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Photogrammetric reconstruction of the Roman fish tank of Portus Julius (Pozzuoli Gulf, Italy): a contribution to the underwater geoarchaeological study of the area.

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Abstract— **This research aims at the 3D reconstruction of a Roman fish tank (*piscina*) located inside the archaeological area of Portus Julius (Gulf of Pozzuoli, Naples) and it is part of a wider research finalized to reconstruct the amount of the vertical ground movements (VGM) occurred during historical times in the Gulf of Pozzuoli. The ancient *piscina* is related to the second life stage of the harbor that, after its construction in 37 BC, during the year 12 BC switched its usage from a military to a commercial one. The photogrammetric survey of the fish tank, curved directly into the embankment of the entry channel of the port, has been carried out in order to better characterize its morphological features, since it represents an important time reference for the area.**

I. INTRODUCTION

The Gulf of Pozzuoli, located in the wide Campi Flegrei Caldera, offers the possibility to collect important information about the modification the coastal landscape and the relative sea level (RSL) changes related to vertical ground movements (VGM) occurred in historical times. In fact, along the littoral, there are several archaeological remains (maritime villae, harbor facility etc.) scattered along the coast and testifying the ancient occupation of the sector. Nowadays the main part of the ancient coastal strip, including all the buildings and maritime structures, is submerged due to overall subsidence started at the end of the Roman period [1].

A multidisciplinary approach made of direct and indirect techniques turns out to be really useful for the study of submerged landscapes, since indirect surveys as the photogrammetric one can provide really accurate morphometric characterization of the underwater features, usually not easily accessible.

The goal of this study is to provide a detailed 3D reconstruction of the nowadays submerged fish tank of the Roman harbor of Portus Julius.

The study site is located inside the Underwater Archaeological Park of Baia, famous all over the world since in historical time the area was affected by sudden VGM that led to the submersion of the entire coastal sector. This intense overall subsidence resulted in a perfect preservation status of the structures still clearly recognizable.

In 37 BC, the area enclosed between the Lucrino and the Averno Lakes was chosen by Agrippa for the construction of the new military harbour system of Portus Julius.

The military purpose of the system ended in the 12 BC, with the conversion of the harbor in a commercial base together with the relocation of the military port in the nearby Misenum, Indeed, Portus Julius was rethought and restructured, with the transformation and the adaptation of military environments into warehouses. [2, 3, 4].

The fish tank here surveyed can be considered as a good evidence of the renovation occurred after 12 BC. This fish tank is particularly interesting because it represents one of the few examples of fish tanks related to commercial activities and not to private maritime villas.

Considering the importance of this feature, together with a direct survey aimed to determine the submersion of its structural element, a photogrammetric survey of the fish tank has been realized. The photogrammetric reconstruction was crucial both for the evaluation of the elements related to the study of the past RSL

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and for the documentation of this singular fish tank built for commercial use, with a great cultural value.

II. METHODS

The fish tank here studied, due to its strategic position, represented the key element of our geoarchaeological interpretations in terms of ground movements occurred during the Roman times. The sluice gate of this fish tank was built directly by cutting the channel embankment. This led to the assumption that it was therefore built in the second construction phase of the Portus Julius, according to Benini and Giacobelli [5]. Therefore, in this area, an underwater photogrammetric survey (Fig.1) has been carried out both to obtain a detailed morphometric analysis of this functional element and to preserve a 3D documentation of this important and unique historical testimony, also considering the extreme fragility of this underwater landscape.

The photogrammetric survey was planned by using a photogrammetric system (Fig. 1a and b) consisting of two high-resolution cameras, having the optical axis vertical.

The stereoscopic base and the submersion of the system were chosen in relation to the bathymetry of the study area and to the resolution of the three-dimensional model of submerged findings (Fig. 1a). With our setting for the cameras, ensuring a minimum overlap of 80% for the images during the survey. Taking into account the characteristics of the video cameras, to ensure a transversal overlap of at least 80%, the stereoscopic base was chosen equal to 30 centimeters. The depth of the photogrammetric system was modified during the survey to guarantee both an adequate completeness of the three-dimensional model and its resolution (see Fig. 1c).

As shown in Figure 1a, the camera system was towed by a rope connected to an emerged float and moved by a diver. This system provides two basic positions, namely position A at -1 meter and position B at -2 meters below sea surface.

The photogrammetric 3D model of the surveyed fish tank was obtained in three two steps [6]:

- The videos at 30 fps recorded by the two Xiaomi cameras (previously calibrated in an underwater environment close to the study area to achieve the inner orientation parameters were synchronized by the use of the trigger system and the images were extracted using a frame every 6th frame. More than one thousand 1920x1080 images were thus obtained;

- The alignment procedure of the images and the dense point cloud extraction was performed by Agisoft Metashape software. The 3D model was not georeferenced because it was not possible to determine the coordinates of the control points, but some linear measurements made by the diver directly on the underwater structure made it possible to scale the dense point cloud.

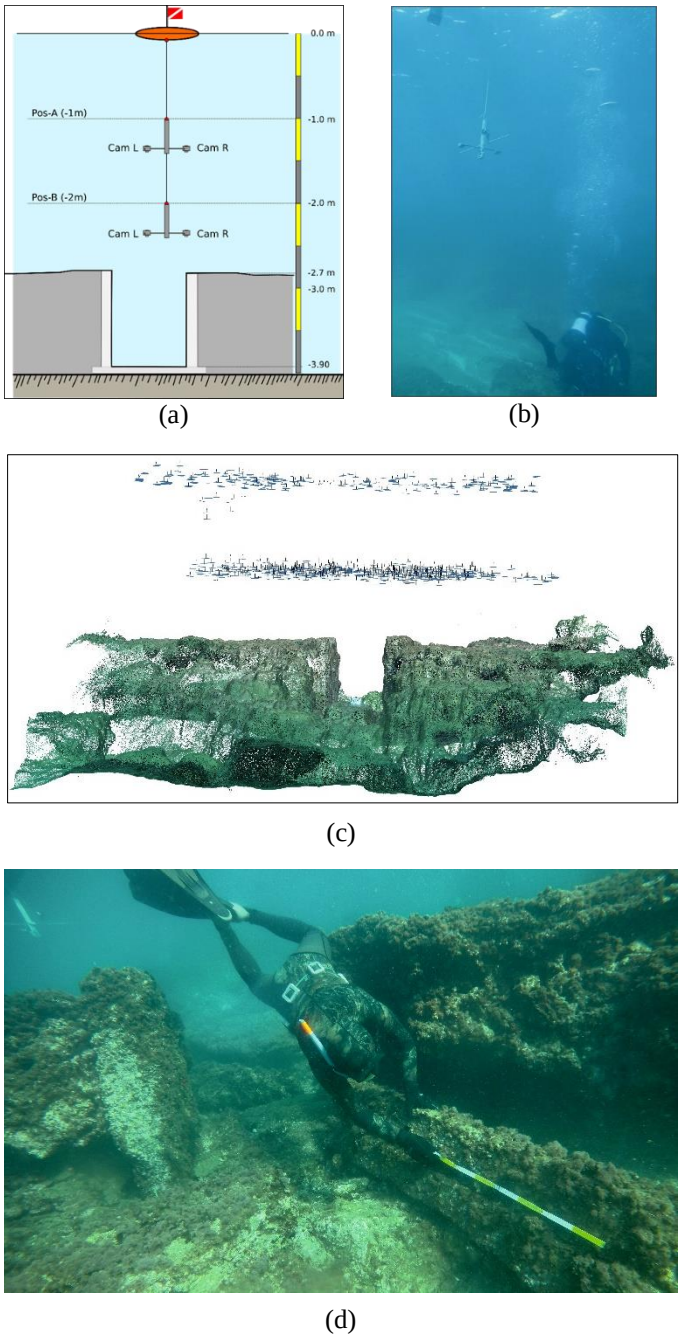

Figure 1. (a) Reconstruction of the photogrammetric system used during the survey; (b) Photogrammetric system used during the survey; (c) Positon of the photogrammetric cameras during the survey; (d) Direct measurement of a linear constrain by a diver.

The buddle adjustment procedure has been performed by using two linear constraints measured directly by a diver and two more distances, used as check in different zones of the sensed fish tank [7, 8, 9] (Fig. 1d). The procedure of alignment produced a difference of less than 2 cm in each of two distances used as check.

III. RESULTS AND CONCLUSIONS

The triangular fish tanks of Portus Julius, with a size of 20x22x16 m, is entirely made of tuff and it appears to be carved directly into the embankment of the entry channel (Fig. 2).

During the direct survey the main constructional element of the *piscina* were measured to evaluate the amount of their submersion. In particular, the measurements concerned the sluice gate of the tank still *in situ* (*cataracta*, i.e. closing gate located at the access of the channels of the tanks into the basin or at communication passage between each tank) [10, 11, 12, 13, 14].

The top of the sluice was built 0.2 m (functional clearance, fc) above the mean high water (MHW), so correcting the submersion measurement with respect to this value and the reference water level (RWL) of the sea level marker, in this case equal to the half of the difference between the MHW and the mean low water (MLW), a RSL of -3.10 m MSL for the 12 BC was calculated [14, 15, 16].

All the measurements and considerations derived from the direct survey have been supported by correlations made on the base of the analysis of the 3D photogrammetric reconstruction (Fig. 2a, b and c).

Nowadays the digital photogrammetric techniques have reached really high levels due to the new technologies. These methods of analysis are becoming more and more common and accessible to a growing number of people due to the low cost of their realization.

The use of the photogrammetry falls into different categories, even in areas of complex approach as in this case of a 3D underwater reconstruction of an element of archaeological interest.

Considering this research carried out on the Roman fish tank of Portus Julius, the results achieved have a meaningful scientific value related to the possibility of carrying out precise measurements of the three-dimensionally reconstructed object. On the other hand, the realization of the 3D model offers a virtual access opportunity to the element located in a submerged environment, normally only open to a specialized public.

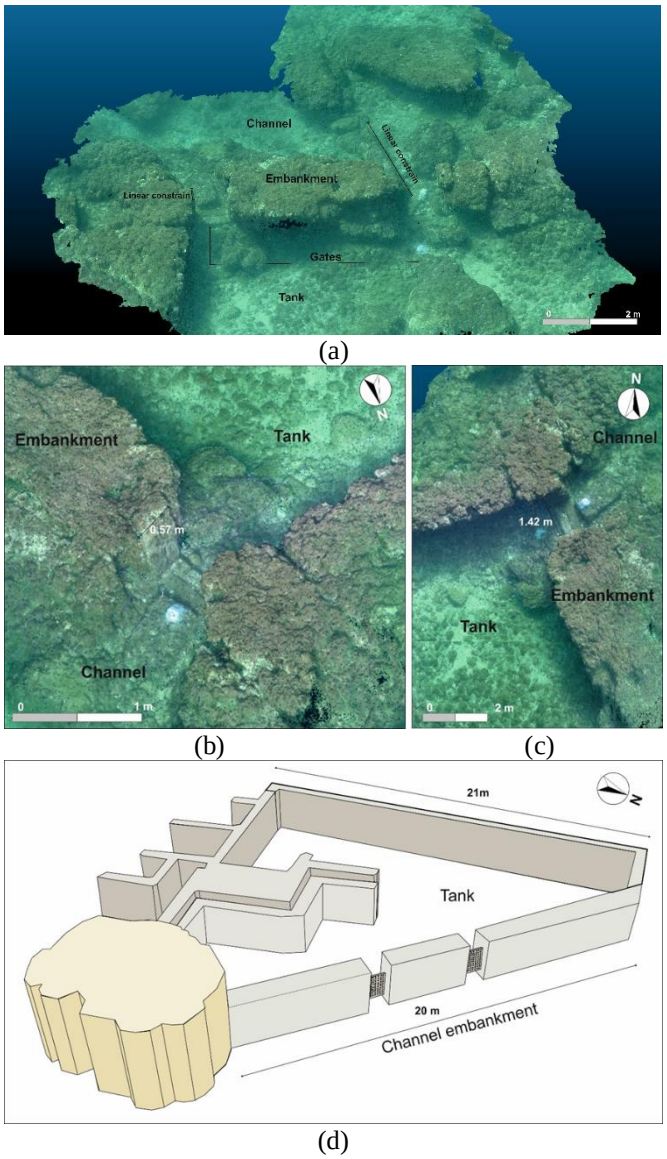

Figure 2. (a) Photogrammetric Point cloud; (b) Zoom of the 3D reconstruction of the well preserved gate; (c) Zoom of the 3D reconstruction of two perimeter walls of the fish tank; (d) 3D sketch of the surveyed fish tank.

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