Underwater 3D Recording of the Harbour System of the *villa maritima* at the Cape of Sorrento

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The appearance and magnificent design of Roman seaside villas, the *villae maritimae*, is – apart from the extant architectonic remains – at least partly known to us on the basis of Roman wall paintings. Although it is doubtful that the paintings allow immediate conclusions concerning really existing villas, nevertheless, the perspective on the maritime villas in paintings and ancient texts focuses on the real life experience of somebody approaching a maritime villa in the appropriate manner, i.e. from aboard a ship sailing along the coast. The ideal "villascape" is formed basically by a luxuriously designed villa, lavishly constructed moles and gardens bordering the shore. Underwater archaeological research on the Roman villa at the Cape of Sorrento resulted in clear evidence of such a villa with two representative harbours, which served both the supply of the villa and the reception of high dignitaries. First, the villa and the rock on which it is built were documented photographically by a drone and terrestrial photographs, and a three-dimensional model of the building was created. By using "structure-from-motion" (SfM) under water as well, the two harbours of the villa were also documented and considered with regard to the interpretation of the whole complex for the first time. The resulting three-dimensional model of the entire complex provides information about the architectural design of the villa as well as the effort that was spent on the construction.

All data generated during the excavation campaigns are available in an online repository at *Edition Topoi*[1] according to the principles of open access. Thus, the research data on the villa are published, secured in the long term and citable. In addition, the open structure of the repository allows other researchers to freely use the data and metadata. Furthermore, the data can be easily integrated into other software packages for further analysis via an interface.

Key words:
underwater archaeology, *villa maritima*, structure-from-motion, open access, data publishing.

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INTRODUCTION

The *villa maritima* is located only ca. 2 km to the west of Sorrento on a foothill of the limestone plateau of the Sorrento Peninsula (Fig. 1). It is just one of approximately two dozen Roman sea villas that ran like a pearl necklace along the coast of the peninsula [Mingazzini and Pfister 1946: pl. 1; D'Arms 1970; Zehnacker 1996: 319-329; Trillmich 1999: 21-29; Lafon 2001: 89-95. 232-234; Pappalardo 2001: 39-50; Dubois-Pélerin 2008; Brun et al. 2012; Perrella 2014: 171-178; Varriale 2015: 227-268; Filser et al. 2017: 64 f. Fig. 2]. It is unclear which Roman senator or other member of the Roman aristocracy owned the villa at the Cape of Sorrento. Like many other villas along the coast of Campania, it was built in the middle of the 1st century BC and destroyed in the 2nd half of the 1st century AD. Reasons for the destruction were at least two earthquakes between 62 AD and 79 AD, while the eruption of Vesuvius itself has been proven to consist only of a thin layer of ashes and lapilli. In addition, the

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[1] https://edition-topoi.org

remains of a previous building – probably an older villa – were discovered during the current excavations. Possibly this building already existed in the 2nd century BC [Filser et al. 2017: 74; Filser 2017]. However, unlike most other villas, it was not the victim of modern building activities. Due to its location on an almost inaccessible rocky promontory in front of the cape, the maritime part of the villa was never built over. The architectural remains are mostly overgrown by bushes or freely accessible. Its relatively good condition and difficult accessibility was a good starting point for new and comprehensive research.

First investigations took place in the middle of the 20th century, when the archaeologist Paolino Mingazzini and the illustrator Federico Pfister made a first architectural plan of the site, which was accompanied by a comprehensive description [Mingazzini and Pfister 1946]. Extensive excavations that took place in the 1960s by the German Archaeological Institute under the direction of Friedrich Rakob were unfortunately never published in detail [Rakob 1987]. At the beginning of the 21st century, the villa was re-examined by Mario Russo and a schematic plan of the structures excavated in the 1960s on the top level was published [Russo 2006: 52 pl. 11]. However, a complete overall study of the maritime villa has only taken place since 2014 through the interdisciplinary cooperation of the team from the Humboldt Universität zu Berlin, which combines the results from terrestrial and maritime archaeology and geology [Filser et al. 2017].

Using a Total Station and a Differential Global Positioning System (DGPS), all visible architectural remains and important geological structures have been measured and converted into an overall plan of the villa, which continues to grow with each excavation campaign (Figs. 2 and 3). Complementarily, a three-dimensional, photogrammetric model of the villa complex has been created using the “structure-from-motion” (SfM) method. Aerial photographs made with a remote-controlled drone, terrestrial as well as underwater photos were taken in several campaigns and repeatedly revised and improved. The comparison of the three-dimensional model with the total station survey data results in an ultra-precise model. The three-dimensional model is now an important tool for the interpretation and reconstruction of the maritime villa, as it makes the overall building complex clear (Fig. 4) [Schmid et al. 2016]. Furthermore, individual details above and below water can also be verified. Thus, it not only documents the state of preservation of the villa, it also enabled the detection of previously undiscovered structures and manmade alterations to the original surface, i.e. the limestone bedrock. In addition, the archaeological excavations, which provided new insights into the predecessor of the villa, architectural features and the afterlife of the villa, are incorporated into the model [Filser et al. 2017: 72 f.].

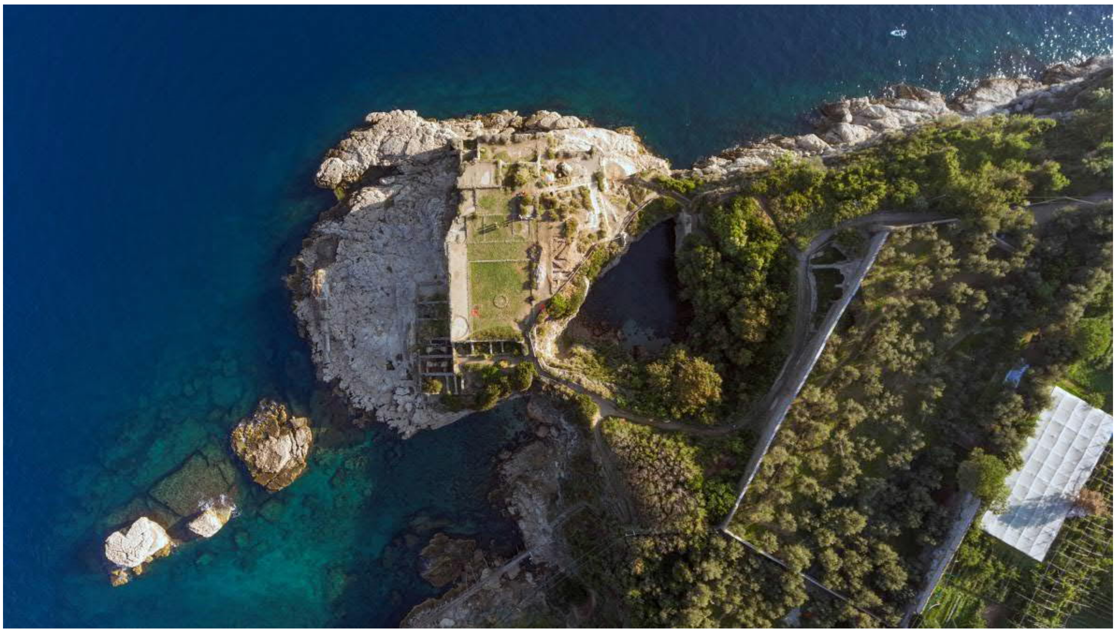

Fig. 1. Aerial view of the pars maritima (© W. Filser)

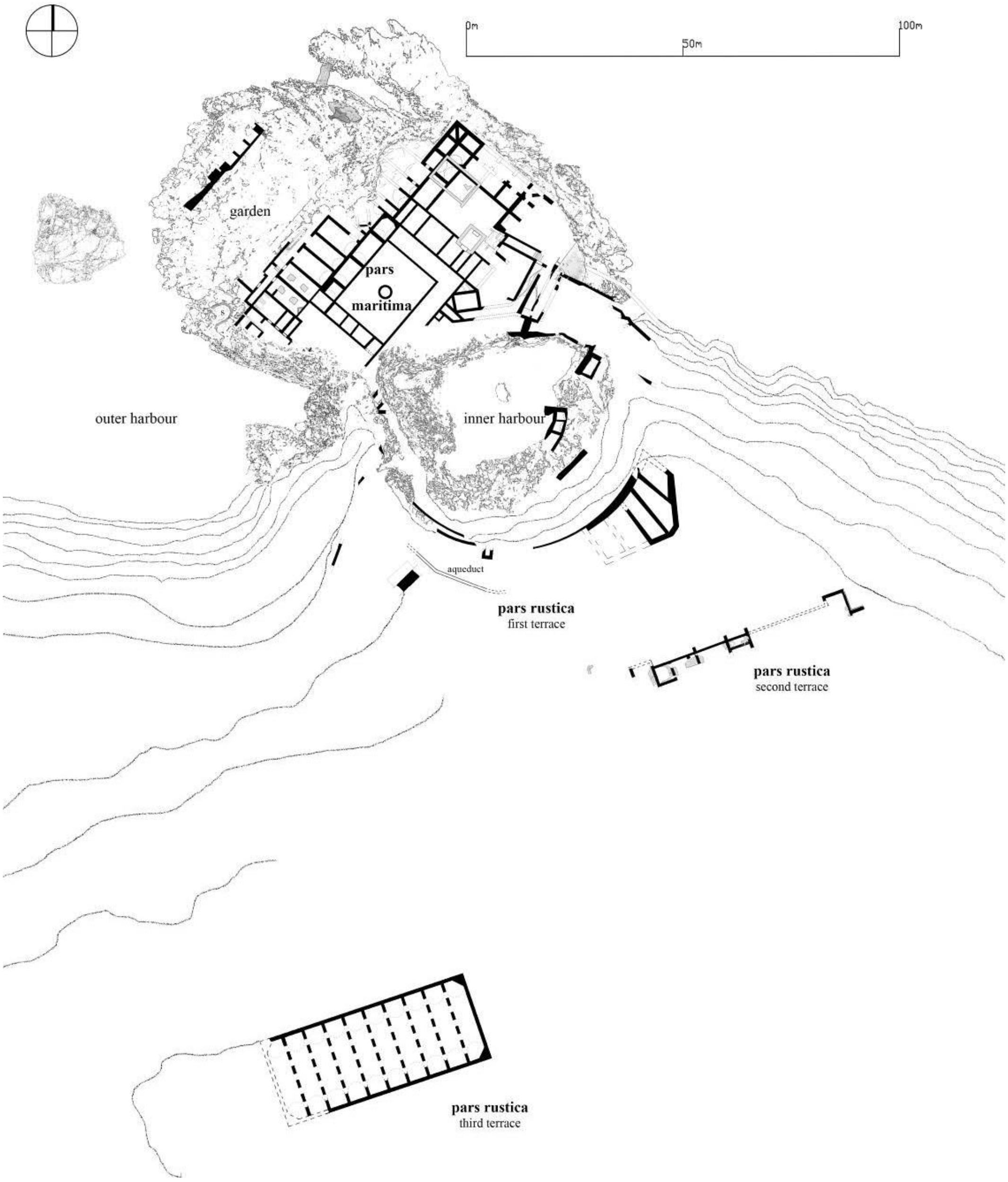

Fig. 2. Ground plan of extant substructures and walls of the villa's main phase („reticulatum phase") including newly excavated structures on the pars maritima and the second terrace of the pars rustica (© W. Kennedy, W. Filser)

Fig. 3. Documentation of submerged structures with the total station (© G. Graf)

Fig. 4. Screenshot of the three-dimensional model of the pars maritima (© W. Filser, B. Fritsch, and M. Reinfeld)

A VILLA WITH TWO HARBOURS AND THREE SEAS

The limestone promontory on which the villa is located had to be massively changed for construction. Great parts of the ancient buildings and substructures have fallen into the sea. The main property ("*pars rustica*") is to be located on three huge artificial terraces on the cape above the *pars maritima* and included further representative buildings, ornamental and agricultural gardens, the domus of the owner, etc.[2]. Via a cistern system and an aqueduct, the whole complex was connected and supplied with water. A small natural depression separating the promontory of the maritime part from the "*pars rustica*" above is interpreted as a harbour basin ("inner harbour") [Mingazzini and Pfister 1946: 121, 129-131; Filser et al. 2017: 71, 74] (Fig. 5). On the west side of the villa is the outer harbour. Previous research had already supposed that the approximately rectangular basin must be a harbour, and the three rocky islets represent the northern boundary and effective protection against waves from the open sea (Fig. 6). However, recent underwater research has for the first time identified structures and architectural elements associated with the use and design of the bay as a harbour. It is now certain that the harbour was part of the luxurious construction program of the villa.

On the east side of the *pars maritima*, it becomes obvious that even during the construction of the villa the maritime routes were of enormous importance for the transport of building materials. Cuttings in the limestone cliff below the *basis villae* can be interpreted as landing places for ships, and are thus evidence of the infrastructure that was associated with the construction of the villa. The limestone flakes that arose during the construction of the staircase were then used as filling material in the *opus caementicium* foundations, which otherwise consist mainly of tuff (Fig. 7). In the *basis villae* probably two courtyards were surrounded by luxurious rooms whose walls and ceilings were decorated with mosaics, wall paintings and stucco (Fig. 8) [Mingazzini and Pfister 1946: 122-129; Rakob 1987: 14 fig. 13; Russo 2006: 42-75; Filser et al. 2017: 74 f.]. From the peristyle court(s) and the surrounding rooms many single views of particular points of the Gulf of Naples and the Sorrentina were created. In the windows of certain rooms three seascapes must have opened up towards West, North and East, just as described by Pliny [Plin. epist. 2, 17, 5]. From the central colonnaded courtyard, a ramp and a monumental portico lead to the *pars rustica* and probably also to the inner harbour. In the northwest of the *pars maritima*, on the large open space of the limestone plateau, a garden and a small fishpond were situated (Figs. 2 and 9) [Filser et al. 2017: 82-87]. Due to its location just a few metres above sea level, the garden probably had to be constantly renewed after being flooded and eroded by winter storms.

Fig. 5. View into the inner harbour with crevice, pier and niche façade (© M. Reinfeld)

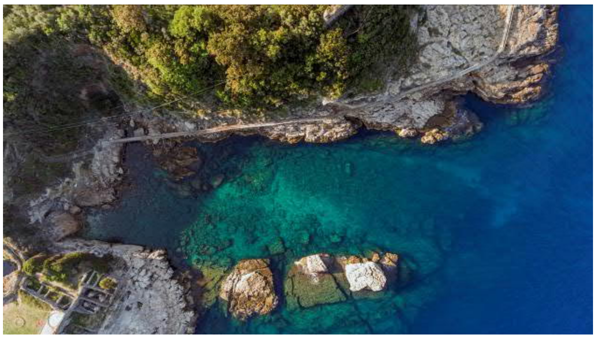

Fig. 6. Outer harbour with three rocky islets (© W. Filser)

[2] The extent of the property can be reconstructed by means of the surface distribution of ceramics and the existence of huge cisterns, which partly serve as substructures for the three terraces of the *"pars rustica"*. The project involves chemical soil analyses and core drillings to understand the composition and provenance of the ancient soil, as well as the use which was made of it. Excavations in 2017 and 2018 on the three terraces have proven the existence of further monumental buildings.

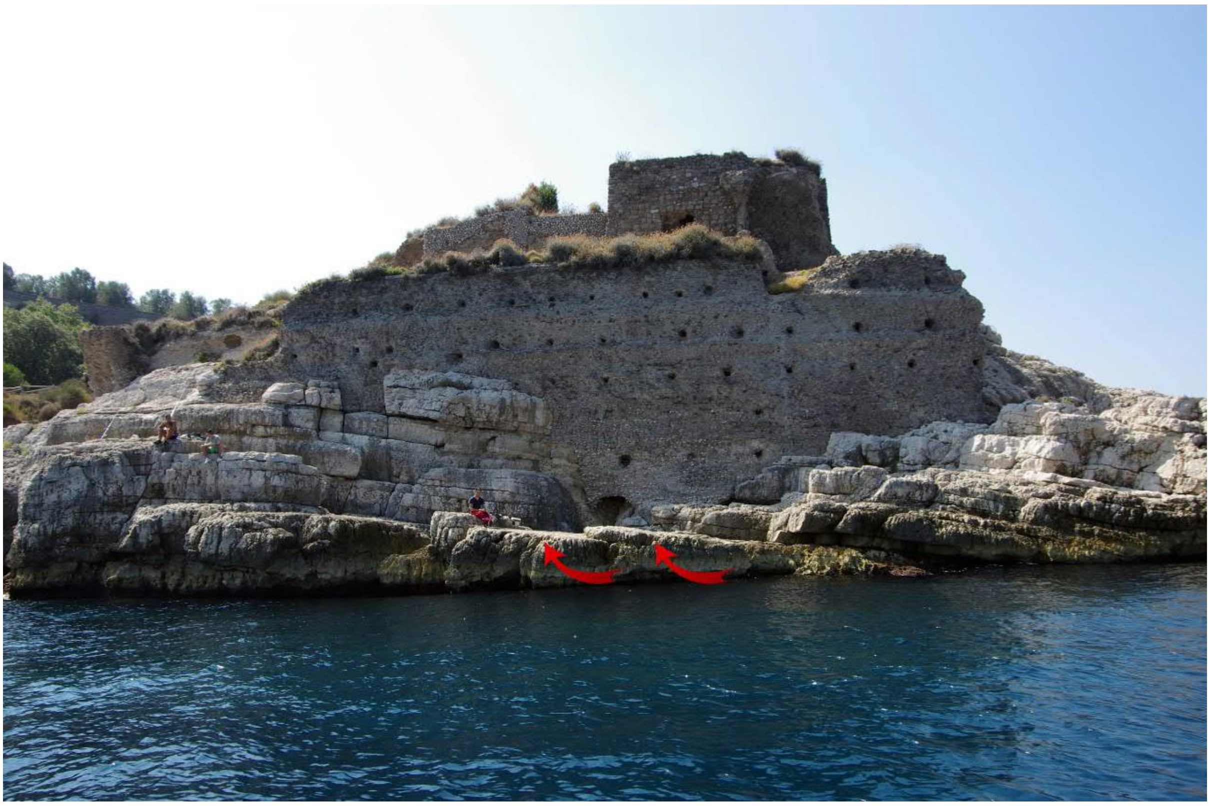

Fig. 7. East side of the pars maritima with levelled rock cuttings for landing places (© M. Reinfeld)

Fig. 8. Remains of a stuccoed vault in a room of the northern facade of the pars maritima, probably used as a triclinium. Screenshot of 3D model (© W. Filser, B. Fritsch)

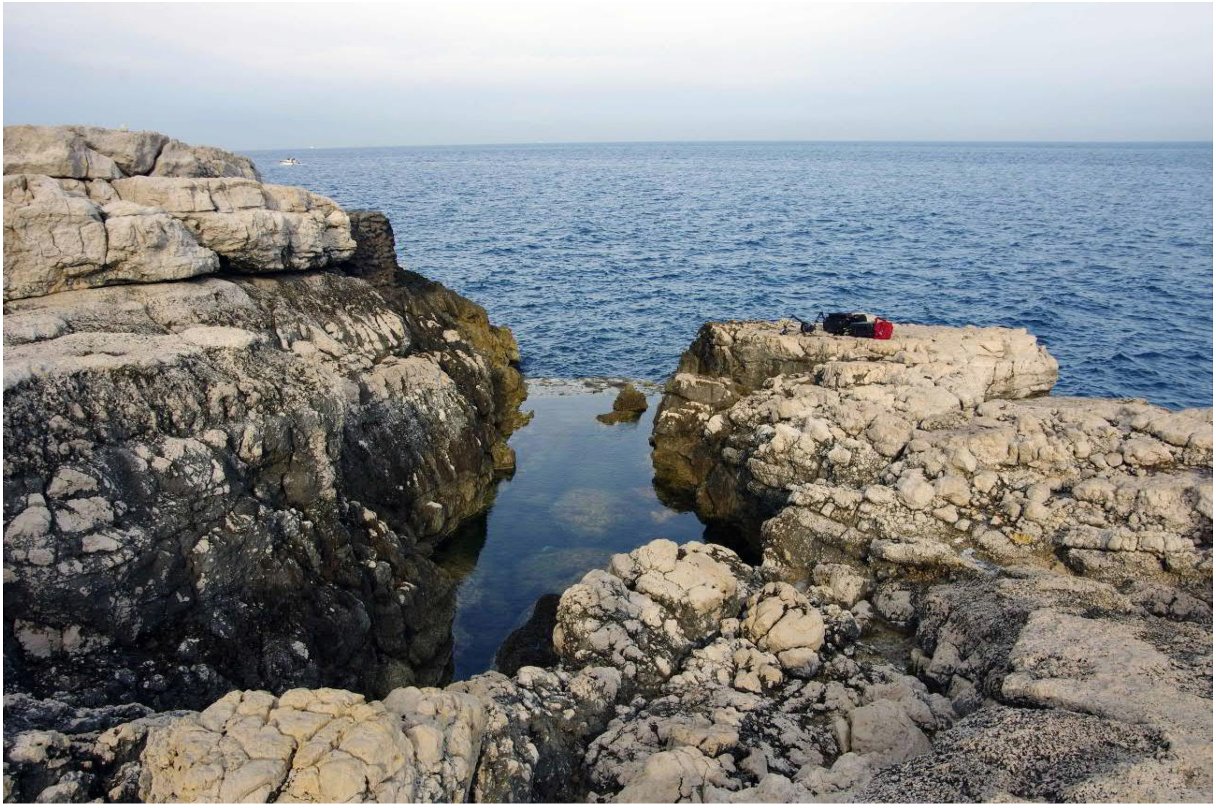

Fig. 9. Fishpond on the northern point of the limestone plateau (© M. Reinfeld)

UNDERWATER ARCHAEOLOGICAL EXPLORATION OF THE HARBOUR BASINS

The inner harbour, a nearly circular rock basin of about 25 to 33 metres in diameter, is located between the *pars maritima* and the *pars rustica*. Already Mingazzini and Pfister had realized its importance on the basis of a small pier (Figs. 10 and 11). However, nobody could ever explain the difficult entrance situation [Mingazzini and Pfister 1946: 123; Mielsch 1987: 60 f.; Russo 2006: 43 f.; Filser et al. 2017: 79]. Apparently, entry into the inner harbour from the east side, via a small natural crevice in the rock, was only feasible with very small boats – impossible for any kind of sailing vessel as we should expect it in the case of a maritime villa (Fig. 12). Still today, the crevice has a height of about 2 m and a width of about 2.50 m, and can only be passed by small canoes. Nowadays, the almost circular “Bagno della Regina Giovanna”, as the inner harbour is called by locals, is two metres deep to about six metres at the entrance. However, the bottom of the rock basin is covered by the debris of the villa and without excavation we cannot say for sure how deep the ancient harbour basin actually was (Fig. 13).

The small pier on the southeast side of the harbour, located directly in front of a two-storeyed niche façade covering the rock wall, could be used for mooring of small boats. As far as can be determined due to the intense marine vegetation, the pier was built from a core of *opus caementicium* that was faced with masonry. Presumably there was a wooden structure on top, which increased the height of the pier. At a depth of about 90 cm under water, an edge can be seen on both the pier and the façade that indicates the former water level (Fig. 14). The upper part of the pier was constructed in a later phase and is now above sea level. Probably the small pier was accessible via a staircase, the remains of which are to be found along the face of the rock above it. The pier was of course very much affected by tidal fluctuations and high waves that can flood the entire basin. As a result, the inner harbour could only be used under favourable weather conditions and never during strong winds. For example, staying in the basin was dangerous when the mistral was blowing from the northwest into it. When determining the height of the ancient sea level, the functional height of a pier and the local tidal fluctuations, both about 30 cm, must be taken into consideration. In addition, local markers for sea level changes were detected at a depth of 90 cm along an eroded edge of the pier and below the opposite rock face. This indicates a sea level change of 120 +/- 30 cm [Aucelli et al. 2016: 113-115. 120].

Of crucial importance for the understanding of the harbour system is the geology of the cape, and especially a massive rockfall between the inner and the outer harbour (Fig. 15). Apparently, it blocks a passage in the form of a natural rock arch – wide enough for medium sized sailing vessels – between the two basins. Today, this passage within the rock arch can be entered for a few metres on both sides, but locals report that they could pass it until some decades ago. Geological analysis and thermoluminescence dating are being used to provide an answer to the phenomenon. Certainly, the existence of the landing pier in the inner harbour would make much more sense if the two harbour basins were connected in antiquity, and the passage between them only blocked in recent times, probably in the course of one or more earthquakes during the 1st century AD or later. In this case, ships would have entered the inner harbour from west by passing beneath the rock arch after sailing through the outer harbour. Thus, the inner harbour might have been reserved for selected guests as well as the owner himself and his family. It must have been an impressive sight to enter this natural "grotto" through the rock arch and discover its magnificent design, which included the natural rock in the overall architectural ensemble. Furthermore, in front of the northern rock wall traces of the fixings of a bronze statue were found. Exactly opposite the landing stage the impressive over life-size sculpture stood in the very spot which was illuminated by the sun in the shady space of the inner harbour [Filser et al. 2017: 79-85; Fig. 14. 15a. 15b. 23]. All these details together created a refined symbiosis of nature, architecture and luxurious effects.

To the west of the villa complex the outer harbour is located and is protected by three small rocky islets on the north side. The rocky islets were connected with the limestone plateau of the *pars maritima* by means of an artificial mole [Iovino 1895: 16 f.; Mingazzini and Pfister 1946: 128 f.; Russo 2006: 46. 49; Filser et al. 2017: 81]. With a length of 121 m, a width of maximum 44 m and an area of approximately 5.000 square meters, the outer harbour was well suited to accommodate larger ships. From east to west, the present depth of the harbour basin slowly rises to a maximum depth of 9.5 metres below sea level, with the entire basin filled with heterogeneous debris and rocks (Figs. 6 and 16). In the area of the islands and the limestone plateau, the water depth increases stepwise, but to the northeast the limestone plateau drops steeply to a depth of 70 m below sea level [Filser et al. 2017: 71].

Over the course of several dives in the harbour large amounts of debris were found concentrated around the three islets. Presumably the results of earthquakes in the first century AD, the debris fell from the islets into the basin. The large stone blocks partly have a smooth surface, indicating that they were artificially worked to create a platform that connected the islets. In addition, dowel holes in the debris of the islets, as well as small columns, were found under water (Figs. 17 and 18). It now appears that the islets not only carried a platform that could be used as a breakwater and quay. The platform was also equipped with a luxurious architecture of columns and possibly statues, again reminiscent of numerous wall paintings with finely decorated harbour facilities in immediate contact with the sea [Rostovčev 1904; 1911; Lafon 2001: 117-122; Hinterhöller-Klein 2015: 329-378; Filser et al. 2017: 68. 81-90]. Clear evidence of its use as a harbour was the discovery of the remains of what probably served as a landing on the southwest side of the limestone plateau below the *basis villae* (Figs. 19 and 20). The platform-like structure in the area between the villa's garden and the first islet probably belonged to a mole that stretched from the limestone plateau over the three islets. The installation on the artificial platform was made of *opus caementitium* and wooden piles, as it is known from many other sites, for example the port of Nero in Anzio or the roman port in Astura [Felici 1993; Felici 2006]. Today, only parts of the limestone plateau with cuttings for the scaffolding of the caissons have been preserved at a depth of about 1.3 m.

Fig. 10. Pier in front of the niche façade in the inner harbour (© M. Reinfeld)

Fig. 11. View on the pier and the niche façade under water (© M. Reinfeld)

Fig. 12. View of the crevice on the eastern side of the inner harbour from southwest (left) and east (right) (© M. Reinfeld)

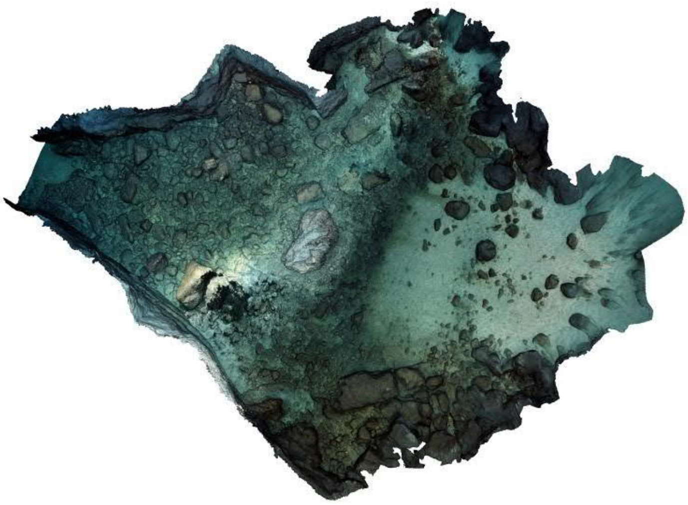

Fig. 13. Screenshot of the 3D model of the inner harbour with crevice (left) and pier (top left) (© B. Fritsch, M. Reinfeld)

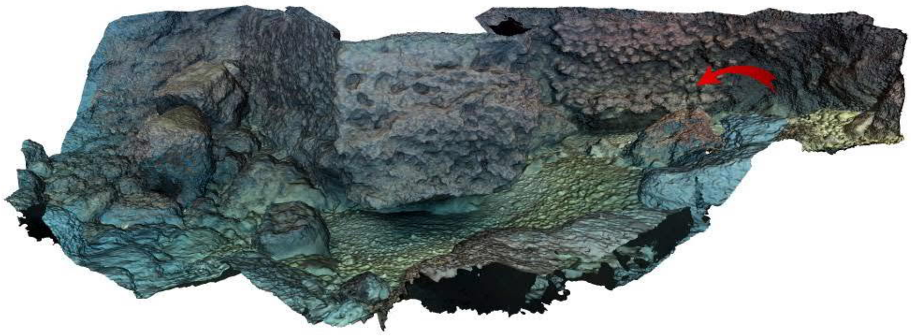

Fig. 14. Niche façade with edge on the right side and pier in the centre of the picture. Screenshot of 3D model (© B. Fritsch, M. Reinfeld)

Fig. 15. Rockslide seen from the outer harbour (west) (© M. Reinfeld)

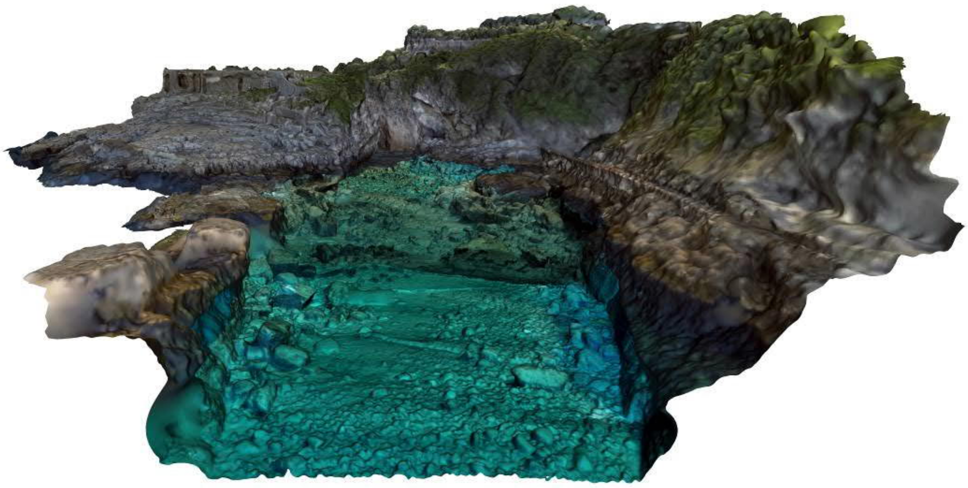

Fig. 16. Screenshot of a section through the 3D model of the harbour basin (© B. Fritsch, M. Reinfeld)

Fig. 17. Smooth-worked stone block with a small column, both of which have fallen from the island into the water (© M. Reinfeld)

Fig. 18. Rectangular dowel hole in the same stone block (© M. Reinfeld)

Fig. 19. Cuttings in the bedrock of the harbour basin attesting the use of scaffoldings for caissons into which the caementitium foundation of the mole had been set (© M. Reinfeld)

Fig. 20. Detail of the cuttings in the bedrock (© M. Reinfeld)

3D MODELLING OF THE HARBOURS

In order to obtain a better picture of the two harbours and to put them in an overall context with the villa, we started to make three-dimensional underwater models of the inner and outer harbour in 2017, which are integrated into the general 3D model of the villa as well (Figs. 4 and 16). When looking at the three-dimensional model and the smoothly worked rock walls of the basin, it becomes obvious that the construction of the harbour is an enormous technical masterpiece. Vitruvius wrote about such efforts of the Roman elite to manipulate nature via costly and laborious modifications of the seaside [Vitr. 5, 12, 1-7.]. The two three-dimensional models are still “work in progress”, but first results already allow important conclusions on the appearance and design of the port. The outer harbour basin is roughly rectangular in shape and the side walls were probably worked artificially to meet nearly at a 90 degree angle on the harbour floor. At its deepest point, in the area of the third island, the basin has a depth of about 9.5 m. To the east, the basin gets flatter, up to the area of the presumed former passageway to the inner harbour, where great quantities of debris of the villa and fragments of the rockslide reach the surface.

The documentation of the outer harbour basin consisted of about 7 hours of video material, from which 24,500 single photos (that is one photo per second) were generated with the free software *ImageMagick*[3] and further processed with a *SharpEdge*[4] filter [Weinhaus 2018] to facilitate the merging of the frames. Presumably due to

[3] https://imagemagick.org

[4] http://www.fmwconcepts.com/imagemagick/sharpedge/index.php

changes in light and visibility, the joint processing of all images into a single three-dimensional model with *Agisoft PhotoScan*[5] was unsuccessful [AgiSoft PhotoScan Professional 2016]. Nevertheless, the films could be combined into groups from individual days and dives, resulting in a total of about 30 submodels. In the next step, the submodels were scaled with *MeshLab*[6] and merged with the program *CloudCompare*[7] and a very clear drone image in a two-stage process [Cignoni et al. 2008; CloudCompare 2017]. First, the models were roughly oriented by hand, then an automated fine adjustment and merging according to the overlap was made. Finally, the PLY file of the 3D model was converted for the web viewer with *NEXUS 3DHOP*[8] (3D Heritage Online Presenter) and uploaded to the repository.

A complete documentation of a nearly 5,000 square metre harbour basin with its side walls using photo and video technology, as well as the integration of underwater and above water data into one comprehensive model, is not an easy task and has never been tried before in this form [McCarthy et al. 2019]. The preliminary model of 2017 and 2018 still has some gaps, which should be closed by further photos and 3D modelling in future campaigns. The biggest problems during the practical work under water were caused by stormy weather, different lighting conditions, the marine vegetation and big fish schools, which can completely obscure built structures and other objects. Moreover, the integration of the harbour model in the overall model of the villa still causes some difficulties. This concerns especially the smooth side walls that do not have a clearly distinguishable structure, the transition area between air and water, as well as the shallow water area. The structure of the ground is indeed easy to recognize by aerial photographs, but aerial and underwater images have different heights or depths that can’t be distinguished by the software. Even an exact georeferencing of the underwater model was not yet possible because strong wind and waves so far made an extensive survey with the total station impossible.

BACKUP AND PUBLICATION

Unfortunately, the 1960s documentation of the excavation work at the maritime villa is largely lost today. Today, we have the technical prerequisites to make the excavation documentation accessible to science in the long term. The research data collected during the excavation campaigns are secured long term in an online repository of *Edition Topoi*[9] in Berlin. In addition, the repository will provide pictures, maps, 3D models and other digitized material about the villa free of charge to the public. The repository is licensed through a Creative Commons license and the data can be used by anyone. All research data have their own DOI and can be cited. *3DHOP*[10] is used as the online viewer for the 3D models, but the data can also be downloaded without the viewer. An API can also be used to directly load the data into other environments, such as *JupyterLab*[11] [Project Jupyter 2018].

CONCLUSION

The impression made by the maritime villas, especially on travellers on boat, and the efforts made by the villa owners to give their property the most aesthetic and luxurious appearance possible, becomes clear when looking at the wall paintings preserved in the Roman villas. Therefore, it is hardly surprising that the villa on the Cape of Sorrento had a magnificently equipped maritime façade, which was visible from afar. Both ships coming from east, from Surrentum, and ships traveling towards south-west to Capri could see the villa on the protruding limestone plateau from a far distance. However, a special feature of the villa is to hold the two lavishly designed harbours and their assumed original connection via a natural rock arch.

In order to gain insights into the construction history, and to create an up-to-date overall plan of the villa complex, an extensive air and ground-based photogrammetric survey using drone images and hand-held cameras was started in 2015. These works were supplemented and extended by the underwater archaeological photographic documentation of the two harbours. The resulting high-resolution three-dimensional model of the Cape of Sorrento is an excellent example of the vital importance of the combined application of terrestrial archaeology, underwater

[5] https://www.agisoft.com
[6] http://www.meshlab.net/
[7] http://www.cloudcompare.org/
[8] http://vcg.isti.cnr.it/nexus/#overview
[9] https://edition-topoi.org
[10] http://vcg.isti.cnr.it/3dhop/index.php
[11] https://jupyter.org/

archaeology and digital methods for the interpretation and visualization of our cultural heritage. A combined three-dimensional model of terrestrial and underwater images on this scale is so far unique. Moreover, the 3D model of the villa complex with its two harbours, combined with a new scaled overall plan, allowed a reinterpretation of individual villa complexes. For example, working traces on the northwest side of the limestone plateau indicate that there may have been a garden. This assumption is supported by the presence of a small fishpond in the north. In addition, for the first time, evidence was provided that the outer harbour was indeed a representative port and artificially shaped.

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