, according to the georeferenced plan, correspond to the alignment of the block to which the San Francisco Church belonged (Fig. 11). For all these reasons, the discovery of the location and the vestiges belonging to the San Francisco Church is confirmed.

8.3 Location of the wall

According to the georeferenced plan, the seaboard would extend parallel to the coast and along Jorge Chávez Avenue (formerly called San Román Avenue), reaching Emilio San Martín Square. The wall would continue through the corners of Constitución Street and Independencia Street. Then, it would extend in the direction of the beach of the Mar Brava, crossing in front of the bastion of San Felipe and the Caballero of the 12 Cannons, inside which four bomb-proof vaults were built, also known as casemates; it would then continue parallel to the Almirante Miguel Grau Avenue (see Fig. 12).

In addition, the foundations of the wall coincide with the description of the location of the wall according to the georeferenced plan. In this way, the exact location of the old port of Callao, its layout of streets and its main buildings are confirmed (Arrús 1904).

8.4 Location of other important buildings

After obtaining the location and structural characteristics of the San Francisco Church and the wall of Callao that were previously destroyed by the 1746 earthquake, it was possible to generate a georeferenced plan of the location of other important buildings, i.e., other churches within the old port of Callao, which were also destroyed by the abovementioned earthquake and subsequent tsunami. Notably, regarding these lost buildings, no previous study of the possible catacombs or any existing records of the current constructions have been made, despite the fact that these structures belong to the heritage and colonial history of the most important port of the viceroyalty.

Thanks to the geographical spatial reference of the plans, the approximate location of the other existing churches can be established as follows (Fig. 12):

- The parish church was located on the border of the Marruecos park at the crossing of United States Avenue and Agustín Gamarra Avenue. Approximate location: Zone UTM: 18 L, X: 265,747.10, Y: 8,665,470.14
- The San Agustín Church was located on the border of Dos de Mayo High School at the intersection of Agustín Gamarra Avenue and Chocano Street.
  Approximate location: Zone UTM: 18 L, X: 265674.59, Y: 8665426.81

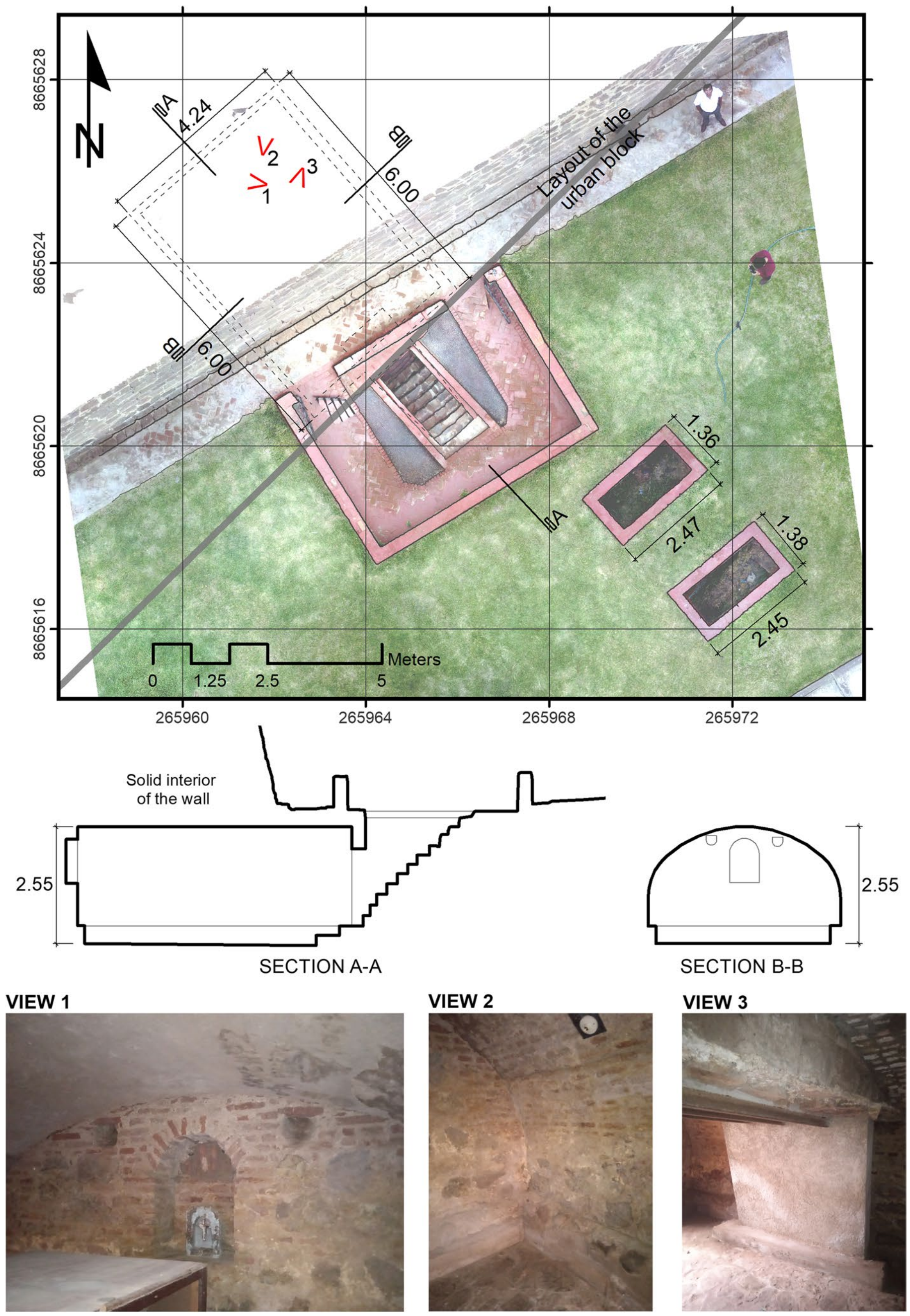

Fig. 11 Georeferenced plan of the location of the catacomb area and the two graves of the San Francisco Church. VIEW 1: You can see the interior wall and its niche, with the ventilation holes on both sides. VIEW 2: The floor is made of stone, the walls of the vault are made of stone masonry with lime mortar, and the vault is made of bricks with lime mortar. VIEW 3: You can see the reinforcement structure installed to avoid vault collapse (Source: the authors)

- The Los Jesuitas Church was located in the middle of the block located between Titicaca Street, Chanchamayo Street and Gamarrita Street.
  Approximate location: Zone UTM: 18 L, X: 265563.49, Y: 8665450.55
- The Santo Domingo Church was located on the border of Concha Acústica Park with Jorge Chávez Avenue.
  Approximate location: Zone UTM: 18 L, X: 265835.51, Y: 8665462.85

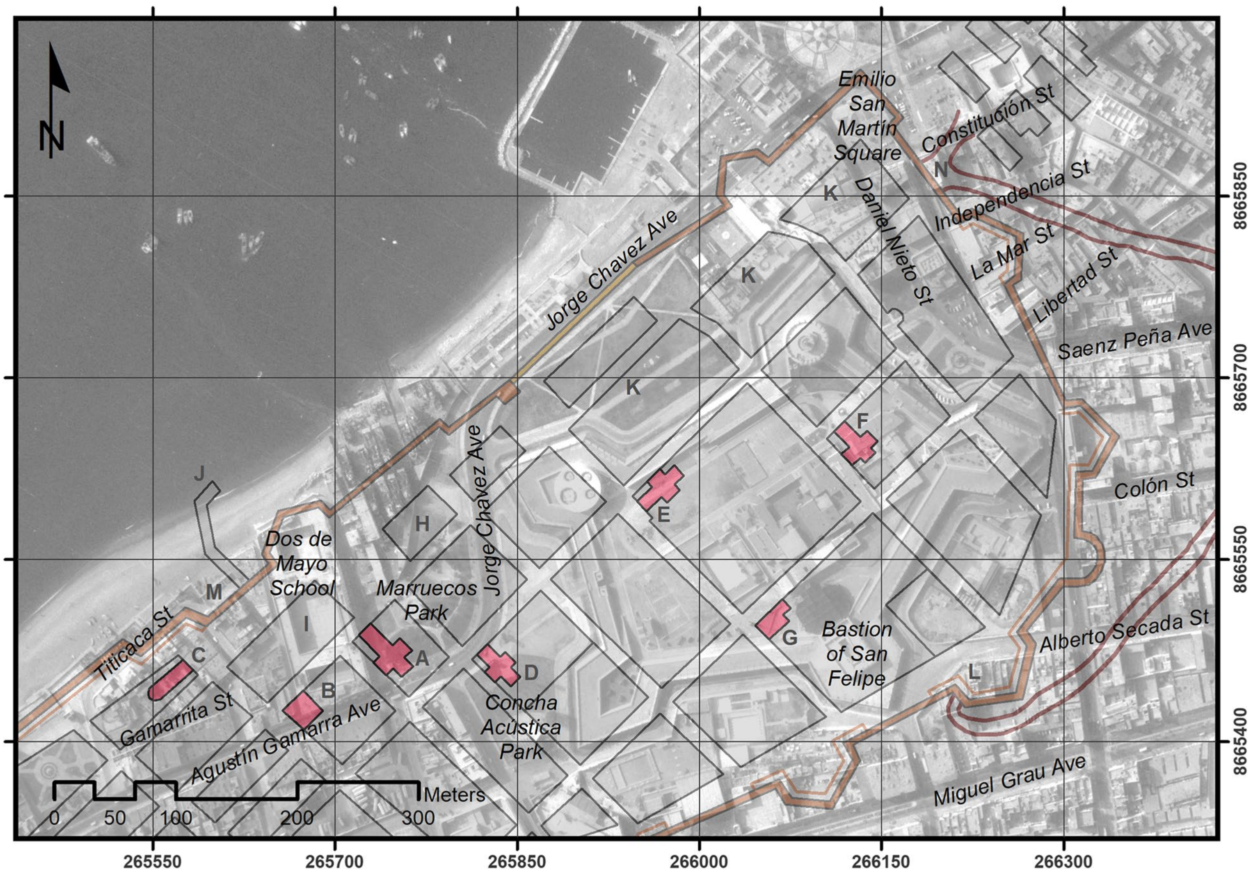

Fig. 12 Georeferenced plan of the layout of the wall and the location of the main buildings of the port of Callao with respect to the current city. CHURCHES: A. Parish B. San Agustín C. Los Jesuitas D. Santo Domingo E. San Francisco F. La Merced. BUILDINGS: G. San Juan de Dios Hospital H. Governor's house I. Viceroy's palace J. Dock K. Main Stores. GATES: L. to Lima M. Santa María N. Santiago (Source: the authors, based on the aerial photograph of the National Aerophotographic Service, 2000)

- The La Merced Church was located inside the Real Felipe Fortress, approximately 45 m in front of the inner face of the main entrance.
  Approximate location: Zone UTM: 18 L, X: 266131.93, Y: 8665642.64
- The San Juan de Dios Hospital was located inside the Real Felipe Fortress, approximately 40 m west of the inner face of the bastion of San Felipe.
  Approximate location: Zone UTM: 18 L, X: 266060.05, Y: 8665498.74

9 Conclusion and discussion

The documentary and graphic evidence used herein shows that the importance of the Real Felipe Fortress lies not only in its having been one of the most important military buildings in the Spanish Empire and its having been the scene of important historical events that helped to procure the independence of Hispanic America but also in its role in preserving the religious archaeological evidence of the old port of Callao, since its interior surface has not been supported by buildings with deep foundations.

Georeferencing is a powerful tool used in the graphic documentation developed by the ArcMap program that was used herein to corroborate and identify the existence of vestiges of the old port of Callao, making clear the usefulness of this digital tool in historical and archaeological investigations.

The importance of the churches as the focal points of decisions made in the viceregal stage presume that they were important precincts where people of diverse social groups, such as the indigenous people, came for their inclusion in not only Catholicism but also the Spanish population; therefore, these churches are places with a potential cultural heritage that are still submerged in modern structures due to the ignorance of their location within the current port city of Callao. This study aims to provide a better outlook with which to carry out actions related to rescuing these examples of cultural heritage history that still exist even after an earthquake and subsequent tsunami erased the visual evidence of their locations.

With the analysis gained by using georeferencing, evidence is shown regarding the early development of architecture and viceregal urbanism in the port of Callao; these are previously unstudied themes that should be examined due to the possible contribution of the areas as both cultural heritage sites and examples of the history of viceregal architecture.

Finally, this research on the port of Callao opens up opportunities for future research in different fields. It permits archaeological and historical research to establish the location of main monuments located not only within the old port of Callao but also in other historical sites such as the City of Kings (Ciudad de los Reyes, or Lima), which was the first capital city of the vast and rich Viceroyalty of Peru and is a city that still hides many surprises about its past. In addition, the use of this technology is important for the discovery, investigation and conservation of the architectural heritage of Peru since the entire national territory is exposed to natural and anthropic disasters; several historical buildings have already been lost to such disasters. Therefore, the methodology outlined in this research can be used for similar case studies.

Abbreviations

m Metres
ppi pixels per inch

Acknowledgements

The authors thank the Universidad Privada del Norte for its support and guidance in the development of this research work. They especially thank the architect Víctor Pimentel Gurmendi for his inspiration to continue researching in this field.

Authors' contributions

All authors read and approved the final manuscript.

Funding

Not applicable.

Availability of data and materials

Not applicable.

Declarations

Competing interests

The authors declare that they have no competing interests.

Received: 15 May 2023 Accepted: 6 September 2023
Published online: 23 October 2023

References

AgiSoft LLC. 2021. *Metashape Intelligent photogrammetry*https://www.agisoft.com/pdf/metashape_presentation.pdf. *Accessed 17 Jul 2023.*

Arrús, Darío. 1904. *El Callao en la época del coloniaje antes y después de la catástrofe de 1746*. Callao: Imprenta de "El Callao".

Augustin, Reinhard. 2011. *Las murallas coloniales de Lima y el Callao*. Lima: Universidad Ricardo Palma.

Business Wire. 2018. *Esri Named on Forbes Best Midsize Employers List*https://web.archive.org/web/20180612142136/https://finance.yahoo.com/news/esri-named-forbes-best-midsize-135100557.html. *Accessed 31 Aug 2023.*

Celis, Diego. 2021. *Estudio y evaluación de las restauraciones y del estado actual de la Fortaleza del Real Felipe del Callao (Perú)*. Valencia: Universidad Politecnica de Valencia.

Celis, Diego. 2022. Estudio y evaluación de las restauraciones y del estado actual de la Fortaleza del Real Felipe del Callao-Perú. *Devenir- Revista De Estudios Sobre Patrimonio Edificado* 9 (18): 133–159. https://doi.org/10.21754/devenir.v9i18.1292.

Centro Virtual Cervantes. 2022. *Toesa (1735)*https://cvc.cervantes.es/actcult/museo_naval/sala8/armas/armas_14.htm#:~:text=La%20toesa%20era%20una%20antigua,patr%C3%B3n%20en%20las%20operaciones%20geod%C3%A9sicas. *Accessed 20 Apr 2023.*

Cristóbal, San, and Antonio. 2011. *Arquitectura virreinal religiosa de Lima*. Lima: Universidad Católica Sede Sapientiae.

De Altolaguirre, Ángel. 1930. *Colección de las Memorias o Relaciones que escribieron los Virreyes del Perú. Vol. II*. Madrid: Imprenta Mujeres Españolas (S.A.).

Distrito.Pe. 2021. *El distrito del Callao*.https://www.distrito.pe/distrito-callao.html. *Accessed 25 Apr 2023.*

Dorta, Enrique. 1960. *Fuentes para la historia del arte hispanoamericano II*, vol. 55. Sevilla: Instituto Diego Velazquez.

Ernesto, Carlín. 2018. *Entre luces y sombras*.https://elperuano.pe/noticia/71166-entre-luces-y-sombras. *Accessed 22 Apr 2023.*

Environmental Systems Research Institute, Inc. 2023. *MarketLine Company Profile: Environmental Systems Research Institute, Inc.* New York: MarketLine.

Frézier, Amédée-François. 1908. *Relación del viaje por el Mar del Sur a las costas de Chile y Perú durante los años 1712, 1713 i 1714. Translated by Peña Nicolás*. Santiago de Chile: Imprenta Mejia 1716.

Fundación Juan March. 2022. *Vocabulario de Comercio Medieval - Legado Gual Camarena. Universidad de Murcia.* https://www.um.es/lexico-comercio-medieval/index.php/v/lexico/15941/vara#:~:text=La%20vara%20de%20Burgos%20(castellana,%3D%203%20tercias%20%3D%204%20palmos . Accessed 22 Apr 2023.

Gálvez, Anibal. 1907. *El Real Felipe*. Lima: Imprenta "Prisma" Mercaderes 48.

GIS&Beers. 2016. *ArcMap*.http://www.gisandbeers.com/arcmap/. *Accessed 20 Apr 2023.*

Hemming, John. 1970. *The Conquest of the Incas*. New York: Harcourt Brace Jovanovich.

Holmberg, Rikard, Nello Sánchez, and Ricardo Pérez. 1989. *Historia del Callao - Historia 1615–1826*. Callao: Centro de Investigaciones Históricas del Callao.

la Barra, De., and Felipe. 1964. *Monografía histórica del Real Felipe del callao y Guía del Museo Histórico-Militar*. Callao: Imprenta del Colegio Militar Leoncio Prado.

Lohmann, Guillermo. 1964. *Las defensas militares de Lima y Callao*. Madrid: Escuela de Estudios Hispano-Americanos.

López, Eleazar. 1926. *El Callao Histórico*. Lima: Litografía del Comercio.

Mazzanti, C. 2021. The construction of the vaults in the cathedrals of the Viceroyalty of Peru. *History of Construction Cultures* 1: 26–32. https://doi.org/10.1201/9781003173359-4.

Melo, Rosendo. 1900. *El Callao, Monografía histórico-geográfico*. Lima: Librería e Imprenta Gil.

Paz Soldán, Mariano. 1870. *Historia del Perú independiente. Segundo periodo, 1822- 1827*. Lima: LEMALE.

Quiroz, Francisco. 2007. *Historia del Callao: De puerto de Lima a Provincia Constitucional*. Callao: Gobierno Regional del Callao, Pedagógico San Marcos.

Regal, Alberto. 1961. *Historia del Real Felipe del Callao (1746–1900)*. Callao: Imp. Colegio Militar Leoncio Prado.

Schilder, César. 2000. *La herencia española: las bóvedas y cúpulas de quincha en el Perú. Tercer Congreso Nacional de Historia de la Construcción: 1019–1026*.https://idus.us.es/handle/11441/67401. *Accessed 10 Apr 2023.*

Suárez, Margarita. 2015. Sedas, rasos y damascos: Lima y el cierre del comercio triangular con México y Manila en la primera mitad del siglo XVII. *América Latina en la historia económica* 22 (2): 101–134.

VanValkenburgh, Parker. 2017. Unsettling Time: Persistence and Memory in Spanish Colonial Peru. *Journal of Archaeological Method and Theory* 24 (1): 117–148. https://doi.org/10.1007/s10816-017-9321-7.
Zapatero, Juan. 1983. *El Real Felipe del Callao: Primer castillo de la "Mar del Sur."* Madrid: Spain. Servicio Histórico Militar.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.