



THE ROMAN PIER OF SAN CATALDO: FROM ARCHAEOLOGICAL DATA TO 3D RECONSTRUCTION

EL MUELLE ROMANO DE SAN CATALDO: DE LOS DATOS ARQUEOLÓGICOS A LA RECONSTRUCCIÓN 3D

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Highlights:

- A key requirement for a better understanding of the Roman pier of San Cataldo (Lecce, Italy) was the creation of a 3D model from an image-based survey.
- The 3D reconstruction process of the monument was based on a production pipeline anchored to metric data and historical-archaeological information.
- The final 3D reconstruction proposal shows the original shape of the Roman pier, the ancient surrounding landscape and its related activities.

Abstract:

The pier of San Cataldo (Lecce, Italy) is located along the Adriatic coast about 10 km east-northeast of the ancient city of *Lupiae*, (today's Lecce), and is the best-preserved port structure of the Roman Age in Apulia. It was researched between 2004 and 2007 by the Laboratory of Topography and Photogrammetry (LabTAF) of the University of Salento, who produced a detailed analysis of the remain and a survey of the portion still visible on the mainland. At the same time, aerial surveys and the study of historic aerial photos from the 1940s and 50s supported a topographic study of the site. Since 2013, within the activities of the LabTAF, the structure has been the subject of an excavation campaign where a further portion of the pier was discovered in the mainland, and the underwater remains were documented. This contribution aims to emphasise the importance of collecting complete metric and historical-archaeological data for a proper three-dimensional (3D) reconstruction of the structure. On this occasion a photogrammetric survey was conducted and a 3D image-based model created that has become the starting point of the reconstruction hypothesis of the pier and its topographical context. The final model represents a reasonable synthesis of the interpretation of the collected data, and serves as a starting point for tackling the future integration or modification of the structure.

Keywords: virtual archaeology; archaeological survey; 3D image-based modelling; cultural heritage; documentation

Resumen:

El muelle de San Cataldo (Lecce, Italia) está situado en la costa adriática a unos 10 km en dirección este-noreste desde la antigua ciudad de *Lupiae* (actual Lecce), y es una de las estructuras portuarias de edad romana mejor conservadas de Apulia. La investigación se llevó a cabo entre 2004 y 2007 por parte del Laboratorio de Topografía y Fotogrametría (LabTAF) de la Universidad del Salento, que produjo un análisis detallados de los restos y la topografía de la porción visible en la tierra firme. Al mismo tiempo, se realizaron vuelos aéreos y se estudiaron las fotografías aéreas históricas de los años 1940 y 50, dando lugar a un estudio topográfico del sitio. Desde 2013, como parte de las actividades del LabTAF, la estructura ha sido objeto de una campaña de excavación arqueológica que desenterró una ulterior porción del muelle en tierra firme, y se documentaron los restos sumergidos. Esta contribución quiere enfatizar la importancia de abordar la reconstrucción tridimensional (3D) fiel de la estructura, siendo necesarios todos los datos métricos e histórico-arqueológicos. En esta ocasión, se realizó un levantamiento fotogramétrico y un modelo 3D basado en imágenes como punto de partida para realizar la hipótesis de reconstrucción del muelle y de su contexto topográfico. El modelo final representa una síntesis razonable de la interpretación de los datos recogidos, y sirve como punto de partida para abordar la futura integración o modificación de la estructura.

Palabras clave: arqueología virtual; prospección arqueológica; modelado 3D a partir de imagen; patrimonio cultural; documentación

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1. Preface

The pier of San Cataldo (Lecce, Italy) is an Apulian Roman port structure with a remarkable conservation status. The seaport was located about 10 km in the east-northeast of the ancient city of *Lupiae*, Lecce, on the low and sandy Adriatic coast. Currently, the remains of the pier are visible immediately southward of the lighthouse of San Cataldo, near Piazza Adriano (Fig. 1). Until a few years ago, the structure was in a state of total abandonment but, since 2004, within the *Portus Lupiae* project of the Topography and Photogrammetry Laboratory (LabTAF) of the University of Salento, a series of multidisciplinary investigations have been carried out with the collaboration of several laboratories of the Department of Cultural Heritage of Lecce. The focus of the project aimed to better understand the constructive features of the structure and the topographic data of the monument and of the surrounding area. The great amount of the collected information has contributed to the elaboration of a 3D reconstruction proposal that allowed us to create a 3D model that expresses technical-constructive

deductions emerged from archaeological investigations. This contribution aims to show that for a proper 3D reconstruction of the pier, it is needed to have the whole metric and historical-archaeological data. This 3D-model valorized the monument and stimulated a series of initiatives from the local institutions aimed at its enhancement and fruition; the latest action provided for its consolidation and restoration works and for the realization of a pier visiting path (Fig. 2).

2. The Roman pier before the archaeological investigations

In a text of Pausanias, the construction of an artificial pier is attributed to the emperor Hadrian (PAUS. VI, 19, 9). It was the port facility of the ancient *Lupiae*, a Roman *municipium* associated to the gens *Camilia* that was granted the colonial status probably by Marco Aurelio. Other sources recall the port of *Lupiae* as Ottaviano landing point from Apollonia (NIC. DAMASC., *Vita Caesaris*, fr. 130, XVII-XVIII; APPIAN., *Bella Civ.*, III 2, 10); these sources demonstrate that between the end of



Figure 1: San Cataldo (Lecce, Italy): a) Aerial photo from southwest of the city; b) Location of the city in southern Italy.

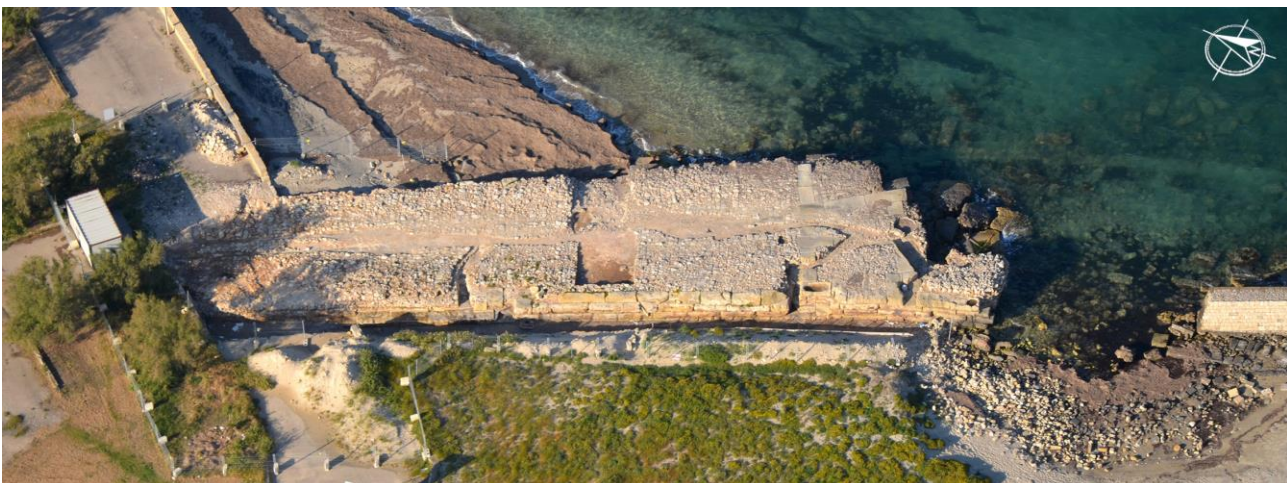


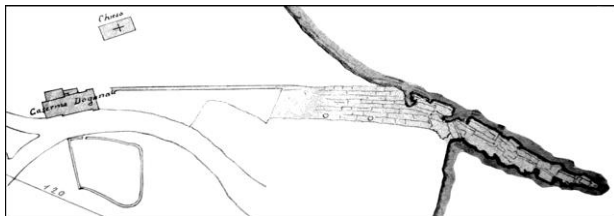
Figure 2: Aerial image from west of the mainland ruins of the Roman pier of San Cataldo (Lecce, Italy).



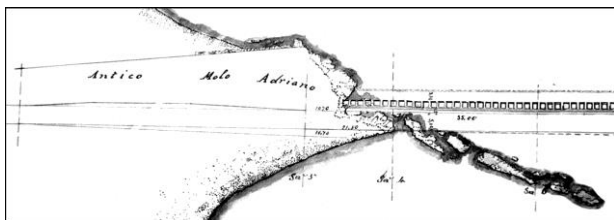
Figure 3: The Roman ruins of the pier on a technical map of I. Bernardini dated 1860 (State Archive of Lecce).



(a)



(b)



(c)

Figure 4: Details of the Roman pier on technical maps from Municipal Archive of Lecce: a) F. Pinto (1866); b) E. Fany (1881); c) E. Dragonetti, I. Sammartino (1890).

the Republican age and the Imperial age the port was already equipped with some infrastructures and then probably enhanced with the construction of the Hadrian pier mentioned by Pausanias (Sammarco & Marchi, 2008).



Figure 5: The southern part of the Roman pier in the late 19th century.



Figure 6: Photo of the 30s of the 20th century where are visible the remains of the Roman pier (A) and the new 20th century pier built in continuation of the ancient remains (B).

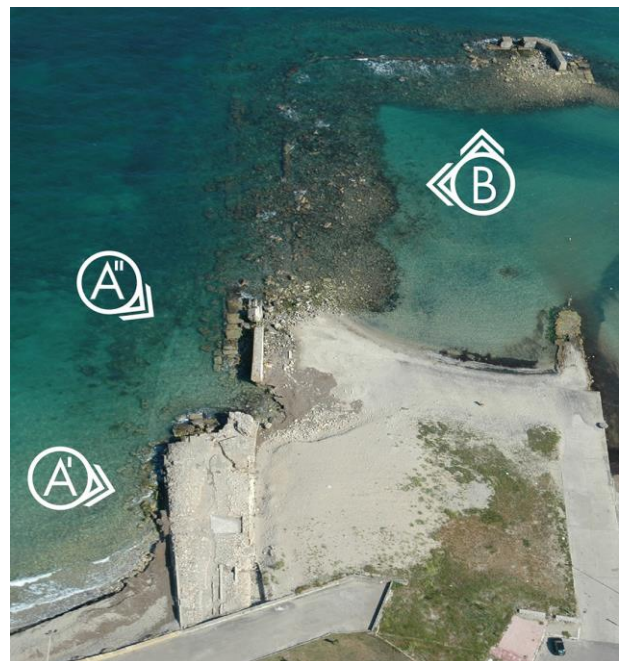


Figure 7: The ruins of the Roman pier (A'), with the submerged portion (A'') and the remains of the 20th century pier (B).

Further historical information on the presence of an ancient port structure in San Cataldo dates back to the 16th century (De Ferraris, 1558). However, over the centuries and until the start of the *Portus Lupiae* project, the pier has never been the focus of a targeted and integrated study, and news from local historians mentioned only simple reports accompanied by brief descriptions (Marciano, 1855; De Simone, 1874; De Giorgi, 1888).

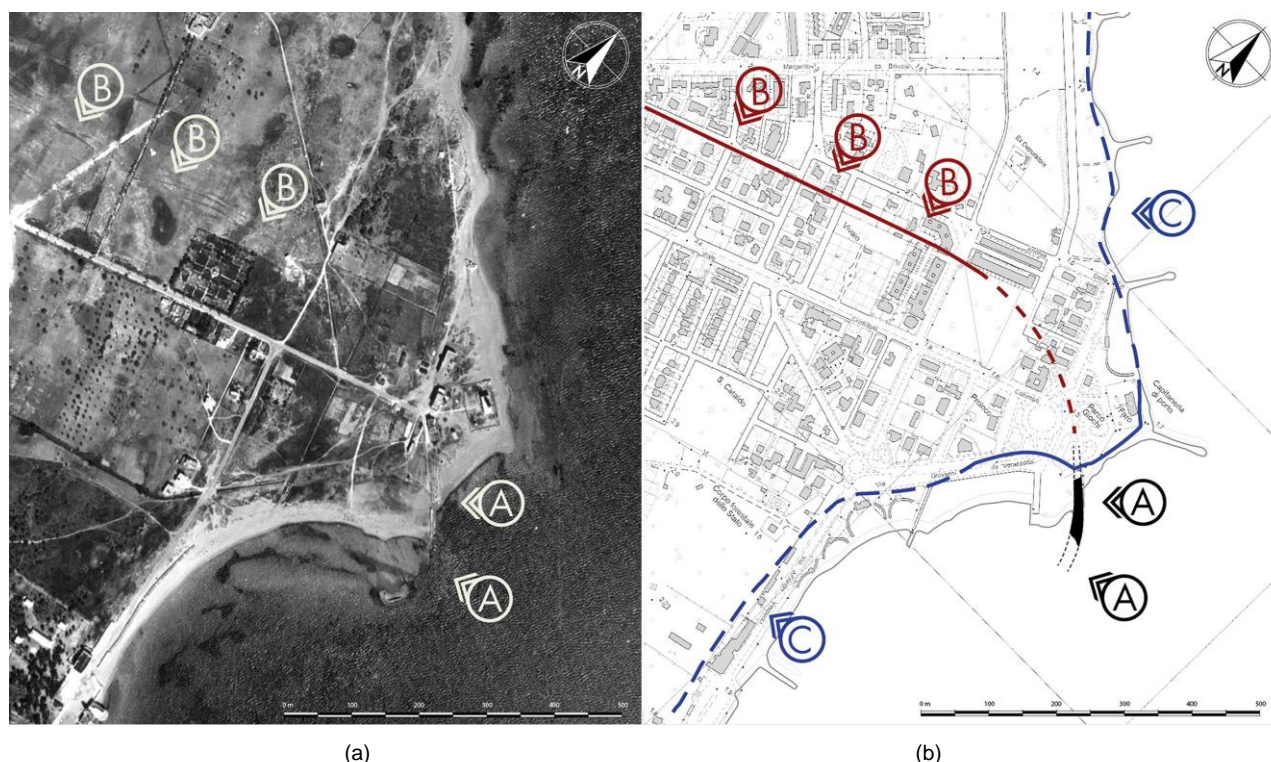


Figure 8: Topographical and aerial surveys: a) Vertical photo (1945) with the remains of the Roman pier (A) and the traces of an ancient road (B); b) Regional technical map (2015) with the Roman pier (A), the ancient road connected to the dock (B) and the hypothetical ancient coastline (C).

In the 20th century, the idea of creating a new pier resulted in a graphic documentation of the entire coast of San Cataldo (Fig. 3) and of the ancient structures (Fig. 4): this allowed us to know that, at that time, the linear extension of the ruins was about 150 m, and to document the presence of the rock just below the sea level, used as the foundation of the pier.

At the beginning of the construction of the new pier between 1901 and 1908, the Royal Inspector of the Monuments and Excavations, Cosimo De Giorgi, avoided the complete destruction of the Roman structure, preserving that portion that did not overlap with the new construction (Fig. 5). The 20th century pier consisted of two arms, the first one with southeastern direction and the second one, connected by a curve, with a southwestern direction with the characteristic “L” shape (Fig. 6), still partially visible today (Fig. 7). In the 1930s the ruins of the Roman pier suffered further damage due to the construction of bathing cabins, as well as during the Second World War, when a casemate and service walkers were built (Sammarco & Marchi, 2012; Sammarco & Marchi, 2014).

The abandoned ruins were exposed to meteorological events and to the sea erosion until 2004, when the research project re-evaluated the area and attracted the interest of the local authorities.

3. The archaeological investigations

The site of the ancient port of San Cataldo has been the subject of a scientific research since 2004 within the *Portus Lupiae project*, led by the LabTAF. Between 2004 and 2007, the investigations provided a direct survey of the visible structure, that measured about 50 m in length,

and lithological analyses of the squared blocks and of the *opus caementicium* (Roman concrete) of the pier have been carried out. These studies confirmed the origin of the materials from quarries around the harbour area.

Furthermore, topographical surveys in the territory between Lecce and San Cataldo were undertaken with the support of aerial surveys (Ceraudo, 2008) also recovering and analysing the historic aerial photos of the 1940s and 1950s, which documented the existence of an ancient road near the Roman pier (Fig. 8). Moreover, geophysical prospections were added to these analyses (Merico & Sammarco, 2014), underwater survey and the study of the edited material (Valchera & Zampolini Faustini, 1997; Auriemma, 2004; Ceraudo & Esposito, 1997), allowed us to outline a first integrated study of the structure which represented an important base for a further and more detailed investigation campaign.

The new project study started with an archaeological excavation in 2013, that unearthed a new portion of the pier (about 20 m) near Piazza Adriano, while an underwater survey documented the extension of the submerged structures (partially visible in aerial photos) of about 70 m. The surviving portions reached a total length of 140 m, with a northwest-southeast direction that bends to south with a slight curvature in the median area, which tends to give to the pier a distinctive semilunate shape (Fig. 9).

The construction technique used in the Roman pier of San Cataldo is widespread in the Mediterranean basin (Brandon et al., 2014) and it is characterized by having **two wall curtains in *opus quadratum* (squared blocks) with squared blocks made of local calcarenite arranged**

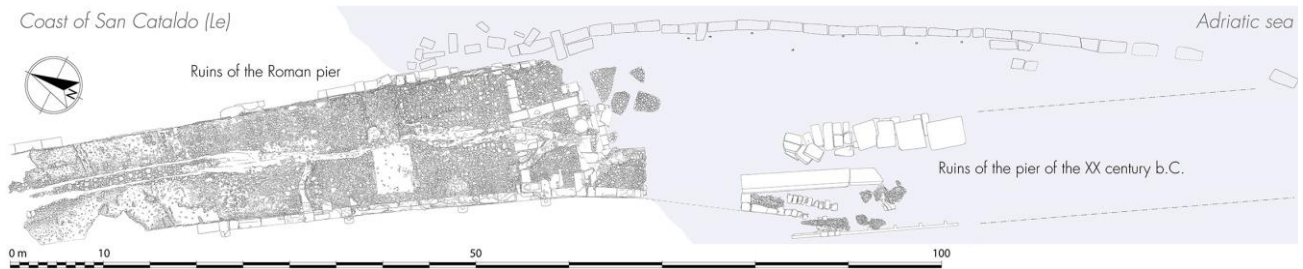


Figure 9: The survey of the pier structures.



(a)



(b)

Figure 10: The Roman pier of San Cataldo: (a) Detail of the western curtain wall; b) Detail of the eastern curtain wall.

mainly along their length (Fig. 10) and a core in *opus caementicium* (Roman concrete) made with irregular stones mixed with mortar and brick fragments, but without pozzolana (Fig. 11).

Of the two wall curtains, only the southern one is preserved almost entirely. On the contrary, on the northern part, the *opus caementicium* nucleus is in plain sight, because of the removal of the blocks re-used for the construction of the 20th century pier. Observing the planimetry, the curtain walls tend to diverge and to expand the width of the pier towards the submerged portion. The width variation between the northern extremity 13 m large (not still corresponding to the true beginning of the pier on the ground) and the southern one that reaches the size of 18 m, allows us to suppose that the pier originally increased the width of its quay in the sea (Fig. 13). At the southern end, two chains are visible due to the blocks perpendicular to the lateral walls: the first one has a medium thickness of about 1.20 m, while the second one, visible on the seaside, is three times wider and is built with five rows of blocks. The chains are connected to each other by walls that strengthen the point most exposed to the action of the sea, where the structure has a greater width and draws a slight curvature. The block fixing system consists of metal clamps found only in the southern portion of the

structure, in the two transverse chains. In total there are seven clamps located both on the long and on the short side of the block and, despite having a double “T” recess, the clamps used are “C” shaped (Fig. 12).

During the second campaign of archaeological investigations, a small excavation along the southern wall curtain brought to light two additional rows of blocks. In the penultimate row, one block is located 10 cm inner than the upper one, while the other, adjacent on the right side, is 63 cm more protruding (Fig. 14).

In the submerged area, seven wooden poles of rectangular shape are located along the inner side of the northern wall curtain wedged with stones: these poles belong to the late medieval age when the structure was restored.

Despite erosion, some graffiti that may be attributable to merchant brands are still recognizable above a block



Figure 11: The southern end of pier with *opus caementicium* (Roman concrete) between the curtain walls in *opus quadratum* (squared blocks).



Figure 12: Example of “T” shaped next to “C” shaped clamp.

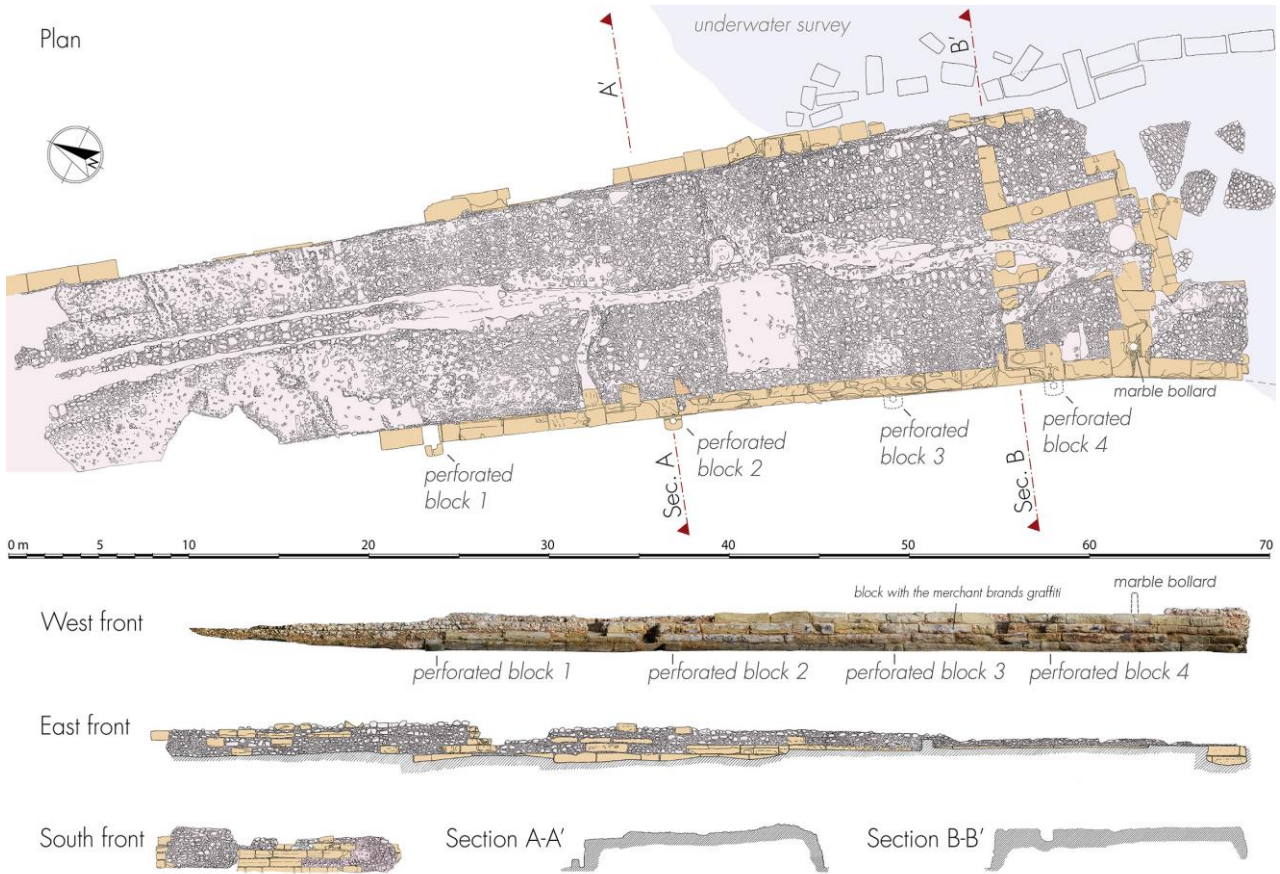


Figure 13: Survey of the Roman pier structures above sea level.

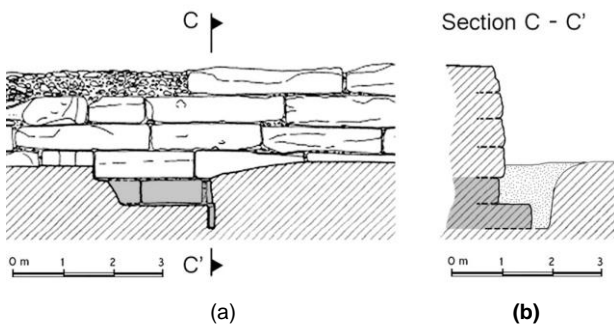


Figure 14: The two additional row of blocks (in grey colour) under the sandstone plan: a) Partial front view relief of the western wall with the C-C' section line; b) C-C' section.

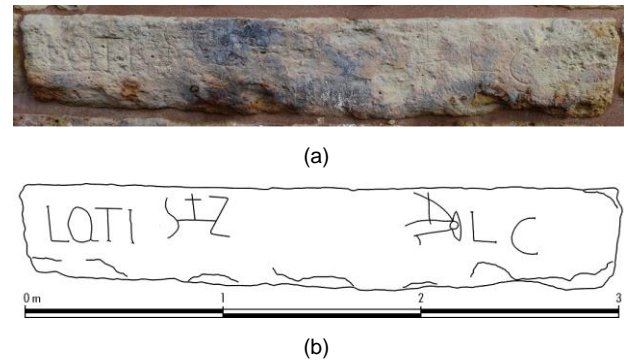


Figure 15: The block with the merchant brands graffiti (cf. Fig. 13, west front): a) Photo; b) Drawing.

localized on the southern side of the pier, as evidenced in other similar Italian cases (Barbon, 2005; Cecchi Aste, 2010) (Fig. 15).

The ancient sources ascribe to the emperor Hadrian the construction of the structure, but the pier could be dated back to the period of Augustan age, during the urban organization of *Lupiae* (Lecce). Moreover, its consolidation and restructuring could be dated to the first half of the 2nd century AD (Sammarco & Marchi, 2008).

4. 3D elaboration of a reconstruction proposal

The 3D elaboration of the San Cataldo Roman pier follows a methodology that should be standard in the

processing of digital reconstruction proposals: a procedure based precisely on a systematic study, 'traceable' in its evolution and possibly 'transparent' and 'intelligible'. This is the main purpose of virtual archaeology: showing to the public the interpretative results of those monuments whose integrity is damaged or compromised. In this study process, all the information that arises from the different archaeological research disciplines converges into a 'knowledge model' that is identified as the 'synthesis' of the collected data (Gabellone et al., 2011). The 3D restitution process of the ancient pier has therefore started in a preliminary phase with the whole historical-architectural information emerging from archaeological and topographic surveys; an image-based survey based on Structure from Motion

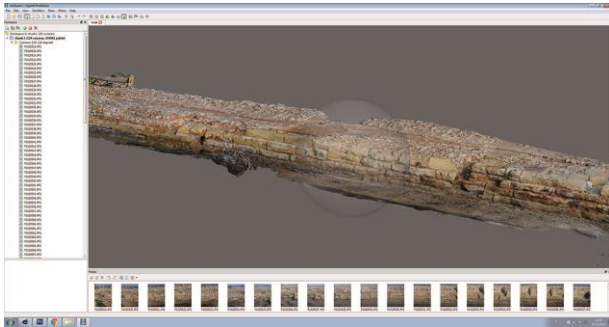


Figure 16: The 3D model of the Roman pier created with SfM algorithms.

(SfM) photogrammetry has been added to a traditional direct survey of the pier (Fig. 16) (Gabellone et al., 2015a; Ferrari & Giuri, 2015; Gabellone et al., 2017b).

4.1. Image-based modelling

Due to the complexity and size of the structure, two image-based photogrammetric surveys have been carried out: the first one concerning the vertical structures (the two wall curtains and the seafront); and the second one concerning the horizontal current planking level of the pier. For the first image-based survey, a high resolution Panasonic DMC-GH4 digital camera was used shooting 124 photos (4608 x 2592 pixels) with a 14 mm focal length and a constant distance of shoot of about 3 m, at a midrange distance from the structures of about 4 m. The entire surface of the pier was covered with a sufficient image overlap (about 70-80%), essential for getting the tracking points in space and their resulting 3D position. The processing of the images by the software Agisoft Photoscan software v. 1.0.1.1812 led to the alignment of all the photos with a minimum margin of error (0.6/1.0 pixel) and to the creation of a dense cloud of about 18 million points. The images took from the ground level also

partially covered the top portion of the pier, but it was impossible to produce a precise morphology of the structures. It was therefore necessary to make a second sequence of photos using a drone (FlyNovex) equipped with a compact digital camera (Sony ILCE 6000). A total of 75 shots were taken at a resolution of 6000 x 4000 pixels, with a 16 mm focal length and a constant base length distance of about 4 m, from a height of about 5 m above the structures (Chiabrando et al., 2018). In the same Photoscan project it was created a second “chunk” in which the images were aligned (error pixels in the range of 0.7/1.0 pixel) to obtain a dense cloud of about 8 million points. Four GCPs (Ground Control Points) were set up, whose coordinates had been previously acquired with the total station for the direct relief. These four “markers” were identifiable because they were placed on the edges of the blocks, and had also been used to align and merge the two point clouds. Then it was created a mesh of about 4 million polygons and a final image texture of 10000 x 10000 pixels. The scaled model was coherent with the traditional direct relief and it was important to acquire new useful elements for the elaboration of the reconstruction proposal.

4.2. Interpretation

The possibility to analyse the orthorectified prospects allowed us to compare them with the historical photographs of the late 19th and early 20th centuries, when the structures of the Roman pier were much greater than the present ones, destroyed by the construction of the 20th century pier (today also in ruins) (De Giorgi, 1913). It was possible to ascertain that the extension of the demolished part was approximately equal to that currently documented in the submerged one (Laudisa, 1995). This portion is identified from two blocks of the western curtain wall in the current southern end of the pier. Furthermore, one of the former blocks is easily recognizable for a recess in the upper corner used as housing for the missing block. The two *in situ* blocks

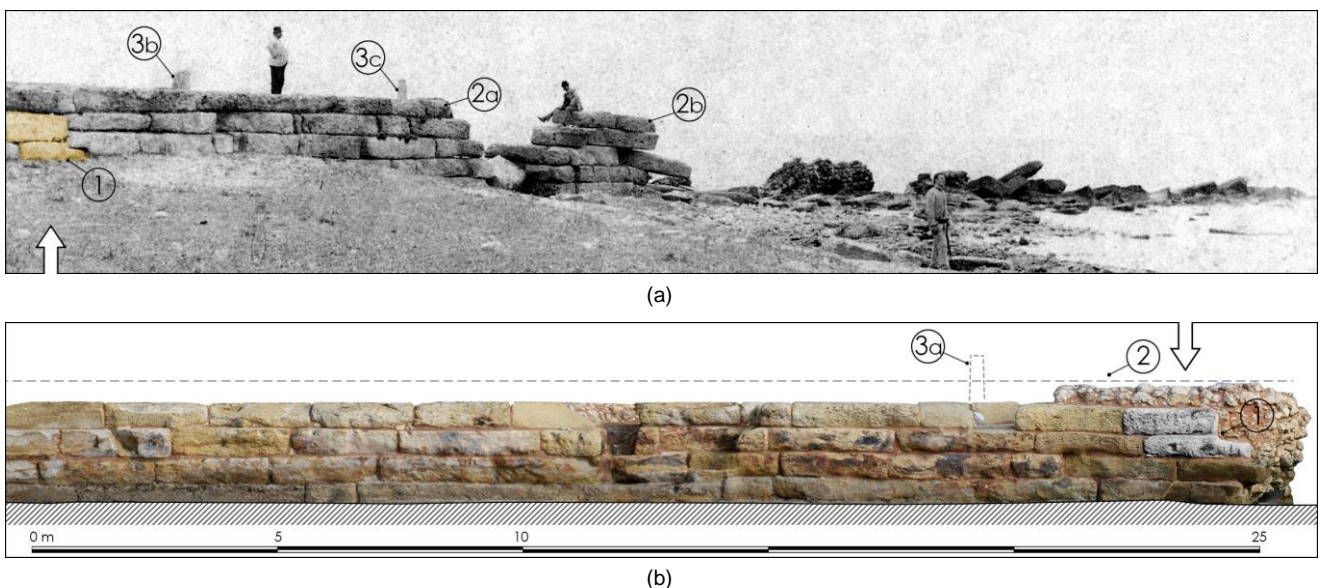


Figure 17: The western curtain wall of the Roman pier: a) Historical photo (1896) in which are highlighted in yellow the two blocks still found in the surviving structures of the pier (1), the presence of a fifth upper row now disappeared (2a, 2b) and two cylindrical bollards also lost (3b, 3c); b) Orthophoto (2016) showing the two blocks found in the photo of 1896 in greyscale (1), the conglomerate without the upper row of blocks (2) and the position of the bollard today partly preserved (cf. Fig. 18) (3a).



(a)



(b)

Figure 18: The marble bollard still visible near the western front of the pier: a) 2017; b) 1925.

are also the only ones still existing and well recognizable in the old photographic documents (Figs. 17a and 18b).

Another important element emerged from this comparison is the confirmation of a fifth row of squared blocks over the sea level, today perceived only by the presence of a clump of conglomerate, which rises in the eastern end over the top of the curtain wall; the level of this row probably indicates the ancient floor plan of the Roman pier. In addition, it is also possible to recognize the presence of two marble bollards in the destroyed portion, and the remains of a third marble bollard which appears still intact in a 1925 photo (Fig. 18).

The image-based 3D reconstruction also allowed us to better reflect on the position and functionality of two projecting blocks transversely inserted in the western curtain, plus the traces of two further ones, having a circular hole with vertical axis (33 cm in diameter), all arranged on the same level and spaced about 10-13 m (Fig. 19). These perforated blocks were initially interpreted as bollards for mooring of ships, but a more careful analysis has contributed to reject this hypothesis for two reasons. The first one is their position of

about 220 cm lower of the hypothetical floor plan of the pier and **just above the sea level**, not useful to an easy mooring of the ships; the second reason is the absence of traces due to the rubbing of the ropes. **A likely hypothesis is that they could have been useful in supporting wooden poles linked to the presence of machines to facilitate the loading and unloading of goods of medium-sized ships, to which probably the pier was destined for its not so large size.**

The 3D image-based model with a metric reference basis was exported with textures in .WRML format. The collection of the whole historical-archaeological data documented by the study of the Roman structures allowed us to develop a 3D reconstruction proposal with the use of Maxon C4D Studio R14, using *point-to-point* and *subdivision surfaces* modelling techniques in order to accurately control the creation process. The texturing of the polygonal surfaces was realized with digital painting techniques in order to create UV mapping, simulating the original materials and colours (Caruso et al., 2015). Fig. 20 displays the result of the proposed 3D reconstruction of the pier with people, animals and naval goods in a real-life scenario dating back to the 2nd century.

4.3. Discussion

In the 3D modelling work, several elements have been considered, such as the semilunate profile of the structure with its slow and progressive increase in the width of the quay as it advances into the sea and the quay that represents only a part of the original one (about 140 m in length, considering both the emerged portion and the submerged portion of the pier). This is because the present state of the structure is a consequence not only of natural causes like the advancement of the coastline and the erosive action of the sea, but also of the anthropic activities. Another important aspect was the understanding of the three different levels associated with the foundations, the floor plan of the quay and the water level in the ancient times. Regarding the last issue, the current sea level is probably not very different from the ancient one and that the original floor plan of the pier was about 270 cm from the sea level (since the rows of squared blocks –each of about 54 cm higher– were originally five).



(a)



(b)

Figure 19: The two perforated blocks with the remains of two others located in the western wall curtain of the pier: a) General overview; b) Details of the four perforated blocks.



Figure 20: 3D reconstruction of the general system for loading and unloading naval goods.

As documented by archaeological surveys, although it has not been possible to ascertain the total height of the pier, there are at least two additional rows of blocks below those currently visible in the western curtain: for this reason the 3D reconstruction proposes an overall height of about 5 m, to ensure a good draft margin of about 2.30 m to the mooring of the ships.

Considering the data collected here and given the absence of clear archaeological evidences about a second western dock, we have proposed a single structure longer than the one preserved, with an extension of its extremities connected to the recession of the coastline and to the continuation of the structures below the current ruins of the 20th century pier. In connection to the perforated blocks, cranes equipped with winches and hinges to move loads both along vertical and horizontal lines have been hypothesized, while, as other port facilities suggest (Brandon et al., 2010), the floor plan of the pier is paved with squared limestone blocks, to give a greater protection and durability to the quay.

Another aspect of the 3D reconstruction concerned the contextualization of the structure within the ancient landscape. According to this elaboration, it is retraced a plausible connection between the pier and the ancient road identified by the analysis of historical aerial photographs and the topographic surveys. Due to a scale factor, merchant ships referring to the 2nd century AD have been proposed in connection with the presence of cranes for the loading and unloading of goods (the chosen time is set when the pier was rebuilt to the growing importance of the *portus Lupiae* in the sea traffics along the Apulian coast and between the two Adriatic riversides) (Fig. 20). Within the 3D final project (about 9.7 million polygons) that managed the production of synthesis images with the external rendering engine V-ray v. 1.2.5 (Fig. 21), the ancient coastal scenery was reproduced with the typical vegetation of the southern Italian coasts (Mediterranean scrub), today completely disappeared due to the anthropic activity (Fig. 22).

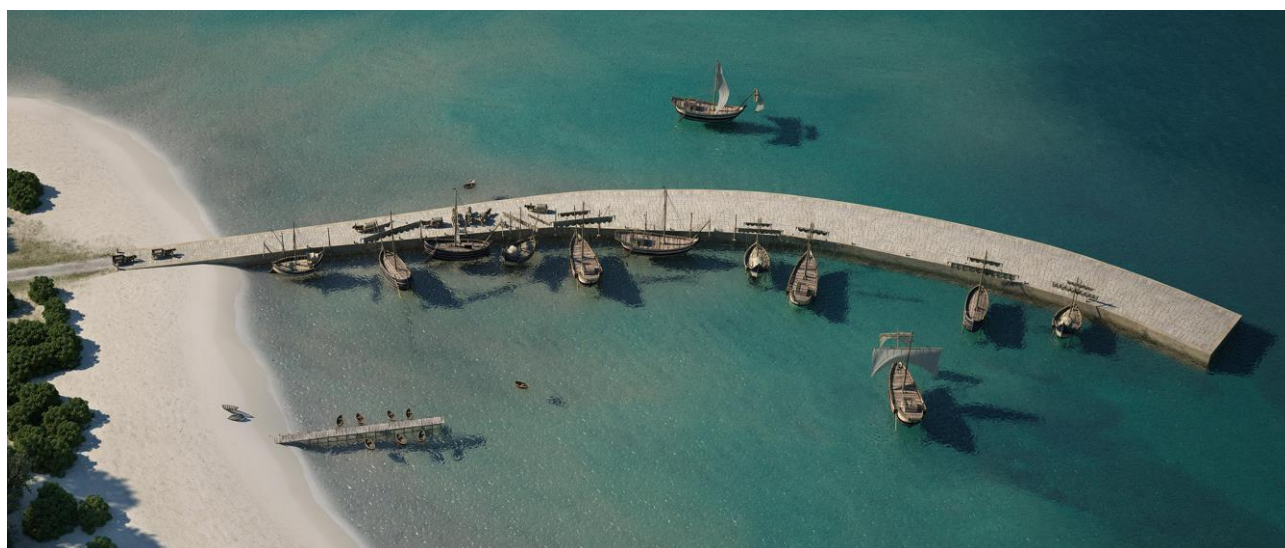


Figure 21: Western view of the 3D reconstruction of the Roman pier.

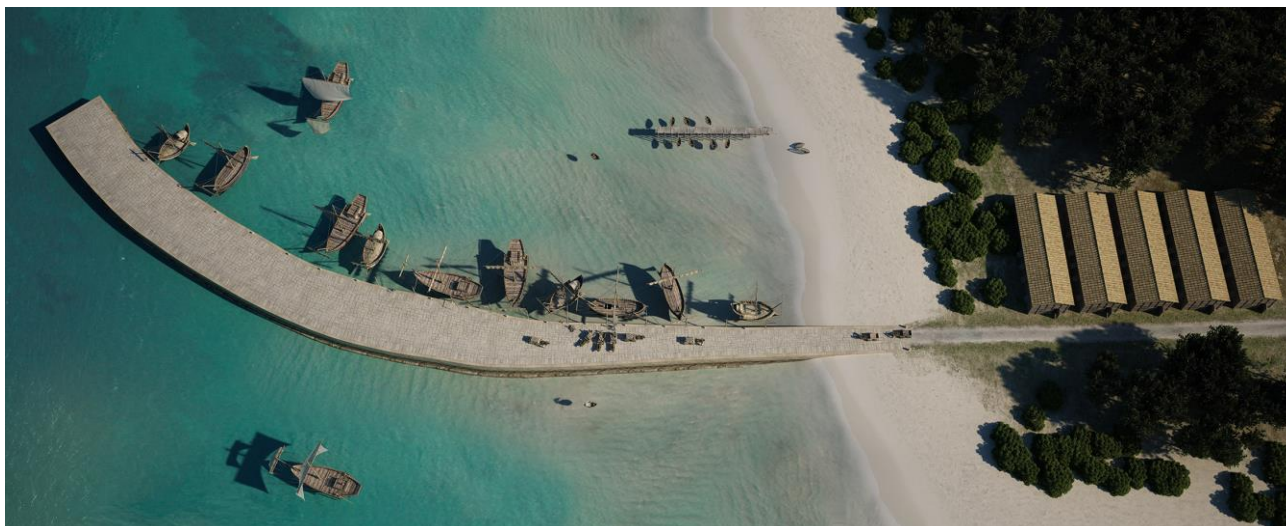


Figure 22: Eastern view of the 3D reconstruction of the Roman dock and of the surrounding coastal landscape.

5. Conclusion

The 3D reconstruction process of the Roman pier of San Cataldo was strictly based on a pipeline production anchored to metric data and historical-archaeological information already adopted in other contexts (Gabellone et al., 2014a; Gabellone et al., 2014b, Gabellone et al., 2015b; Gabellone et al., 2017a), and for this reason it was able to give new topics of discussion merged and synthesized within the same reconstruction proposal. This process contributes to helping the visit of the monument *in situ* and it is a further witness to how technologies applied to cultural heritage, now widespread and settled, are increasingly needed (Gabellone, 2013), in the framework of communicative languages more and more engaging, able to give to the visitor information that is not all the times understandable by contemplating the simple view of the surviving structures. In this case, the 3D elaboration has led to the creation of a short computer graphic animation

(movie) that illustrates the Roman pier, the surrounding landscape and its related human activities, with the specific aim to engage the public, making the historical site (pier) more understandable than what it is currently visible (Ferrari et al., 2016). The focus is to promote, increase the interest and disseminate better the archaeological and historical data, to make the visitors aware of this remarkable excavation, conservation and restoration work.

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