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The heating system of Piccole Terme in Baia: some hypotheses

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***Abstract* – Piccole Thermae in Baia, well known to whom deal with archaeology, are a little jewel from the thermo-technical perspective as they are the first example of heating system based upon renewable sources of energy.**

Unfortunately, as for all the antiquity baths, their thermo-technical mode of operation is known only from a merely qualitative point of view. This means that the principles of operation are well known due to the possibility to detect the presence of some components, but there are no reliable technical data on the installations.

Probably due to the lack of an updated mapping, the studies and research carried up until now on the Piccole Termae in Baia mainly focused the description and the understanding of the formal and historical characteristics of the archaeological complex. In few words, this site is a challenge for those, like the engineers, who approach on tiptoe to the fascinating and engaging world of the archaeology trying to transfer some knowledge to their research field.

In particular, this paper presents a dimensioned plan of the Piccole Thermae's building and the graphic outline of some of the mail elements of the thermo-technical system that represents a first fundamental step for the reconstruction of the mode of operation of the whole system.

I. INTRODUCTION

Thermal buildings are an important testimony of the civilization and technical knowledge in antiquity. This is the reason why they were the subject of several studies focusing their social and anthropological [1, 2], engineering and architectural [3, 4] aspects. In particular, the archaeological remains of the bath complexes of the Roman period are a valuable source of information on the ancient Romans knowledge in the field of the fluid-dynamics and heat transfer. From this perspective, the archaeological complex of Baia, in the Gulf of Naples, is undoubtedly a very interesting site due to the high number of thermal systems most of which is still in a good state of conservation.

Baia is placed inside the Campi Flegrei, an area characterized by a wide and deep geothermal system related to a significant volcanic activity and it can be considered the most large and important center of the antiquity devoted to the thermal mineral water [5]. Built on artificial terraces, the thermal complex were provided with a heating system based upon local hot thermal springs [6]. From this perspective, the most ancient building of the complex known as Piccole Terme, can be considered as the first Italian building where heat was obtained by means of a renewable source assimilated to geothermic.

The main source of heat was the steam produced by an underground water spring that reached the thermal environments through a duct dug 121 meters inside the mountain [7]. The large scientific production devoted to the thermo-mineral complex of Baia [8, 9, 10, 11, 12] and the Piccole Terme [6, 13] mainly focuses on archaeological and architectonic facets and on the chronological development for the first century B.C. to the second A.D. Unfortunately there are no in-depth technical analyses about thermo-technical facets of thermal spring buildings.

To advance some hypotheses on the thermo-technical mode of operation of the heating system of the Piccole terme is necessary an exact knowledge of the geometry of the single environments and the steam duct. In particular, the knowledge of the exact diameter of the duct would allow the calculation of the steam flow rate and, consequently, the amount of energy available for the

heating of the thermal environments (e.g. under right hypotheses about the behaviour and the thermostatic properties of the fluid).

The literature research required for this paper revealed neither plans nor detailed sections. In a study made by Paget [14] in the 60s and merely devoted to the position of the steam duct (renamed The Great Antrum) within the complex, the planimetry of the Piccole Terme is only schematic with no dimensions. Despite the schemes reported in [6, 13] are clear from the perspective of the functional distribution (being also provided with some dimensions), they do not provide accurate information for the thermo-technical reconstruction of the bath system. The only architectonic plan enough detailed (but not completely useful for thermo-technical purposes) is the one drawn by hand by Pinacos consortium in the 90s [15]. Unfortunately, there is no the representation of hypocaustum of the calidarium, which at the time had not yet been brought to light.

II. METHODS

The stratifications occurred during the centuries resulted in an altitude profile very complicated with several irregularities along the three dimensions. This is the reason why we have decided to study the elements of interest in a separate manner. In this way the 3D reconstruction of the tunnel (partially hosted inside the tuff rocks) and the architectural plan of the Piccole Terme were obtained. Consequently, different survey techniques were used also due to the poor accessibility of the tunnel which required a special technology.

In the following sections the techniques used to obtain the different graphic works will be discussed.

A. Traditional survey

To obtain an updated planimetric representation of Piccole Terme, the basic survey has been carried out by means of traditional methods and instruments (e.g. wooden folding ruler, taper measure, laser distance meter). The architectonic plan made by the consortium Pinacos depicted in figure 1 [15] has been manually vectorized with Autocad® and was used as the basis for the metric survey operations in the field.

B. Photographic survey

To obtain a detailed description of the geometry of the irregular elements and provide proofs about their state of conservation, the traditional survey techniques have been integrated with photography.

The high resolution photos taken in situ have been adjusted to reduce optical distortions and then processed with Photoshop®. Obtained photographic planes have been brought to the full scale in proportion to some reference dimensions measured in situ and, finally, they were used as a basis for the metric survey of the elements of detail.

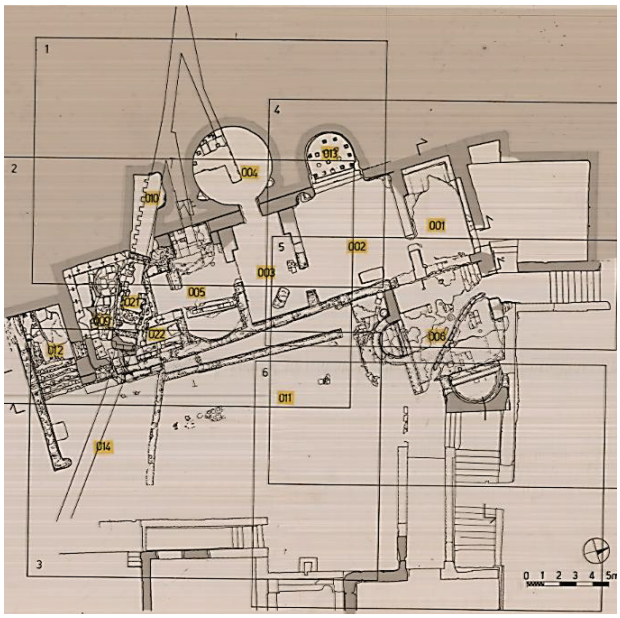

Fig. 1. Architectonic plan of Piccole Terme made by Pinacos consortium [15].

C. Laser scanner survey

To obtain a detailed mapping of the steam duct, a special laser scanner system (ZEB1) based upon the SLAM (Simultaneous Localization and Mapping) data acquisition technique has been used. This technique allows to overcome the limits exhibited by GPS (Global Positioning System) systems when satellite signals do not reach the receiving device avoiding the possibility to obtain the mapping of confined environments.

III. RESULTS

This investigation has produced the first graphic documentation of some unknown facets of Piccole Terme.

The most important and definitive result has been the realization of an architectonic plan provided with dimensions of the complex (figure 2). Based upon the literature survey above discussed, this is the first case of a document detailed as the present.

In parallel, the ZEB1 system has allowed to obtain a first mapping of the steam duct. Unfortunately the map is not complete due to the small dimensions of the duct and the impossibility to carry out the survey operations inside the areas built in the tuff shelf. In total, starting from the point cloud depicted in the figure 3, we have obtained 25 sections, six of which inside the tuff shelf.

In addition, five technical details of interest from the thermo-technical perspective have been documented: a housing for the fistula placed against the southern access wall of the tunnel; three fistulae found close to the wall placed between the tunnel and the calidarium; two openings found in the separating wall between the calidarium and the tepidarium; the system pilae-suspensura-concameratio of the calidarium and the system pilae-suspensura of the laconicum.

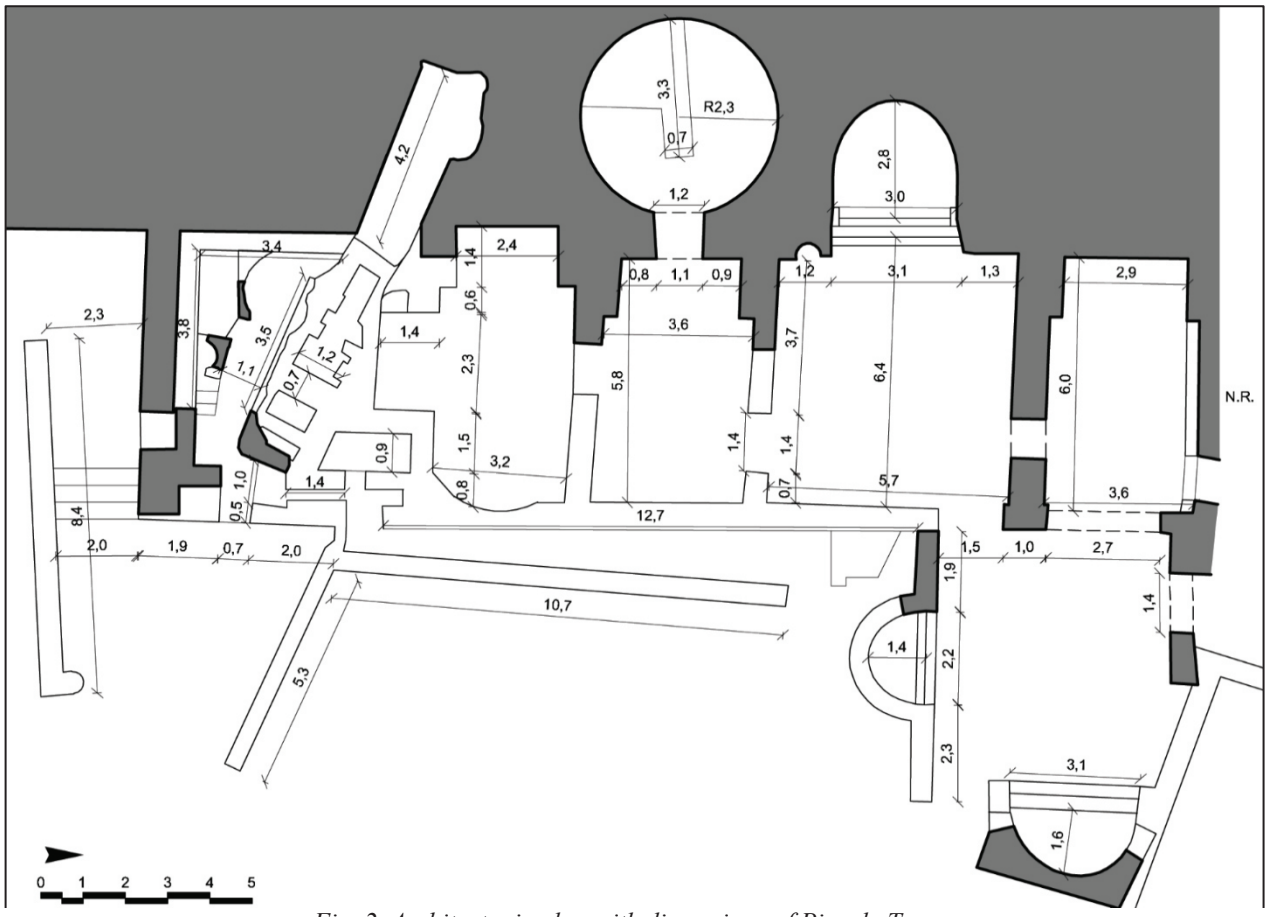

Fig. 2. Architectonic plan with dimensions of Piccole Terme.

The description of each detail and some hypotheses to be verified with archaeologist is reported as follows.

A. Housing of the fistula

The first detail depicted in figure 4 is a housing for the fistula built with a brick channel supported by terracotta stacks with a regular step of 60 cm.

This system was made integral to the wall apparatus by means of concrete coated by hydraulic plaster. The housing of the fistula is not covered by the thick layer of limestone present on the surfaces of the steam duct. This occurrence allows to hypothesize that these elements were built in different periods. Probably, the housing was built in a second moment to carry hot water to the baths placed at the intermediate level (this is the most recent building of the whole thermal complex [13]).

The water coming from the baths of the higher level (or from the Augustan aqueduct: this would be an interesting matter to investigate) passed through the fistula and was heated by the steam flowing inside the duct. In few words, this is an example of modern shell and tube heat exchanger.

It is likely that the presence of the traces along the same wall (both in the section of the tunnel towards to the intermediate level and inside the tuff shelf) can be considered as an extension of the housing of the fistula above described.

B. Fistula

The second detail is represented by the three fistulae which were probably fed by a stone tank placed on the arched structures of the tunnel. Unfortunately, it is impossible to reconstruct their path and consequently the final destination of the water is quite uncertain. Nevertheless, if we take into account that water in the tank was heated by the steam in the duct, we can assume that the outlet of the fistulae were placed just on the pools of the calidarium.

C. Openings inside the walls

Other details are the two openings in the wall which separates the calidarium from the tepidarium. The lower opening, placed under the ancient suspensura, probably connected the hypocausta of the two environments. The upper opening, significantly smaller, probably was a secondary duct which favored the heat transfer between the two environments.

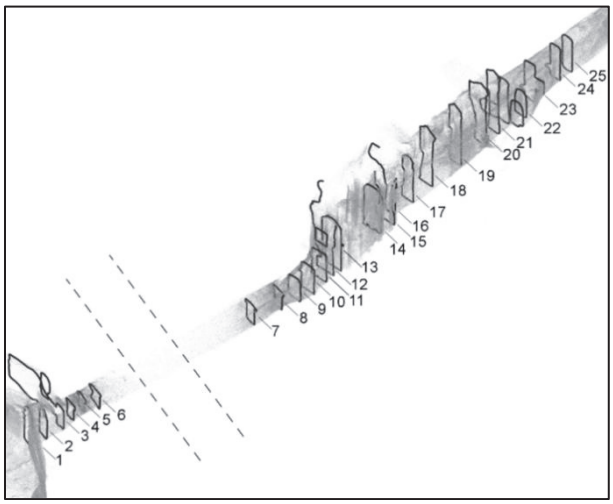

Fig. 3. Sections and point cloud of the steam duct.

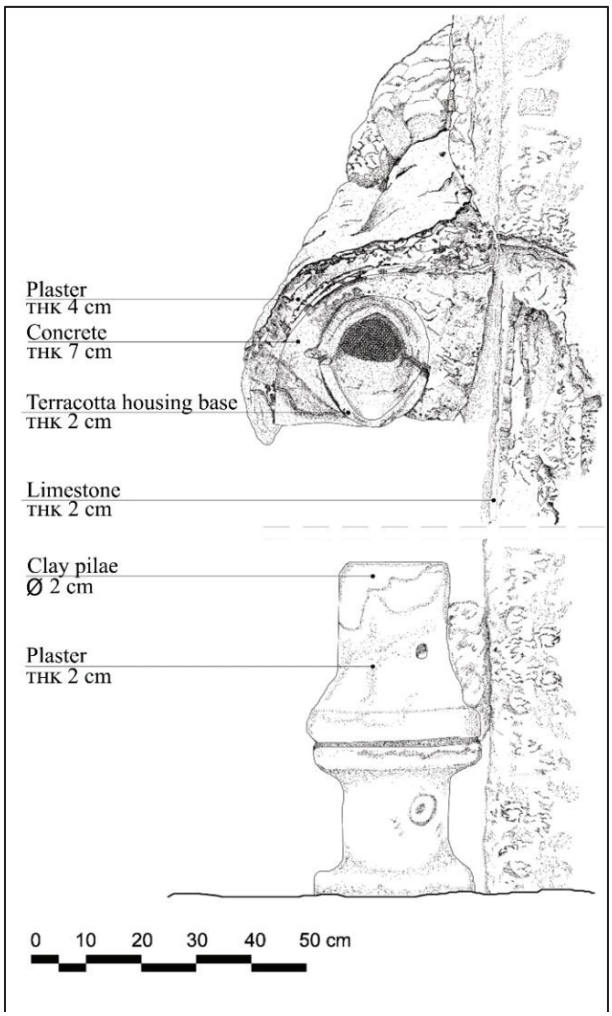

Fig. 4. Housing of the fistula and clay pilae.

D. Hypocausta and concamerationes

The last two components make part of the heating systems of the calidarium and the laconicum. In particular, the pila-suspensura-concameratio unit of the calidarium and pilae-suspensura unit of the laconicum will be discussed.

This advanced heating system was characterized by the presence of gaps in the floor and in the walls named as hypocausta and concamerationes. The circulation of the steam inside of them, resulted in the heating of the surfaces with the consequent increase of both mean radiant and operative temperatures.

This mode of operation, quite a standard of the Roman Age, is the same on which work the radiant panels introduced at the end of 90s.

In the NW corner of the calidarium is even now visible a small section of the ceiling sustained by two terracotta pilae. In addition, just on the corner of the wall, two tegulae mammatae in the concameratio were found.

Finally, inside the laconicum the system pilae-suspensura has been surveyed in detail.

It is important stressing that, contrarily to other environments where the pilae are monolithic clay systems, some pilae hosted in the laconicum were built by alternating bessales brick and mortar layers. This occurrence suggests an intervention carried out in a second time and consisting in a remake of the suspensura probably due to a collapse. However, such a hypothesis requires further investigations.

IV. CONCLUSIONS

The dream of reconstructing the mode of operation of the Piccole Terme of Baia has started from the survey of the site and, at the present, it results in the first case in the literature of a plan provided with dimensions and a 3D survey of the tunnel. In addition, the details of some elements of thermo-technical interest have been carried and some hypotheses have been formulated.

These results, obtained by the work of a team of engineers, obviously need to be shared with skilled archaeologist and analysed in-depth in order to decide whether and how to proceed.

Particularly, it would be very important proceeding with further excavations, especially in the case of the tepidarium. In this way the hypocaustum could be brought to the light helping to investigate its interactions with adjacent environments of the laconicum and the calidarium.

In addition, it would be desirable carrying out a full survey of the tunnel [16] also assisted by speleologists. This kind of analysis could favor the understanding of its role in the Piccole Terme and its relationship among the different sectors of the complex, even from the perspective of the mode of operation of the heating system.

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