

Article

New Acoustic Design for the *Piscina Mirabilis* Located nearby the Port of *Misenum*

Antonella Bevilacqua^{1,*}, Gino Iannace², Emanuele Navarra², Nicola Manzo³ and Luis Gomez-Agustina⁴¹ Department of Architecture and Engineering, University of Parma, 43126 Parma, Italy² Department of Architecture and Industrial Design, University of Campania L. Vanvitelli, 80138 Caserta, Italy; gino.iannace@unicampania.it (G.I.); emanuele.navarra@unicampania.it (E.N.)³ Agenzia del Demanio, Direzione Regionale Campania, 80138 Caserta, Italy; arch.nicolamanzo@gmail.com⁴ Department of Civil and Building Service Engineering, London South Bank University, London SE1 0AA, UK; gomezagl@lsbu.ac.uk

* Correspondence: antonella.bevilacqua@unipr.it

Abstract: Many heritage buildings from ancient Rome are being refurbished based on their original plan's structure. One of them is the *piscina mirabilis* located nearby in Naples, which was a cistern used by the Romans to collect drinkable water for the navy waiting in the port of *Misenum*. The *piscina mirabilis* has similar architectural characteristics to a "cathedral"; however, its current precarious architectural state is the result of high levels of humidity that have caused the proliferation of mold on its vertical and horizontal surfaces over the centuries. Acoustic measurements were conducted inside the *piscina mirabilis*, highlighting an existing condition of the room being very reverberant, not suitable for occasional speech and conversations. The design proposed by the authors involves some mitigation solutions for the acoustics, mainly focused on controlling the low–medium frequencies and the realization of a restoration project consisting of a raised timber-floored walkway that runs along the perimeter walls, with the addition of water covering the existing floor as a natural element dominating the room volume, which represents the primary function of the building in antiquity. A waterfall was designed to be on the northern side wall. Acoustic studies were an important part of the refurbishment strategy, and a mitigation solution was devised to control medium–low frequencies by using inflated balloons of different sizes that were suspended from the ceiling vaults instead of widely used acoustic panels. The proposed strategy lowered the reverberation time by 3–4 s to accommodate a minimal level of conversational understanding. Such a solution is appropriate for this heritage building as well as other future conservation projects.

Keywords: architectural acoustics; cultural heritage; Roman treasures; acoustic simulations; *Misenum*; *piscina mirabilis*; Naples



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1. Introduction

Romans were clever engineers in the realization of hydraulic structures, like aqueducts, to supply thermal baths, military installations and public fountains. The aqueducts terminated into basins of massive dimensions that could be part of the significant infrastructure for urban contexts [1].

The *piscina mirabilis* is the largest water cistern dating to the Roman imperial period and similar to the reservoir of Yerebatan Sarayi located in Istanbul, Turkey [2]. The Yerebatan Sarayi was realized in 476, to be connected to Adrian's aqueduct, and its dimensions are very significant, 70 × 140 m in plan, while the brick vaults are supported by 336 columns in Corinthian style [3].

Another similar structure to the *piscina mirabilis* is located within Domitian's villa in Albano, which is another cistern that is 11 m wide and 123 m long, divided by two partitions in three compartments. This cistern was used to supply the entire villa, including the

fountains dislocated in the garden. After this ornamental use, the water was collected and reused for irrigation [1].

It was named *mirabilis* for its extraordinary dimensions and for being excavated in a tuff rock for a depth of more than 15 m [1]. The geometric aspects, the architectural characteristics dominated by pillars and the soundscape of this memorable place have been compared to a Gothic “cathedral”, and for this reason, it has also been named Bacoli “cathedral”, referring to the city of Bacoli where it is located, as part of the archaeological Flegrean area, close to the port of *Misenum*.

The common factor between the *piscina mirabilis* and the Yerebatan Sarayi cistern/reservoir is the realization of cruciform pillars surmounted by barreled vaults [4]. Many cisterns are nowadays monitored from an engineering perspective, due to some damage provoked by earthquakes or land slits since many of them are built underground. On the other hand, different architects focus their attention on the revival of fascinating structures whose marvels astonish for their grandeur never repeated in history.

This paper deals with the refurbishment design as a proposal for the *piscina mirabilis*, involving the exploration of the architectural aspects and the acoustic features of this space. The scope of the architectural design is to create conditions more suitable than the existing status for visitors and tourists turned to the research of Roman treasures [5], but the proposed design is based on the concept of a minimal impact on the existing structure. As such, the design involves a wood-finish walkway raised from the existing ground to be supported by a steel frame that is fixed to the floor of the *piscina mirabilis* in selected points [6], whose distance corresponds to the length occurring between every other vault. Water, as the main element giving significance to this place, is reintroduced with a system of pumps that is creating a waterfall on the northern side wall, which is going to fill all the ground for a height of 400 mm [7].

From an acoustic perspective, the installation of floating balloons covering the barreled vaults was designed to control the low frequencies [8] that otherwise would create a booming effect, as revealed by the measured values that make conversations very difficult to comprehend [9]. The properties of the inflated balloons were measured in a reverberant chamber, where different sizes of diameters were singularly tested. The semi-transparency of the balloons was intended to create a diffuse light that was currently hitting the floor of *piscina mirabilis* with very narrow beams created by the holes in the vaults [10,11].

2. Literature Review on Heritage Acoustics

Many heritage buildings, when subject to restoration or conservation works, lack a good acoustic response, since they focus only on architectural renovation. It is important to understand how acoustics can complete the description of a room based on the behavior of its soundwaves which bounce on the boundary surfaces and create a series of reflections commonly known as reverberation [12]. The acoustic quality of the room is also a function of its usage such that the criteria related to music or speech intelligibility can be achieved based on the adaptation to this purpose [13].

There are many predictions that experts in acoustics calculate before delivering an executive project since the variables involved in the simulations are various, all depending on the finish materials, geometry, shape architectural elements and similar [14]. Due to the development of technology, nowadays, it is possible to achieve a high level of accuracy in terms of predictions, providing a wide variety of configurations useful to architects in selecting the best organization of spaces. The synergy of different disciplines remains the path to success since the best expertise can be merged into a unique product [15]. The methodology that is largely used for acoustic predictions is determined by the simulations of geometric acoustic models, from which the acoustic parameters can be obtained, by studying the interaction between soundwave emitted by virtual sources and material properties applied to the digital entities of models, taking into consideration that the accuracy at very low octave bands becomes less since the variety of software is based on image-source computation [16]. An additional computation for the soundwave motion

is necessary to complete the acoustic description whereas is necessary. Many acoustic predictions deal with speech comprehension and intelligibility, thus the bandwidth to be studied is less wide, generally going from 125 Hz to 2 kHz [17].

The challenges of acoustic predictions consist of missing data on material properties, sometimes due to the restrictions over archaeological sites which do not allow for the extraction of samples with invasive techniques, and other times due to the inexistence of descriptions/discoveries related to monuments lost forever [18]. In these cases, the methodology of comparisons found in other similar heritage buildings can be adopted, by leaving open the possibility of being updated in case of further discoveries. In this paper, the acoustic approach to the renovation design was hybrid, consisting of simulating scenarios with different materials with known properties and measuring the absorption and scattering coefficients by physically reproducing the objects that were intended to be used [19].

Many research studies in heritage acoustics are focused on the faithful reconstruction of the soundscape through the aid of virtual and augmented reality (VR and AR) devices which allow the users to freely moving within the virtual environment, rebuilt based on scientific discoveries [20]. This technique can be potentially used as an addition to the current work, consisting of using special goggles that allow a visitor in ancient times to overlap the current reality with the reconstructed one.

3. Historical Background and Construction Materials Used in the *Piscina Mirabilis*

Traces before the presence of Romans can be found even in the 6th century BC when the port of *Misenum* was important during the battle between Greeks, coming from *Cumae*, and Etruscans in 524 BC. A similar situation occurred in 474 BC, when the Etruscans were defeated in a naval battle in the Bay of *Neapolis*. After centuries, this place was famous for the construction of villas by aristocrats, like Villa Lucullus and others which transformed this bay into a very posh residential area [21]. It was Augustus who transferred the naval basis from *Portus Iulius* to *Misenum* (Appendix A), becoming definitively important during the civil war between 68 and 69 AD.

Piscina mirabilis was built during the Augustan period, in the middle of the 1st century AD. At that time, it represented the end point of the Roman aqueduct running from the mountains of Serino, located at a height of 330 m, to Naples and other Flegrean fields. The still water of the Irpinian hill was conducted to Bacoli for a path of 96 Km long, from which cities like Pompeii, *Herculaneum*, *Neapolis*, *Puteoli*, *Cumae*, *Misenum* and a few others were supplied with potable water [22], as shown in Figure 1. Other than the civic aspect, the main reason why the *piscina mirabilis* was built is related to the needs of the Roman sailors (*Classis Praetoriae Misensis*), who used to request continuous fresh water supply.

The *piscina mirabilis* was supplied with water from the Augustan water (*Aqua Augusta*), which was realized in 33 BC. The cistern was out of use when the *Aqua Augusta* was destroyed, which happened between the 4th and 5th centuries AD [22].

After the Roman Empire, *Misenum* lost the privilege of being a city (*castrum*) and was governed by a count, representing the influence of the Duke of Naples in that territory. Thereafter, *Misenum* was invaded by Longobards like many other Italian cities, and it was definitively destroyed during the 9th century by Saracens.

Before the first restoration works of the 20th century, the *piscina mirabilis* was an abandoned, empty volume where the humidity from the underground dominated the surfaces of the walls and floor. This place was locked and never used for any other function after the purpose of being a water cistern.

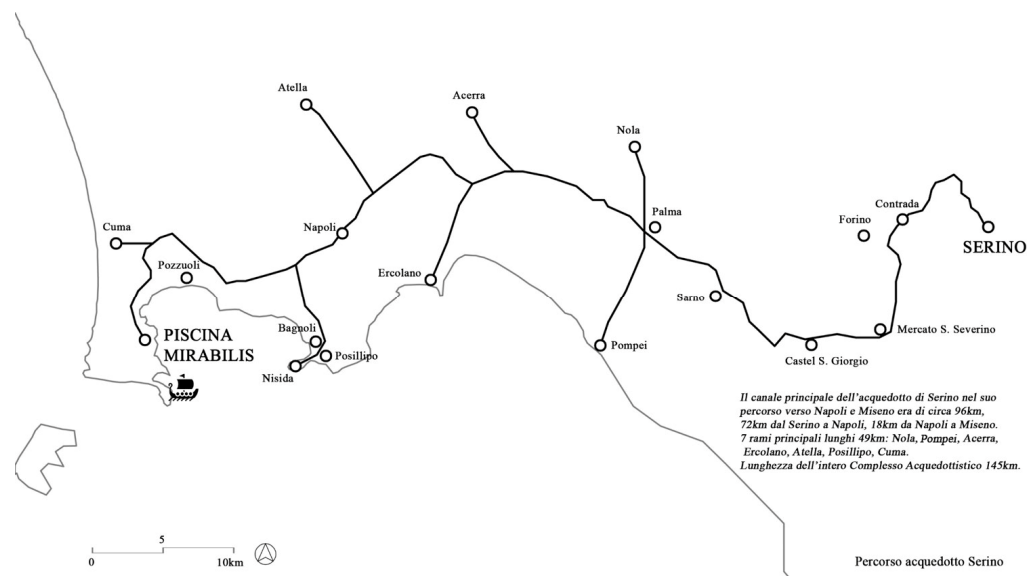


Figure 1. Path of the Roman aqueducts from Serino to *piscina mirabilis*.

The first restoration of *piscina mirabilis* occurred in the first half of the 20th century and was mainly focused on the consolidation of some pillars and vaults and on filling some cracks [1]. The completion of the archaeological excavations occurred between 1910 and 1926, followed by the consolidation of the damaged walls [1]. In 1926, further restoration works were necessary to consolidate the second and third arches of the largest nave by using pozzolan mortar within the frame of the existing *opus reticulatum* [23]. In 1929, there were some works on the staircase, and then in 1936, there was the consolidation of the last damaged and missing arches. In 2007, there was a new project regarding complete consolidation and waterproofing of the terrace on the roof of this “cathedral”.

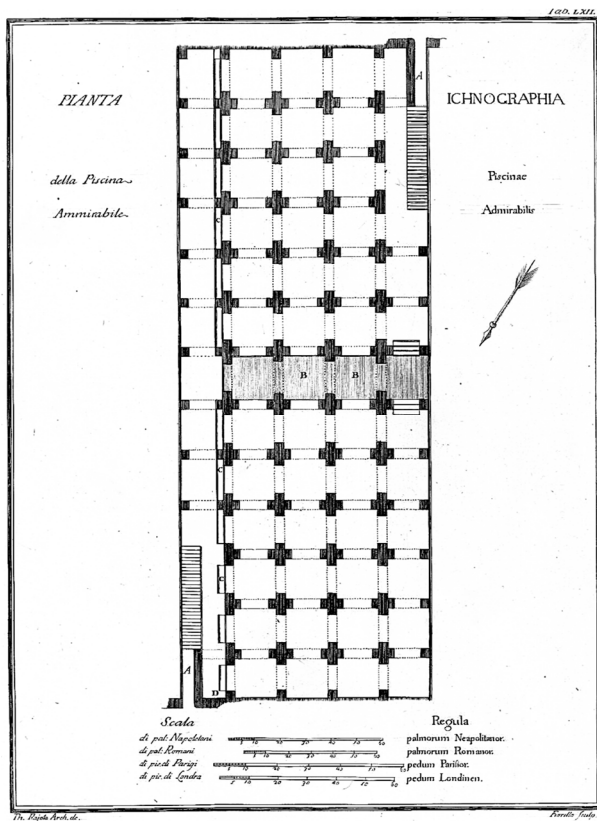
The *piscina mirabilis* is a structure excavated in tuff rock for at least 15 m depth. In plan, it is 72 m long and 25 m wide, for a total volume of 12,600 m³, as shown in Figure 2. The barreled vaults in concrete and pasted bricks are supported by 48 cruciform pillars, organized into four rows and creating five long naves and thirteen short naves, which divide the internal space into 13 courtyards, similar to a Gothic “cathedral”.

The *piscina mirabilis* was provided with two doors located at the top of the staircases, specifically in the northwest corner, still in function, and in the southeast side, which is currently closed. Figure 3 shows the staircase of the north side. The disposition of these two ingress points is due to the collection of water from the northwest side and to the extraction of water from the southeast corner through hydraulic systems. Nowadays, there are gaps in place of the wooden hydraulic tools, where the sun rays create unique colors when penetrating inside the structure.

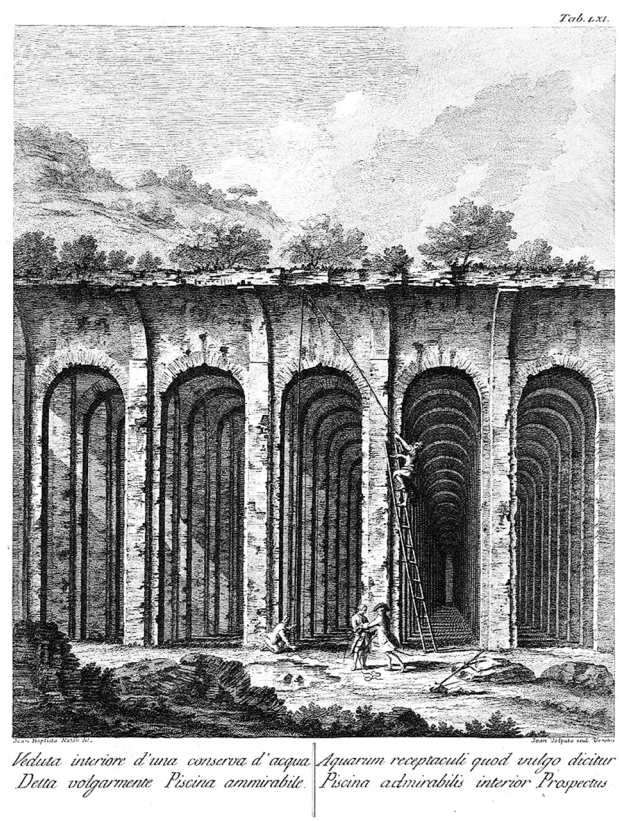
Walls and pillars of the *piscina mirabilis* are in *opus reticulatum*, which is a construction technique mainly diffused during the Augustan period (1st century AD), characterized by horizontal layers of bricks for walls and layers of small tuff stones for pillars [26]. The entire structure is waterproofed by a coating layer of plastered painted bricks. In the central nave, there is a basin of 1.1 m depth, called *piscina limaria*, which was used for maintenance and cleaning procedures during the periodic depletion of the whole cistern.

There are 12 small rooms outside the cistern, also provided with barreled vaults and walls in *opus reticulatum*, which were probably used for storing hydraulic tools.

Roman engineers used to utilize flakes of rough tuff stone for the construction of the cistern in combination with the water of hydrated *cocciopesto* (or *opus signum*) characterized by a mixture of lime, pozzolan and broken tiles and ceramics. It can be noticed how important the composition of the cement matrix was, deriving from the reaction of lime, *cocciopesto*, chalk and Tobermory [27].



(a)



(b)

Figure 2. Historical drawings of the *piscina mirabilis*, Italy: plan layout (a) [24] and sketch of the internal view (b) [25]. Credit to Th. Rajola Arch. de. & Fioroli, Sculp, and Joan. Baptista Natali del. & Joan. Volpato scul, respectively.



Figure 3. Internal view of the *piscina mirabilis*. Particular detail of the northwest staircase, the only one used for access.

4. Renovation Design Proposal

A renovation design of the *piscina mirabilis* is proposed in this paper to make the environment more pleasant for visitors who would like to explore the “cathedral” of

Misenum [28]. Different are the observations in terms of materiality and organization of the space; nevertheless, this architectural design proposal consists of using the Roman cistern for an art exhibition space, where the public can be fully immersed in reading or simply watching paintings of famous artists in a semi-open-air space that is far away from any urban distractions [29]. The renovation project design is focused on two main aspects:

- The restoration process involves the cleaning of fungi in the construction, which can furthermore damage the original mortar made of *cocciopesto* and hydraulic cement.
- The creation of a continuous ramp running along the perimeter of the volume is proposed, designed to be supported by thin steel legs fixed onto the ground, along which the paintings can be deployed for exhibition.

4.1. Restoration Process

All perimeter walls of the *piscina mirabilis*, except those around the *piscina limaria*, were built in *opus reticulatum*, a construction technique used by Romans by placing the stone blocks 45° out of lean. The blocks have a pyramidal shape, with a square base installed on the external skin. With *Flavii* emperors, the *opus reticulatum* started to be combined with bricks such that a layer of bricks was mounted on the build-up wall at 1.5 m [30].

The pillars of *piscina mirabilis*, instead, are in *opus quadratum*, another construction technique consisting of placing regular parallelepiped blocks at a constant distance from each other, as shown in Figure 4.



Figure 4. Status of the structure of the *piscina mirabilis* that should be restored to eliminate fungi and bacteria and make the place healthier for visitors.

The floor of the *piscina mirabilis* is in *opus signum* (or *cocciopesto*), which is a mix of gravel and fragments of tiles with hydraulic cement to protect the structure from humidity, as typical of thermal buildings [31]. It can be said that in some samples of pillar fragments, a trace of mercury has been detected along with the micrococcus, which is a bacterium characterized by a yellow-orange patina, becoming green where there is no exposure to

sun rays and where the humidity is consistent [32]. The micrococcus is spread in colonies and is detectable also by its moisture odor.

The restoration design would involve only the external surfaces of the structure, with natural treatments applied against the proliferation of bacteria which could help to make the whole environment healthier for vulnerable people like children and seniors.

4.2. Architectural Acoustic Design

As a second step of the renovation design, a continuous ramp in wooden planks recycled from other construction sites is intended to be installed onto a Corten steel frame, supported by thin pillars fixed onto the ground. A system of pumps is designed to be in place of the old pipeline in order to have a layer of water of 400 mm in height, highlighting the importance of this natural element in the *piscina mirabilis*, as shown in Figure 5. The short north side wall is characterized by a waterfall that would represent the main natural musical instrument resonating in the reverberant volume.

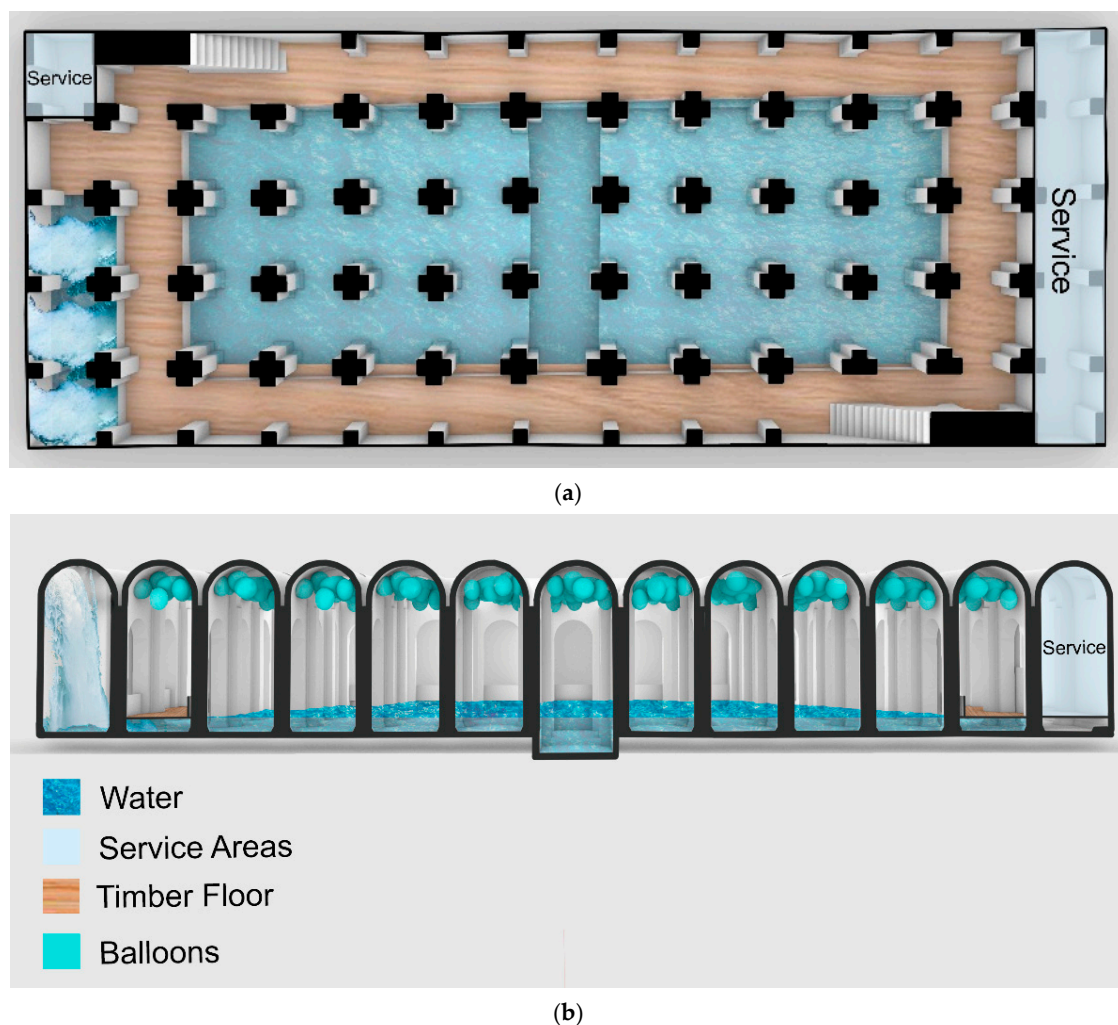


Figure 5. Drawings of the restoration design related to the *piscina mirabilis*: plan (a) and section (b).

A series of balloons with different diameters were designed to control the reverberation time and other acoustic parameters. They were designed to be suspended from the ceiling, taking advantage of the concept related to the absorption given by membranes at low frequencies, especially if the balloon diameter was consistently large. This idea takes inspiration from the exhibition called Heartbeat which occurred in Covent Garden, London, in 2015, by the French artist photographer Charles Petillon for the occasion of the London

Design Festival, as shown in Figure 6. Petillon said that he wanted to create a connection between the past and present to allow visitors to re-examine the routine in the heart of London, as released in an interview on the Colossal [33].



Figure 6. Cloud of 100,000 balloons suspended inside Covent Garden, London, by Charles Petillon, 2015.

In terms of acoustics, the balloons inside the *piscina mirabilis* have the intent of decreasing the booming effect through the absorption of a large sound wavelength, other than reducing the large volume of the entire space [34]. The transparency of the inflated balloons would also accentuate the diffusion of natural light that is concentrated in specific locations with narrow and sharp beams.

4.3. Examples of Restoration for Similar Heritage Buildings

Different are the cultural heritage buildings that are currently in a state of degradation which require structural and surface interventions to be preserved for future generations. In Italy, given the abundant patrimony, it is difficult to build new constructions, but on the other hand, the existing structures should be preserved and maintained to be converted to new use functions. Heritage buildings are living testaments and not mere relics of the past. A good restoration project should collect the memory and the identity of the community to endure the cultural narratives through the adaptation of unique architectural challenges of the past for modern uses [35].

One of the goals of this proposed design project is the promotion of social interaction and cultural exchange by providing spaces for community gatherings and events to fulfill the vitality of contemporary life. If this achievement can be obtained within a priceless artifact that offers glimpses into the past and at the same time an opportunity for education and enlightenment, this would represent a source of inspiration for generations to come.

Adaptative reuse and thoughtful preservation are given by a minimal intervention that leaves almost the entire existing structure intact. The architectural nuance consists of the continuous waterfall which is intended to create a unique sonic experience in a very reverberant volume, encompassing a full sound envelopment while immersed in understanding artworks [36]. In this view, the proposed restoration design enhances the building's functionality, accessibility and sustainability without compromising its historical integrity. Even the raised walkway along the perimeter walls represents a minimal visual impact that disappears in the forest of pillars for some perspectives.

The safeguard of this architectural treasure with minimal intervention of sustainable materials makes possible an imaginary bridge between the past and present time which creates a tangible link to ancient Rome when the feelings of sailors around this area were vibrant and exciting before any naval mission.

This research project has some limitations that can be improved with the utilization of innovative technology: the employment of a 3D laser scanner instead of meter tape for more accurate building information modelling could be employed to enable a more realistic virtual reconstruction. This is the route by which other restoration projects can be inspired. Since the *piscina mirabilis* is compared to a “cathedral” for its elevated numbers of pillars and vaults, acoustic mitigation in these and similar religious places can be made with the innovative strategy of balloons suspended to the ceiling instead of the application of acoustic panels on walls which are more suitable for other environments.

5. Methodology

5.1. Acoustic Measurements

Before talking about the site survey, it should be mentioned that Romans did not pay attention to the acoustics of the *piscina mirabilis* since it was a structure only used for collecting water. In addition, Romans did not imagine that the *piscina mirabilis* could have had a function different from a cistern. As such, the placement of finish materials provided with only reflecting properties is due to the intention of protecting the structure from humidity and water infiltration.

A campaign of acoustic measurements was conducted within the *piscina mirabilis* in compliance with ISO 3382 [37] for the validity of this research study. Compliance with the standard requirements involved the minimum distance between source and receiver, the minimum distance between the source and boundary surfaces of the room (i.e., walls and floor), and the minimum number of microphone positions for each source position [38]. The sound source was placed in two positions, while the microphone was moved into 11 positions, across half of the whole space, due to the specular geometry along the transversal axis. The equipment used for the measurements consisted of firecrackers as a sound source [39] and a Brahma Field 4 microphone as a receiver, as shown in Figure 7. The choice of the sound source was mainly influenced by the site conditions, although it is widely used especially for outdoor spaces. The uncertainties related to repeatability and directivity are typical characteristics of firecrackers, even if they are used for acoustic measurements for their good signal-to-noise ratio (SNR) [40]. The Brahma microphone was featured in the tetrahedral disposition of the transducers, which allowed for the 3D capture of the sound field, for a panoramic sound description up to the first order of ambisonics (O1A). Figure 8 shows the location of the equipment during the acoustic measurements, while Figure 9 summarizes the results of the measured acoustic parameters.



Figure 7. Equipment used during the acoustic survey within the *piscina mirabilis*.

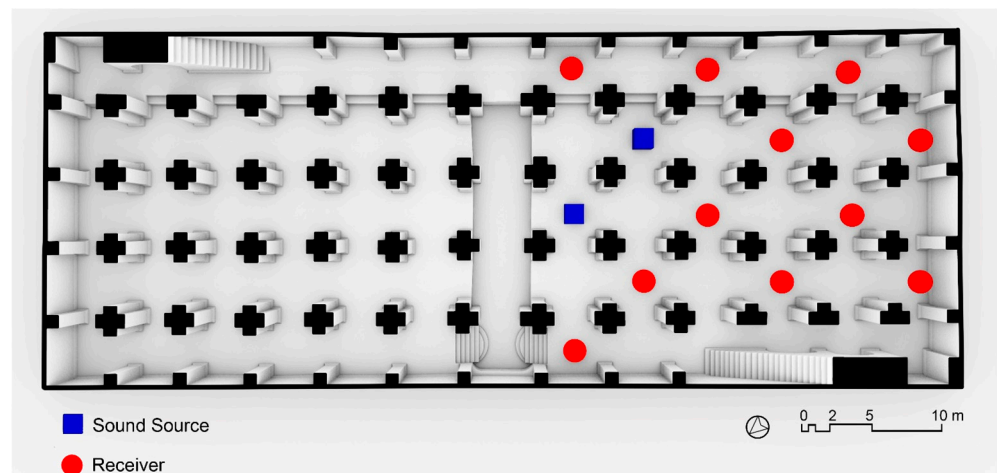


Figure 8. Positions of the equipment taken during the acoustic measurements within the *piscina mirabilis*.

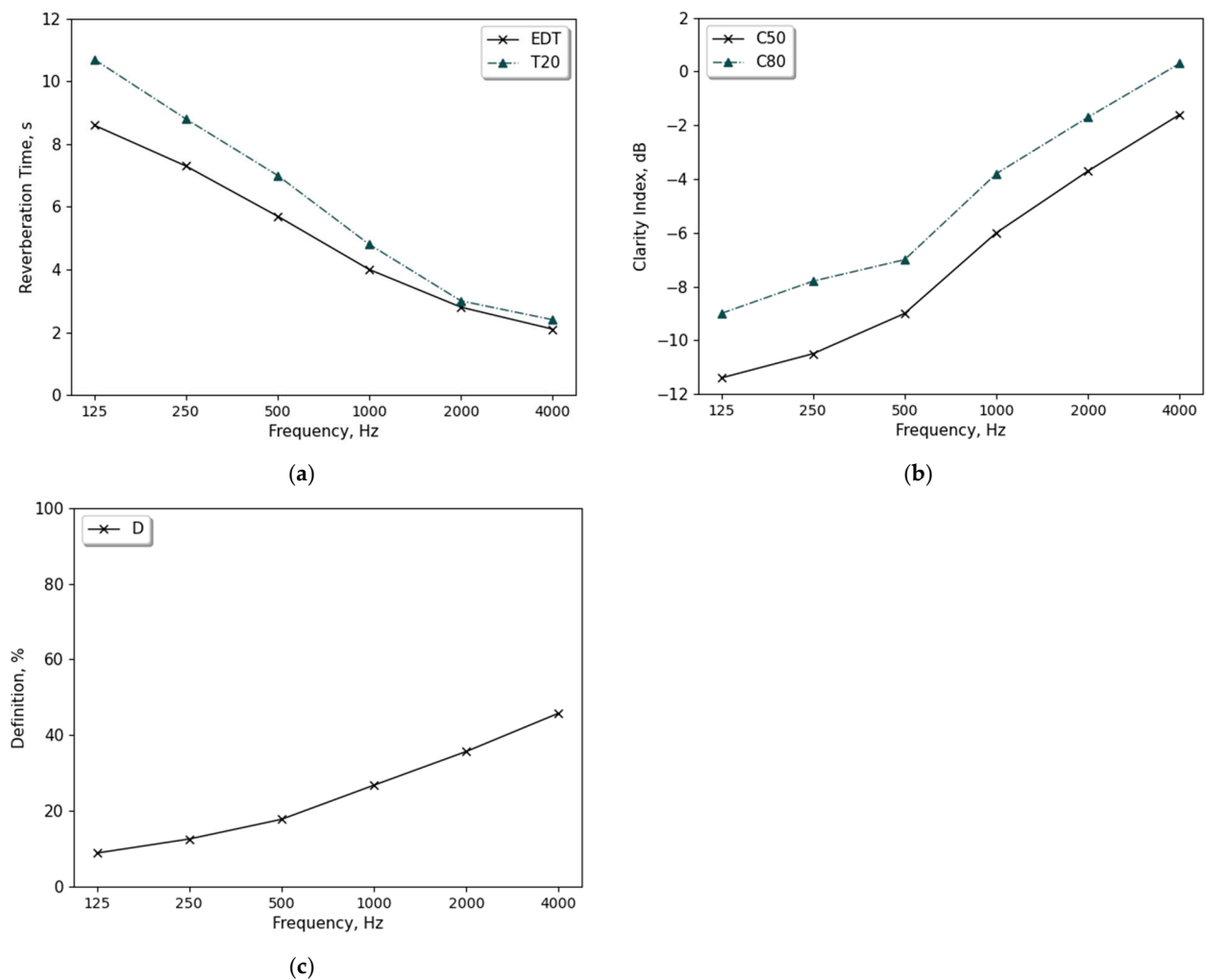


Figure 9. Measured values of the main acoustic parameters related to the *piscina mirabilis*: EDT and T20 in comparison (a), clarity indexes C50 and C80 (b), and definition D50 (c).

The acoustic measurements were analyzed with the software Adobe Audition, and the main acoustic parameters were gathered with the plugin suite Aurora.

Figure 9a shows that the early decay time (EDT) values were around 7–8 s at low frequencies, with a downward trendline toward the high frequencies whose values were around 2 s. A similar trendline was found with the reverberation time (T20), where the values differed from the EDT only at low frequencies, reaching up to 11 s, while the difference between the EDT and T20 values at medium–high frequencies was very negligible. Overall, this space is considered very reverberant [41], similar to a large “cathedral” where the walls, columns and floor are characterized by reflecting materials like stone. Other than the finished materials, the other component making this space very reverberant was the volume size, equal to 27,000 m³, as the equation of reverberation time was directly proportional to the room volume [42].

In terms of the clarity index (C50), speech intelligibility was very poor at low frequencies, up to −9 dB, while a better response was found at very high octave bands, reaching approximately 0 dB, as shown in Figure 9b. Similarly, the trendline related to music clarity (C80) was shifted downward by about 2 dB, going from −12 dB to −2 dB. The results showed that this space is acoustically characterized by an overwhelming number of words (for speech) and notes (for music) whereas any performance about the functions just mentioned is going to happen.

Figure 9c shows that the definition is below 50% across all of the spectrum bandwidth, to be around 9–10% at low frequencies and 40% at high octaves.

5.2. Digital Model

From the architectural survey, a digital model representing the existing conditions of the *piscina mirabilis* was created, as shown in Figure 10. In particular, the digital model was used to propose the new architectural design of the same space other than to perform acoustic simulations related to a new acoustic design. All the element surfaces were drawn as flat planes in AutoCAD 2024. All layers were grouped based on the finish material [41]. Table 1 summarizes the architectural features of the *piscina mirabilis*.

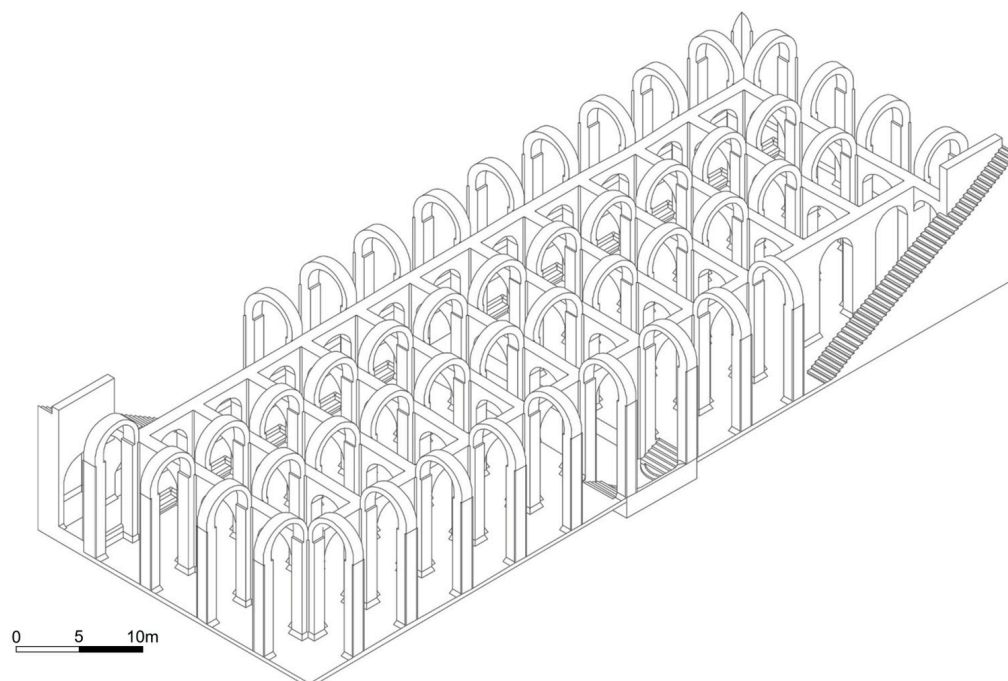


Figure 10. Axonometric view of the digital model related to the *piscina mirabilis*.

Table 1. Architectural features of *piscina mirabilis*.

Description	<i>Piscina Mirabilis</i>
Longitudinal axis (m)	72
Transversal axis (m)	25
Height at the center of the vault (m)	15
No. of barreled vaults/arches	65
Net volume (without pillars) (m ³)	16,170

5.3. Acoustic Simulations

A set of acoustic simulations was performed with Ramsete 3.13 software [43], based on the new design, as explained in the previous section. The acoustic simulations were performed by placing the sound source in two different positions while 200 receivers were homogeneously distributed across the naves.

Table 2 reports the absorption and scattering coefficients for the proposed materials, which were taken from the literature [44,45], while the absorption coefficients of the inflated balloons were taken from measurements conducted by the authors in a reverberant chamber [46]. The balloons were made of latex material inflated with helium gas. The advantage of having differently sized diameters has a major impact on the specific octaves that are intended to be mitigated; the larger the diameter, the more absorbent the low frequencies.

Table 2. Surface, absorption and scattering coefficients for all the materials considered in the simulations.

Material	Area (m ²)	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	Scattering (@ 1 kHz)
Plastered on brick/stone	9038	0.06	0.05	0.05	0.04	0.04	0.04	0.05
Solid timber–ramp	803	0.10	0.23	0.07	0.02	0.30	0.03	0.05
Inflated balloons (ϕ 1.5 m)	334	0.35	0.19	0.10	0.11	0.15	0.20	0.05
Inflated balloons (ϕ 1.0 m)	825	0.22	0.16	0.07	0.09	0.14	0.15	0.05
Inflated balloons (ϕ 0.5 m)	726	0.29	0.14	0.06	0.10	0.14	0.19	0.05
Water	801	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Openings	80	1.00	1.00	1.00	1.00	1.00	1.00	0.01

The properties of solid timber were measured in the archaeological site of Tyndaris, as one of the materials found in Greek–Roman theatre, by employing the technique of a laser Doppler vibrometer (LDV) [47].

6. Analysis of the Simulated Results

The main acoustic parameters as outlined in the ISO 3382 were analyzed [37], as shown in Figure 11. The acoustic simulations were carried out in unoccupied conditions and by considering the average values of all the receiving points.

Figure 11a shows that the EDT values were lowered at low frequencies, specifically by more than 4 s at 125 Hz. The contribution of the balloons at high frequencies was negligible, with a difference of less than 0.5 s from the measured results. A similar trendline was found with T20, as shown in Figure 11b, but all values were shifted upward by 0.4 s. The graph related to the T20 results shows that the simulated values at low frequencies were definitely absorbed with the strategy of balloon installation; with the new design project, the T20 values were equal to 4 s at 125 Hz, increasing to 6 s at 500 Hz, going up to 2 s at 4 kHz, similarly to the measured values.

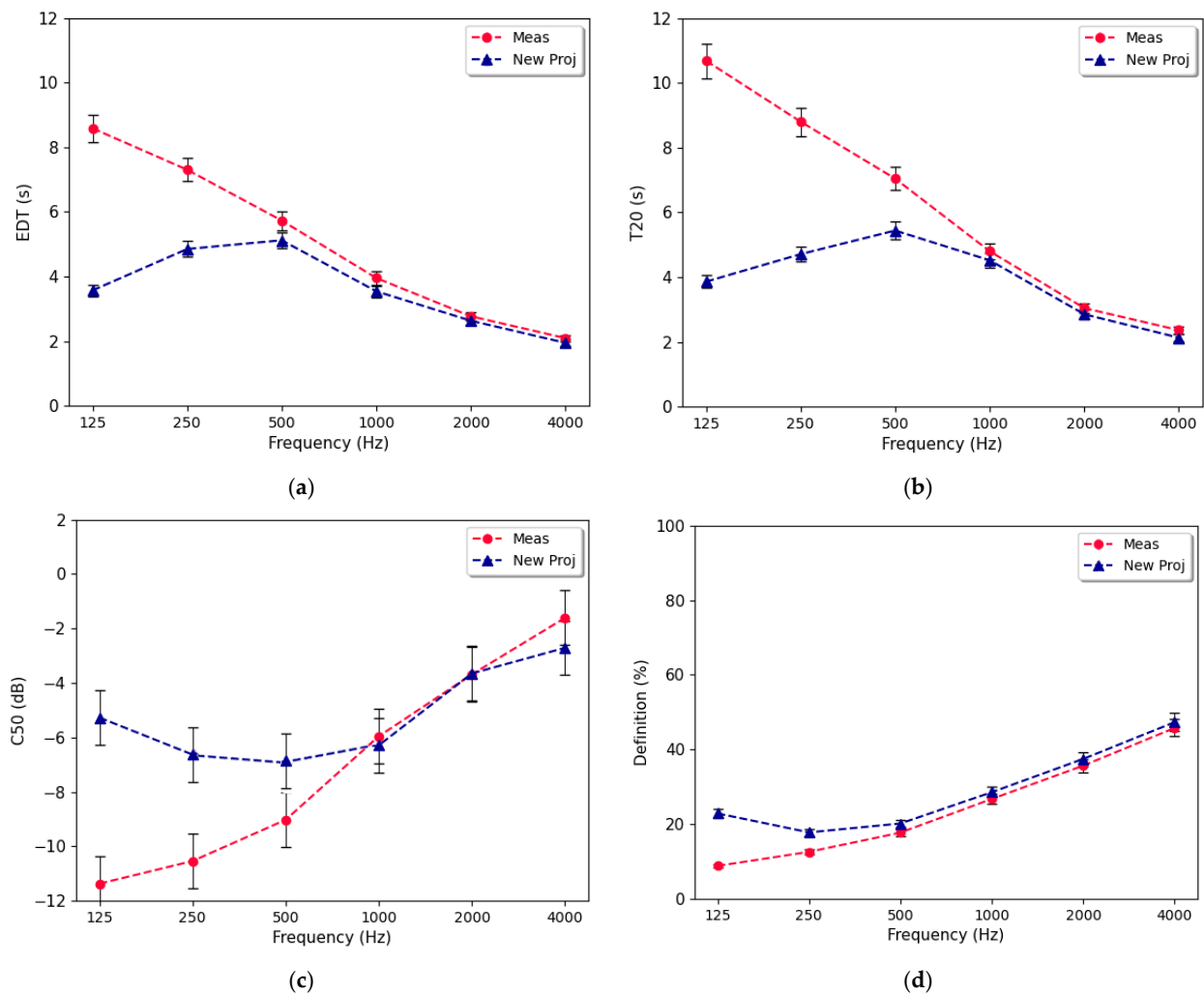


Figure 11. Simulated results related to the restoration project of the *piscina mirabilis*: EDT (a), T20 (b), C50 (c) and D50 (d).

In terms of clarity, the C50 values were only up to 2 dB far from the lower limit of the optimal range, fluctuating around -6 dB, which is reasonably good for a room volume of such size; low frequencies result in more intelligible occasional conversations [48]. Differently, definition was found to be around 20% with the addition of balloons covering the ceiling vaults, meaning that the speech definition would be affected for communications at far distances, although this was not likely to happen. Regarding the medium–high octaves, the simulated values were comparable with the measured results in an upward trendline that reached 42% at 4 kHz.

7. Discussion and Conclusions

The ancient buildings inherited by Romans are always subject to discussion for types of interventions that could be considered invasive. The proposed design involves the installation of a raised walkway in a steel frame structure so that the impact on the original structure is limited to the vertical support fixed to the ground. The floor finish of the walkway is intended to be in timber, possibly recycled from previous constructions to be 100% green [49]. A system of pumps was designed to bring water into the *piscina mirabilis*, for which this building was designed. The waterfall on the northern side wall represents the only sound source within this massive building. The acoustic design has the intention of having the waterfall sound be of primary importance for relaxation during leisure time. This idea comes from the intention of visitors who would like to explore this “cathedral”

for resting purposes, breaking the common routine polluted by road traffic noise as typical of urban contexts.

Based on this condition, the installation of balloons covering the barreled vaults is the only mitigation intervention suggested to control the reverberation time at low frequencies for a minimal level of conversational comprehension. The introduction of different sizes of balloons favors sound absorption at low–medium octaves, which corresponds to the requirements driven by the architectural intents. The acoustic response of the simulated predictions showed that the proposed design achieved the desired goals and, by comparing the simulated with the measured values, the outcomes were suitable for being immersed in a suggestive soundscape dominated by the broad spectrum of waterfalls.

This proposal for the restoration project can inspire many other interventions on dismissed heritage buildings which are currently in a state of degradation. Non-invasive mitigation solutions are proposed for its reversibility as the main route that the restoration methodology should persevere without lacking in efficiency and compliance with conservation principles. The conservation process is not meant to create a frozen relic but to respond to the emergency of social requirements with respect to the architectural heritage that needs to be preserved by adapting the structures to contemporary lifelike social gatherings.

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Appendix A. Latin Terminology

Aqua Augusta. Also called the Serino aqueduct, it was one of the largest aqueduct systems in the Roman world. It supplied water to at least eight ancient cities in the bay of Naples, including Pompeii and Herculaneum.

Castrum. A camp of the Roman army that thereafter became fortified; when permanent, the *castra* were organized in boroughs.

Classis pretoriae Misensis. Imperial Roman navy created by Augustus in 27 BC; it was settled in *Misenum* and represented the most important navy of the Empire.

Cocciopesto. Construction material used for a waterproofing coating layer applied to floors and walls, both indoor and outdoor; it is composed of fragments of broken bricks and tiles, mixed to fine mortar.

Cumae. Ancient name for Cuma, it was the first Greek colony of the Magna Graecia on the mainland of Italy; it became a rich Roman city, close to Bacoli and Naples, in the Region Campania.

Herculaneum. Latin name for Ercolano, it is a town located in the bay of Naples, lying at the western foot of Mount Vesuvius, buried in 79 AD by the eruption of the volcano.

Mirabilis. Latin name for something extraordinary, remarkable and marvelous, that creates astonishment.

Neapolis. Latin name for Naples, it was founded by Cumans in the 7th century BC and was the most important city of the Magna Graecia, dominating the gulf of Vesuvius.

Opus quadratum. Ancient Roman construction technique in which squared blocks of stone were set in parallel courses; this technique was used to build walls, roads and bridges.

Opus reticulatum. Another ancient Roman construction technique created with small pyramidally shaped tuff blocks, embedded into a concrete core; it was adopted by Romans to accommodate a more uniform and accessible workmanship of unskilled laborers.

Opus signum. Latin name for cocciopesto, it is a form of Roman concrete created by small pieces of broken pots, amphorae, tiles or bricks instead of other aggregates.

Piscina. A pool or pond for bathing or swimming.

Piscina limaria. In the piscina mirabilis was a waste bath, a drainage basin for the decantation and cleaning procedure of the cistern.

Portus Iulius. Latin name for the port of Julius, located in the suburban area of Puteoli; it was one of the most important ports for Romans.

Portus Misenum. Latin name for Miseno, this port was an important military, naval harbour, constructed at the far west end of the bay of Naples.

Puteoli. Latin name for Pozzuoli, a city located nearby Naples.

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