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The heating system of the Piccole Terme in Baia: Some hypotheses

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ABSTRACT

Piccole Thermae in Baia is a little jewel from the thermo-technical perspective as it is the first example of heating system based upon renewable sources of energy. Unfortunately, its thermo-technical mode of operation can only be supposed due to remains of some components. In addition, there are no reliable technical data on the installations. Probably due to the lack of an updated mapping, the studies and researches carried up until now, mainly focused on historical and archaeological issues. Consequently, this site is a challenge for HVAC engineers and researcher who approach on tiptoe to the fascinating and engaging world of the archaeology trying to transfer some knowledge to their research field. To provide useful information about the entire complex and its thermo-technical mode of operation, this paper presents a dimensioned plan of the *Piccole Terme*'s building and the graphic outline of some of the main elements of the thermo-technical system. The implementation of the laser scanner system ZEB1 based upon the SLAM Technique and the integration with standard relief technique allowed us to reconstruct the steam duct and discover coarse errors in the positioning of some architectural elements and in the orientation of the whole site.

1. Introduction

Thermal buildings are an important testimony of the civilization and technical knowledge in antiquity. This is the reason why they most important studies focused on 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 was provided with a heating system based upon local hot thermal springs [6]. This is why the most ancient building of the complex known as *Piccole Terme*, can be considered the first Italian building where heat was obtained by means of a renewable geothermic source of energy.

The main source of heat was the steam produced by an underground water spring that reached the thermal environments through a duct 121 m in length dug inside the mountain [7]. The large scientific production devoted to the thermo-mineral complex of Baia [8–12] 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.C. 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 each single environment 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 behavior and the thermostatic properties of the fluid).

The bibliographic investigation revealed neither plans nor detailed sections. In a study made by Paget [14] in the 60 s and merely devoted to the position of the steam duct (renamed *The Great Antrum*) within the

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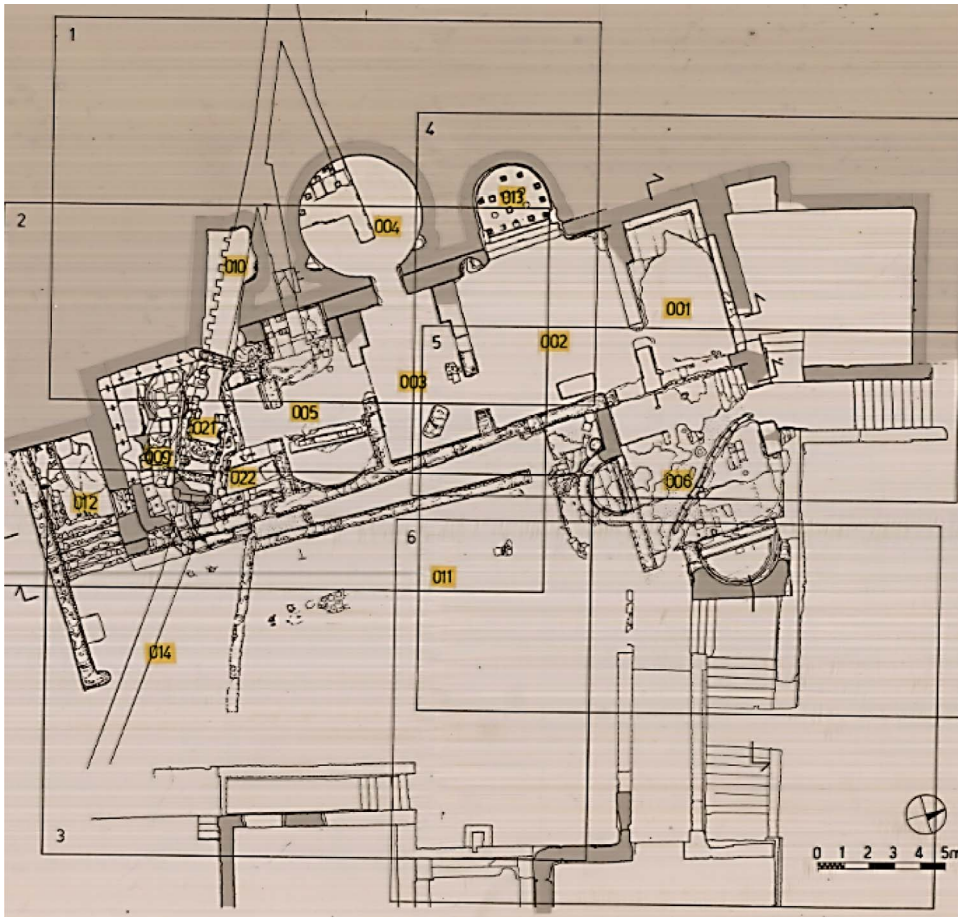

Fig. 1. Architectonic plan of Piccole Terme made by Pinacos consortium [15].

Table 1
GeoSLAM ZEB 1 main specifications.

Data acquisition speed	43,200 measurement points per second
3D measurement accuracy	± 0.1% (typically)
Maximum range	up to 30 m (15 m outdoors)
Laser safety class	Class 1 Eye Safe
Angular field of view	270 × 100°
Weight of scanner head	665 g
Dimensions of scanner head	60 × 60 × 360 mm

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 that drawn by hand by Pinacos Consortium in the 90 s [15]. Unfortunately, there is no the representation of the *hypocaustum* of the *calidarium*, which at the time had not yet been brought to light.

This paper is mainly addressed to obtain a dimensioned plan of the *Piccole Terme*'s building and the graphic outline of some of the main elements of the thermo-technical system (e.g. the steam duct) that represents a first fundamental step for the reconstruction of the mode of operation of the whole system. The most original peculiarity of this investigation has been the implementation of the laser scanner system ZEB1 based upon the SLAM technique which was the only system able to assure high accuracy levels for the correct documentation of the archaeological site and the reconstruction of the steam duct.

2. 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 and measurement techniques were used. This is also because the poor accessibility of the tunnel (e.g. small cross section, presence of debris) required special methodologies of investigation.

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

2.1. The traditional survey

The point of departure of the survey were the plans and the sections created by Pinacos Consortium [15] that were rediscovered at the Archives of the Authority for the Cultural Heritage of Naples. These (handmade) documents are very accurate (especially for the details of the wall apparatus) but unfortunately, they do not report the representation of the elements found after the excavations carried out since the 90s.

To obtain the digital architectonic plan depicted in Fig. 1, the plan of each of the six sectors of the complex was preliminary scanned at 300 dpi then merged with Adobe Photoshop CS6® by verifying the alignment of overlapping areas. Finally, the resulting image was imported in Autocad 2017 and vectorialized manually.

Fig. 1 is the basis for the metric survey carried out in situ that was mainly addressed to the verification and the update of the old planimetric representation which did not account the most recent