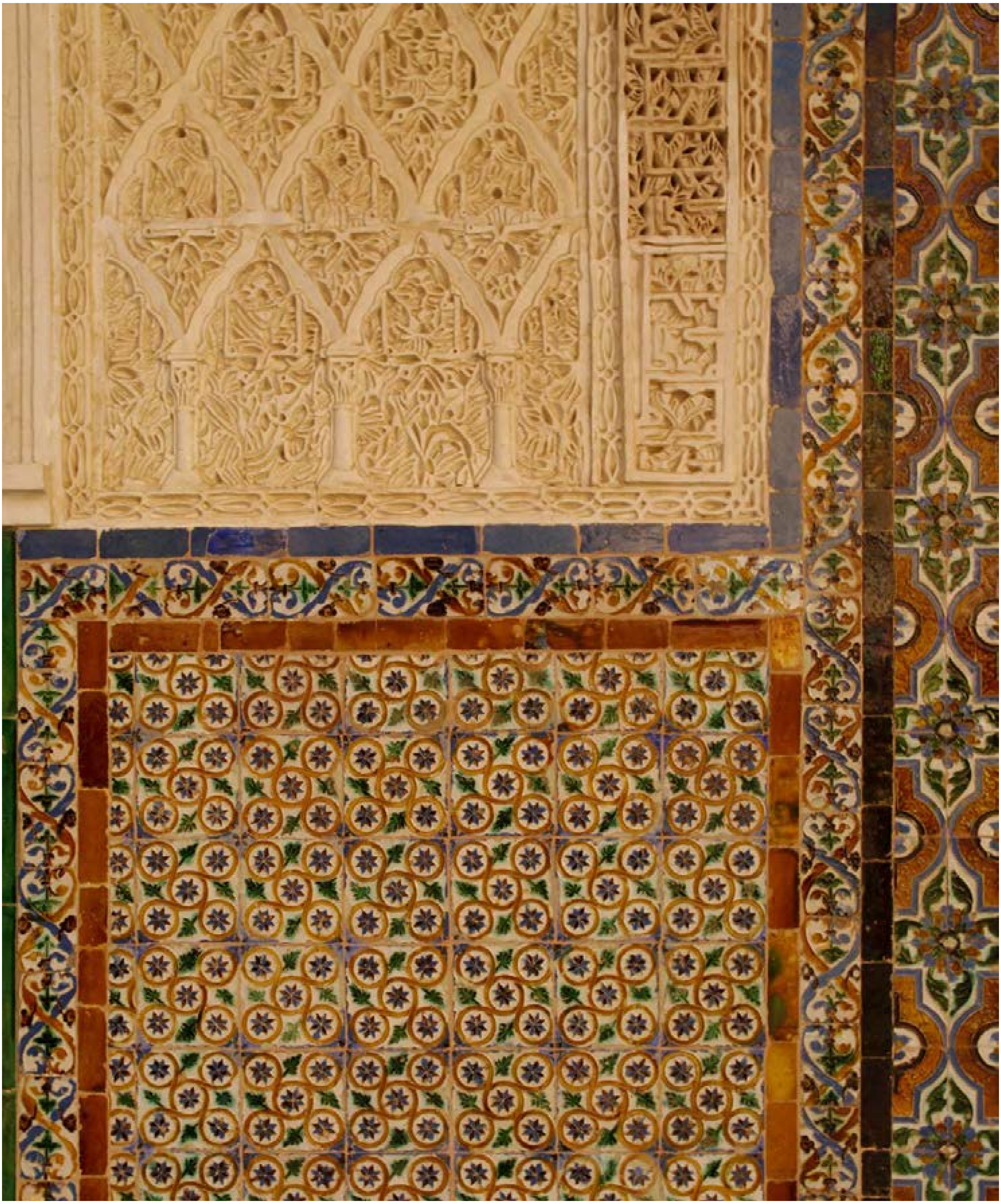

TEMA
Technologies Engineering Materials Architecture

Journal Director: R. Gulli

e-ISSN 2421-4574

Vol. 7, No. 1 (2021)

Issue edited by Editor in Chief: R. Gulli

Cover illustration: Azulejos, Casa de Pilatos, Seville. © Renato Morganti, 2017

Editorial Assistants: C. Mazzoli, D. Prati

TEMA
Technologies
Engineering
Materials
Architecture

e-ISSN 2421-4574
Vol. 7, No. 1 (2021)
Year 2021 (Issues per year: 2)

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TEMA: Technologies Engineering Materials Architecture
Vol. 7, No. 1 (2021)
e-ISSN 2421-4574

AN INTERDISCIPLINARY APPROACH FOR THE INVESTIGATION AND DATING OF ROMAN THERMAL BUILDINGS: THE INDIRIZZO BATHS AT CATANIA, SICILY

TEMA Technologies Engineering Materials Architecture
e-ISSN 2421-4574
Vol. 7, No. 1 - (2021)

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DOI: 10.30682/tema0701e

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Highlights

The dating campaign has confirmed that these baths were built at the end of IV century; There is no chronological evidence of different construction phases during the Roman time; The VII century is the *terminus post quem* for the baths' operation interruption; The proposed methodology can be effectively replicated for the study of other Roman baths.

Abstract

Roman baths are not only fascinating architectural structures but also provide many insights into the ancient culture. They represent an emblematic step in the process of civilization, indicative of the importance of cities or the families that had them built. Their heating systems exemplify the outstanding level of technological progress achieved by the Romans. A novel interdisciplinary methodological approach is presented to bridge the knowledge gap that often still concerns Roman baths. It integrates in-situ analyses, laser scanning surveys, thematic 3D models, computational fluid dynamics simulations, thermoluminescence, and optically stimulated luminescence dating, providing an in-depth investigation of the 3D spatiality, the functional layout, the construction techniques, the operation, and the diachronic development of thermal complexes. In this paper, the proposed approach is applied and validated on one of the best-preserved thermal buildings anywhere in the Roman Empire: the Indirizzo baths at Catania (Sicily). The dating campaign confirmed that the complex was built at the end of the IV century and stayed in operation until the VII century. The outcomes are a fundamental premise for future conservation and exploitation activities, while the proposed methodology constitutes a useful approach that can be effectively replicated to better understand and promote other Roman thermal complexes.

Keywords

Roman baths, 3D survey and models, Historical construction techniques, Thermoluminescence; Brick and mortar dating.

1. INTRODUCTION

Bathing was a central part of Roman culture, and the thermae not only epitomized the healthy ideal of Roman urban living they were also a symbol of power [1].

They also constitute one of the most significant technological innovations of Roman civilization.

Romans tried out different configurations of architectural layouts of thermal buildings, improved the water and space-heating systems, and distributed the heat flows inside horizontal (*hypocaustum*) and vertical flues (*wall tubuli*), which diffused the radiant heat evenly through the floor and walls. In particular, the development of wall heating systems was among the most important Roman bath technology inventions.

The hypocaust was a heating system based on the convective circulation of hot air and smoke, produced by furnaces, between empty spaces under the floors and in the walls of the rooms to be heated. The underfloor spaces were created by the *suspensurae*, set on piers, known as *pilae* of clay bricks or less frequently stone, on which the floor was laid in *tegulae bipedales*, then the *opus signinum* and covering (marble slabs, mosaic) was applied. The cavity walls, made of hollow box-shaped tiles (*tubuli*), generally rectangular, set one on another in parallel rows to create vertical ducts.

According to Vitruvius [2], Roman baths were usually designed with unheated rooms (*apodyterium*, *frigidarium*) facing north and heated ones (*caldarium, laconicum,* and *sudatorium*) towards the south. Moderately heated rooms (*tepidaria)* enabled a gradual transition from cold to hot environments. The main openings were arranged in the southern fronts, while only small windows were set in the northern façades, conforming perfectly to the basic principles of bioclimatic architecture today.

Sicily also had a wealth of thermal buildings, both public and private.

On the eastern coast of the island, Catania has abundant water sources, and consequently, there are numerous thermal buildings, many conserved today, of which the "Rotonda" and Indirizzo baths are especially noteworthy. The so-called "Achilliane" baths are also widely known, though their thermal bathing function has recently been questioned [3].

The Indirizzo baths, which are analyzed in this work, stand in the center of the city, in today's Piazza Currò, in an advantageous position to intercept a branch of the Amenano underground river.

The name and the destiny of the building are closely linked to the church of Santa Maria dell'Indirizzo and the adjacent Carmelite Convent [4], now a school, between whose structures the baths have been incorporated for centuries. Wholly rebuilt after the huge 1693 earthquake that struck Catania and the entire "Val di Noto" (a broad segment of the south-eastern corner of Sicily), the convent building agglomerated the baths, which despite some alterations helped at the same time to preserve them until today.

The Indirizzo baths at Catania caught our interest since they are the best-preserved Roman baths on the island and probably among the most intact thermal buildings anywhere in the Roman Empire.

However, the study of such complex and sophisticated structures needs novel interdisciplinary approaches to define their dating, and historical evolution and better comprehend their operation and functional layout in view of future desirable conservation, education, and exploitation campaigns. In the light of this, we have built a multidisciplinary research team, which integrates different knowledge and methods from experts of 3D surveys and 3D simulation models, historic building techniques, Roman archaeology, computational fluid dynamics (CFD) simulations, ThermoLuminescence (TL), and Optically Stimulated Luminescence (OSL) dating. This research team's principal aim was to study in depth the Indirizzo baths by developing and validating a new methodology effectively usable to analyze other Roman baths. The team started working in 2014, publishing several outcomes, and this paper constitutes the final report of the conducted activities.

In Section 2 we present previous studies and reports already carried out on the Indirizzo baths and the proposed interdisciplinary methodological approach. In Section 3, 4, and 5 we illustrate the functional layout, the heating system, and the construction techniques of the complex, respectively. In Section 6 we describe the dating campaign tailored explicitly for ancient thermal buildings, presenting and discussing a set of chronological data, which brought to light new interesting information about the considered monument.

2. PREVIOUS STUDIES AND INTERDISCIPLINARY METHODOLOGICAL APPROACH

The first investigations on the monument were undertaken by Ignazio Paternò Castello, the Prince of Biscari, in 1779. He promoted excavations that made some sectors recognizable, until then partially buried or used by the Carmelite Fathers' convent. Biscari identified a *laconicum* in the large domed octagonal room of the convent [5-7], previously believed to be the old assembly hall of the town hall or, again, a temple [8].

During this investigation stage, the landscape artist Luigi Mayer from Rome (Fig. 1a) made the oldest existing perspective drawing we know of today [9].

The plan drawing and perspective views by the French painter Jean-Pierre Houël are from the same period. They are replete with interesting details, observed by the painter during his trip to Sicily, where he met with the Prince of Biscari (Fig. 1b-d) [10].

The planimetric survey and vertical sections made by Carlo Chenchi (Fig. 2a) date from after 1779. They show some rooms, now no more existent.

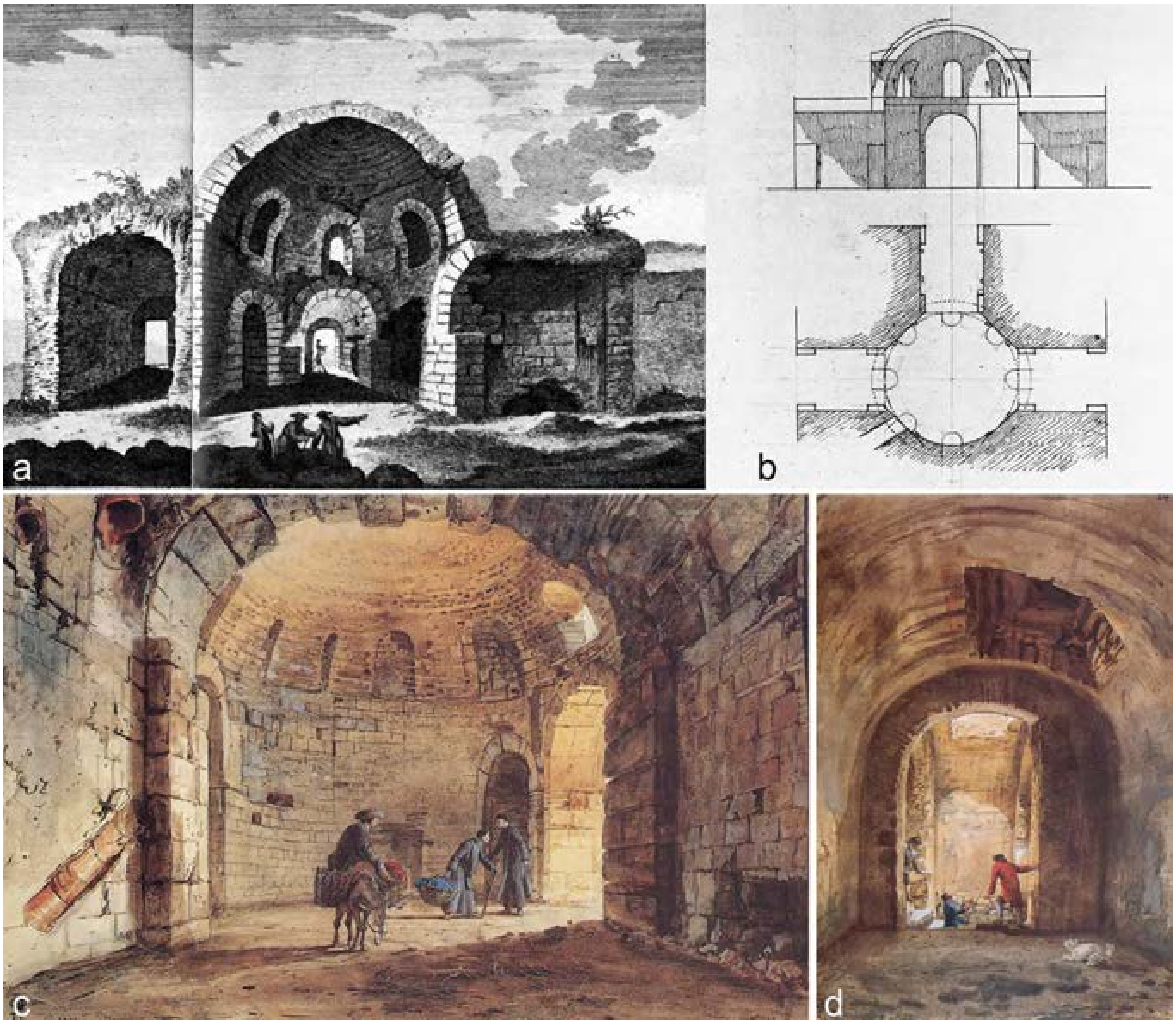

Fig. 1. *(a) L. Mayer: perspective section of the caldarium; (b) J.P. Houël: horizontal and vertical section of the caldarium and the surrounding alvea (rooms 9, 10, and 11); (c) J.P. Houël: perspective view of the caldarium and room 10; (d) J.P. Houël: perspective view of room 7 and 11.*

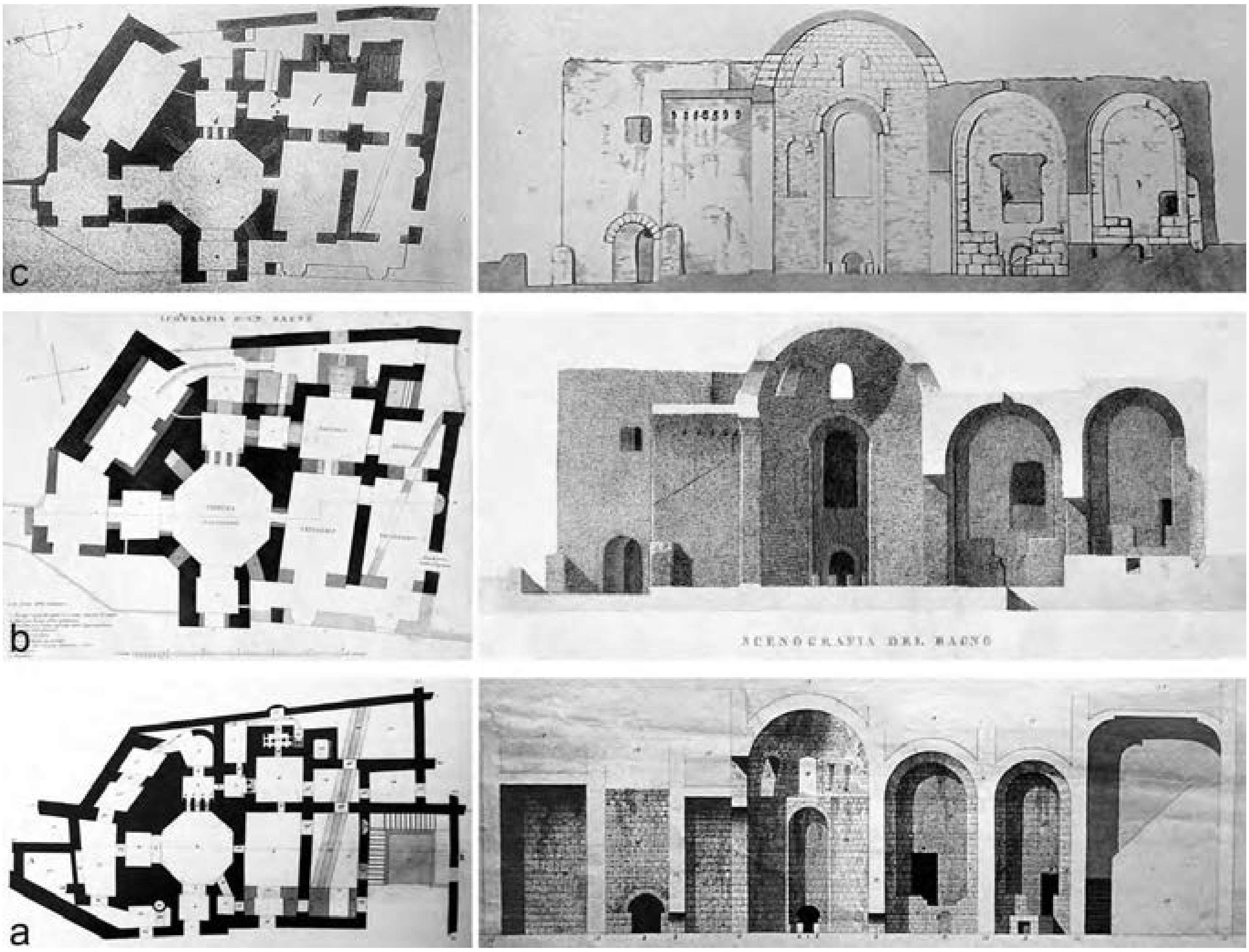

Fig. 2. *Plans and longitudinal sections of the Indirizzo baths by: (a) C. Chenchi (Private collection of Paternò Castello Prince of Biscari, around 1779); (b) S. Ittar [11]; (c) S. Cavallari [12].*

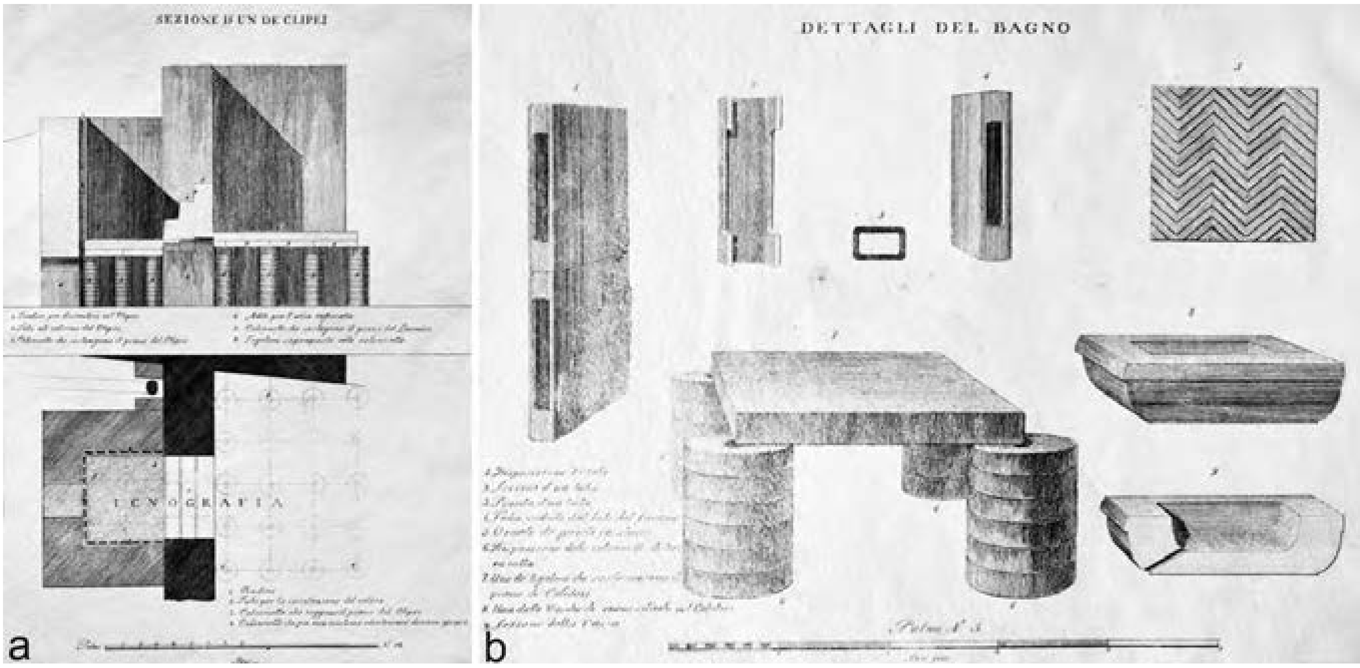

Fig. 3. *S. Ittar [11]: (a) section of an alveus (rooms 5 and 6); (b) details of the baths.*

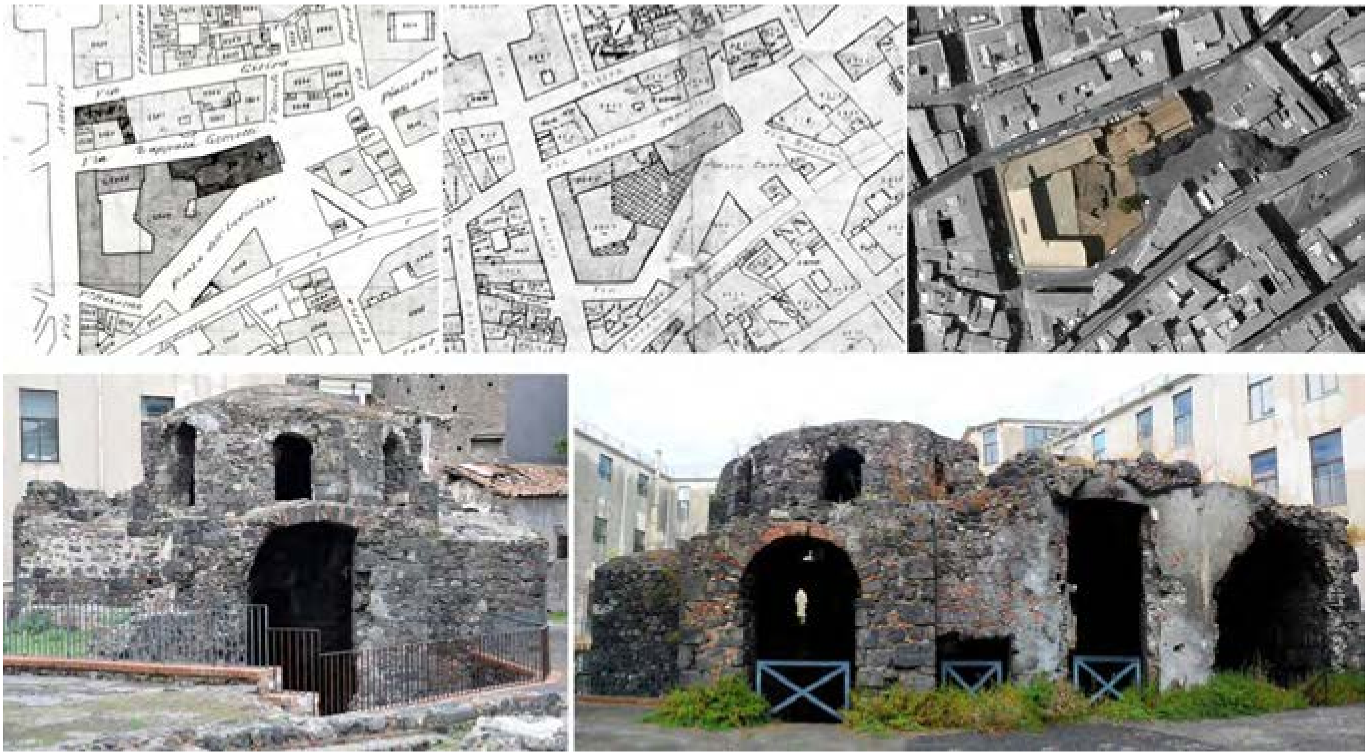

Fig. 4. *Above: comparison between the cadastral maps (from 1876 and 1962) and a current aerial view of the former Carmelite Convent; below: south and east fronts of the Indirizzo baths.*

Sebastiano Ittar later published a careful study of the monument in the early XIX century (Fig. 2b and 3) [11]. He drew beautiful plans and sections of the building, along with several components of the heating system. The study was later taken up by the Duke of Serradifalco (Fig. 2c).

Nonetheless, the monument remained concealed within the convent until the 1930s, when renovation works were carried out on the XVIII-century building, in the meantime converted into a school. The demolition of the south wing of the convent freed the ancient building that was made accessible by an independent entrance from the adjacent square. Later demolitions on a lower part of the building, used as a school gym, in the south-eastern section of the complex, allowed creating an observation area for the monument, as we see it today (Fig. 4) [13]. Some renovation works to consolidate the monument, and further excavations were later carried out during the 1980s [14].

Despite these works, the baths were still neglected, receiving little attention either from the public, not always able to access the monument, or even by researchers. Only a few studies were dedicated to the building. The most significant, following that by S. Ittar, were made by R.J.A. Wilson [15] and M.G. Branciforti [13]. In particular, Wilson, according to various architectural and construction evidence, attributed the building to the late imperial age (IV-V century). For Wilson, clear indications were the rudimentary construction of the masonry, of a substantially lower quality than in other Roman public buildings in Catania, windows set in the caldarium ceiling just below the springing line, and the generally poorly connected rooms with misaligned axes.

Coming to the XXI century, new excavations and maintenance services were done on the site between 2011 and 2013, which had fallen again into a partially abandoned state. Together with a new survey, the results of these works have been published by Branciforti [13], who has provided a topographical framework of the monument in today's urban setting and significant plans at different elevations. As a result of her studies, Branciforti attributed the building to the III-IV century without supporting this dating with excavation pieces of evidence.

Further studies have been recently carried out by the research team presented in the previous section. In particular, Gagliano et al. [16] specifically investigated the thermo-hygrometric behavior and the operating temperatures of the baths, while Gueli et al. [17] published some preliminary results of a first TL dating campaign that attributed the construction of the monument to the IV century; however, due to the limited number of analyzed bricks, additional sampling were suggested, along with the need to investigate the influence of the moisture in the dating of historical thermal buildings. About this latter issue, Gueli et al. [18] have verified that the water content of samples is fundamental for minimizing the uncertainties and improving the accuracy of luminescence ages. Finally, Liuzzo, Margani, and Wilson [19] have provided new elevation drawings and detailed identification and description of the different rooms of the thermal complex, recognizing two possible construction phases; the study has also suggested a chronology of the second half of the IV century, based on stylistic criteria (e.g., untidy wall appearance, not really paralleled plan, prominent octagonal caldarium with large windows that recalls the Temple of Minerva Medica in Rome or the Baths of Bacucco near Viterbo).

Despite the interesting knowledge provided, these studies do not yet give conclusive results on the monument dating and its diachronic development through the centuries and do not systemize a methodology to investigate Roman baths adequately.

Given the above, this work aims to suggest a novel interdisciplinary methodological approach, specifically developed to better understand the 3D spatiality, the functional layout, the construction techniques, the operation, and the diachronic development of the Indirizzo baths and, in general, of other historical thermal buildings. Moreover, as a direct result of the suggested methodology, the outcomes of a new extensive dating campaign are presented.

This approach is articulated in the following phases: (i) bibliographic research to study the history, the archaeological and restoration campaigns, and the diachronic development of the monument; (ii) topographic and 3D laser scanner surveys to investigate the functional layout and the 3D spatiality; (iii) direct survey on-site to determine the adopted building materials and techniques and to identify the most proper samples for the last phase; (iv) CFD simulations to confirm the functional layout and to estimate the operating temperatures of the different rooms, necessary to adequately perform the next phase; (v) TL and OSL dating to give more reliable insights into the age and the diachronic development of the considered baths.

During phase (i), whose primary outcomes have been already illustrated above, we have analyzed the available bibliography, included ancient drawings and plans, and the available reports of the excavation and restoration campaigns conducted during the last century, which allowed us to comprehend better the monument layout and its evolution, as well as the transformations and alterations suffered over its long history.

Phase (ii) has drawn on the results of a preliminary measurement survey done in 2004-2005 with 3D laser scanning technology [20], which has already enabled elaborating profiles of horizontal and vertical sections of much of the structure in the configuration of 2004, before the latest excavations. This laser scanner survey has been afterward considerably updated, extended, and completed with a campaign of further surveys carried out with direct and instrumental methods (Figs. 5 and 6). The collection of metric data enabled undertaking further investigations, aimed at giving new information about the use of the different rooms and the operation of the heating system. In particular, the planimetric layout, which displays several asymmetries and subsequent additions, and the geometry of the elevation and the vaulted roofs were accurately reconstructed. Laser scanning also allowed surveying the remains of the heating system that cannot be directly reached, such as the exhaust flues.

Phase (iii) was conducted through direct observations and surveys on site, which have expanded the knowledge already presented by Liuzzo, Margani, and Wilson [19]. On the one hand, it permitted to characterize the building construction of the baths and to confirm and complete the information gathered in the previous phase; on the other, it represented an essential step to adequately select the brick and mortar samples to be dated, with the specific aim to distinguish specimens most likely attributable the baths and those imputable to pre Roman buildings or post-Roman alterations.

The CFD simulations of phase (iv) were conducted in a previous study by the same research group [16]. As previously mentioned, these simulations permitted

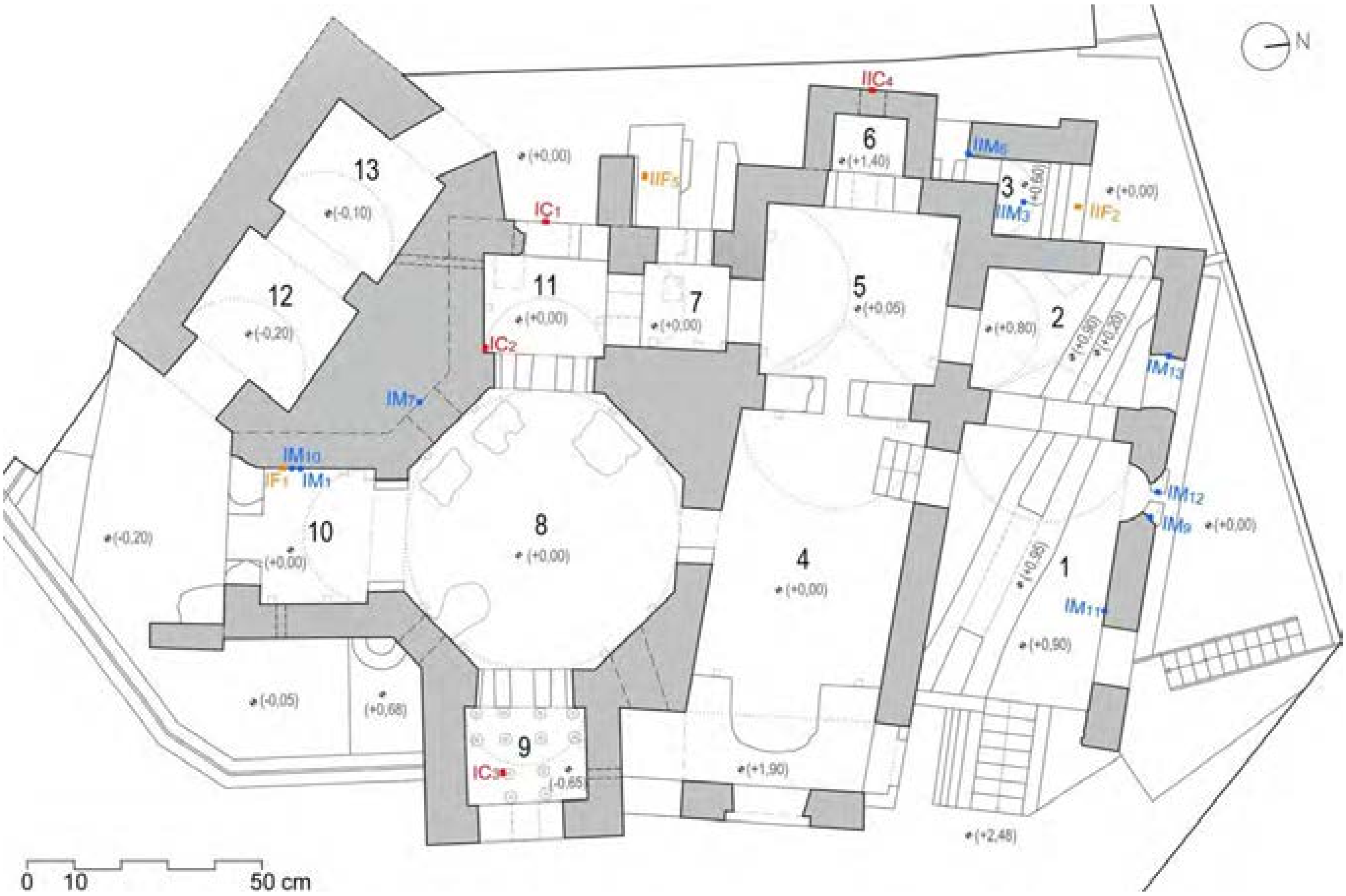

Fig. 5. *Current indirizzo's geometrical plan, with evidence of samples collected for TL and OSL analysis.*

to evaluate the operational temperatures of the various rooms (cold rooms, warm rooms, hot rooms, hypocausts, kilns, etc.) and to validate the hypotheses on their original use. It is worth noting that the temperature evaluation constitutes an essential prerequisite for the next stage since temperature may considerably influence TL dating results, and sampling activities must take into proper account the environmental conditions of the collected specimens during their life.

Finally, in phase (v), the brick and mortar samples, accurately selected according to the outcomes of phase (ii) and (iv), were removed, collected (Figs. 5 and 7a), and analyzed through TL and OSL dating techniques to provide new and more objective information about the diachronic development of the building.

3. THE LAYOUT OF THE BATHS

As it stands today, the thermal complex comprises thirteen rooms (Figs. 5 and 7), each covered by stone vaulting. It is an architectural structure with a north-south longitudinal axis. It has an uneven planimetry owing to the non-orthogonal walls and the presence of some later additions, which protrude from the main body (rooms *3* and *6*) or are only tangent (i.e., not bonded) to it (rooms *12* and *13*).

Therefore, the complex would have two construction stages [17, 19]: rooms *1-2*, *4-5*, and *7-11* from the first, while rooms *3*, *6*, and *12-13* are from the second phase. The extensions on the east front of rooms *1* and *4* may be ascribed to the convent's post-earthquake reconstruction (Fig. 7a).

These later additions only partially altered the spatial layout of the first construction phase. It shows a compact geometry with the main nucleus being a sequence of rectangular rooms, *apodyterium/frigidarium-tepidaria*, with the octagonal caldarium at the hub, surrounded by the three *alvea* [21–23].

The pattern of the Indirizzo baths seems to refer to a cross-shaped type of plan. This is a typical layout in Mediterranean area [23], especially in Sicilian buildings with a bathing function (original or converted), such as

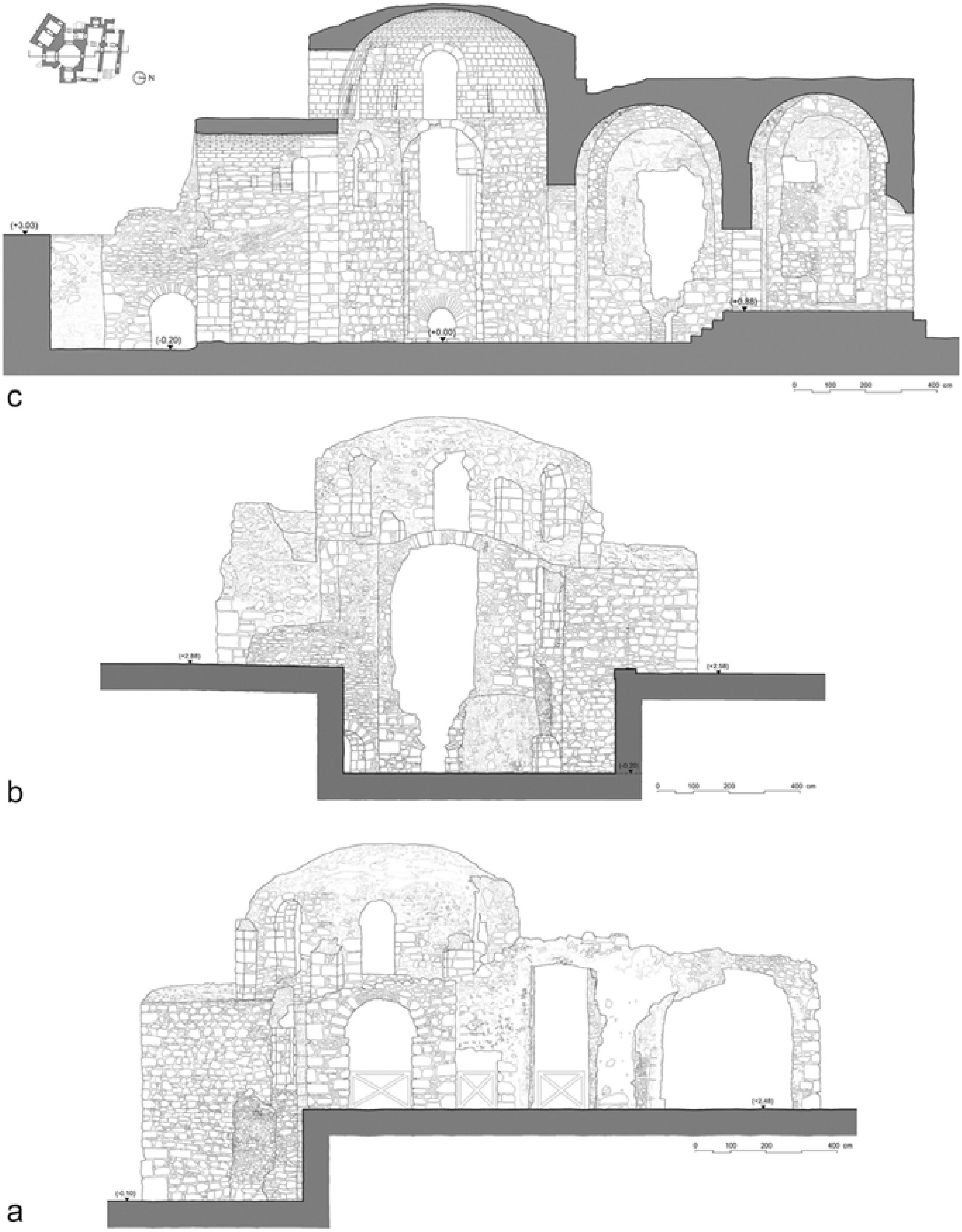

Fig. 6. *(a) East front, (b) south front, (c) longitudinal section of the baths.*

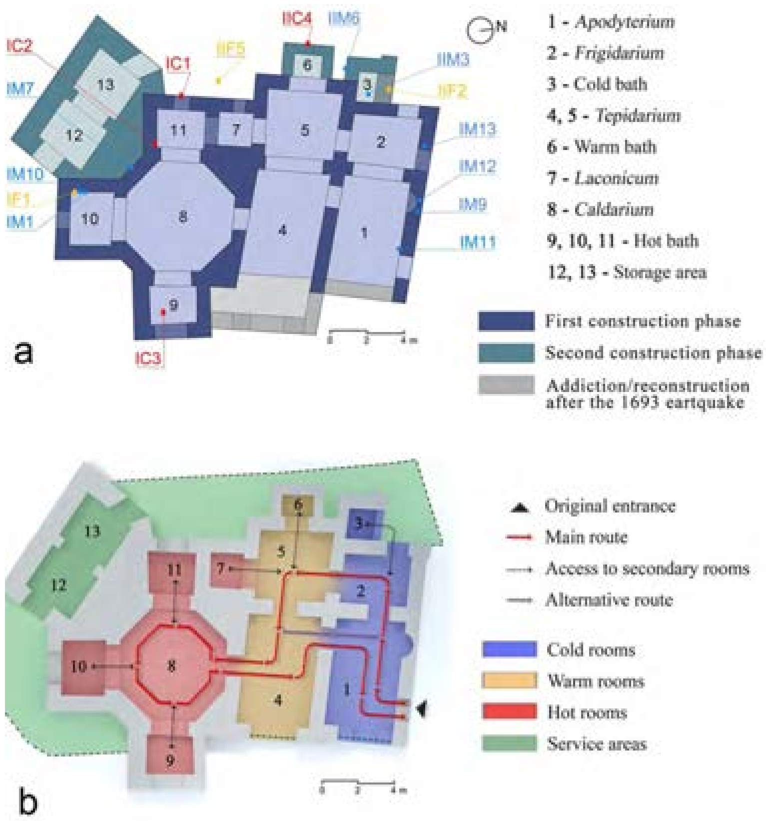

Fig. 7. *Schematic plans of the Indirizzo baths with evidence of construction phases, possible rooms function and collected samples (a), and probable bathers' routes (b).*

the hypocaust on the Santa Sofia hill in Catania, the baths at Bella Cortina in Paternò [5-7, 10, 24], the buildings of "Bagno di Mare" and "Vigna di Mare" near Santa Croce Camerina [25], and the baths of "Erba Bianca" in Misterbianco, with a more compact initial configuration, albeit with a different functional arrangement to the Indirizzo baths [5–7, 15, 26].

The current access to the Indirizzo baths is on the east side, although archaeological evidence suggests that the original entrance was on the northern side (Fig. 7b). Many scholars recognized the first room as the *apodyterium* (Fig. 7a). According to this hypothesis, from this chamber, following an anticlockwise route, bathers could access the *frigidarium* (room *2*), then cross two *tepidaria* (rooms *4* and *5*) and finally reach the main room: the impressive octagonal *caldarium* (room *8*). From the *caldarium*, passing through the greater *tepidarium*, bathers could return to the main entrance. By secondary routes, they could access the *laconicum* (room *7*) and three pools with different water temperatures: cold (room *3*), warm (room *6*), or hot (rooms *9-11*). The south and west sides of the building are flanked by service areas that were probably once used to fuel the furnaces [15].

In observance of Vitruvius [2], all the cold rooms were located to the north and the hot ones to the south, with warm rooms in-between, while no heated room had north-facing openings.

The following evidence has deduced the use of these rooms: (i) between heated and unheated rooms, there is a height difference of about 90 cm that implies the presence of a hypocaust (Fig. 5); (ii) in rooms *7* and *9*, there are the remains of circular brick *pilae*, which once supported the raised floor (*suspensurae*) (Fig. 8a); (iii) in room *11* a portion of a rectangular *tubulus* – a hollow, box-shaped tile – is still set in a wall, suggesting the existence of a wall heating system (Fig. 8b); (iv) exhaust *tubuli* are inserted into the vaults of rooms *4*, *5*, and *7-11*, confirming that they were heated (Fig. 8c).

Nevertheless, investigations carried out to date do not allow affirming that this room layout is complete, and Chenchi's plan actually shows other rooms on the north and southeast sides [19]. In fact, in the southeast corner of the open space adjacent to the baths, some

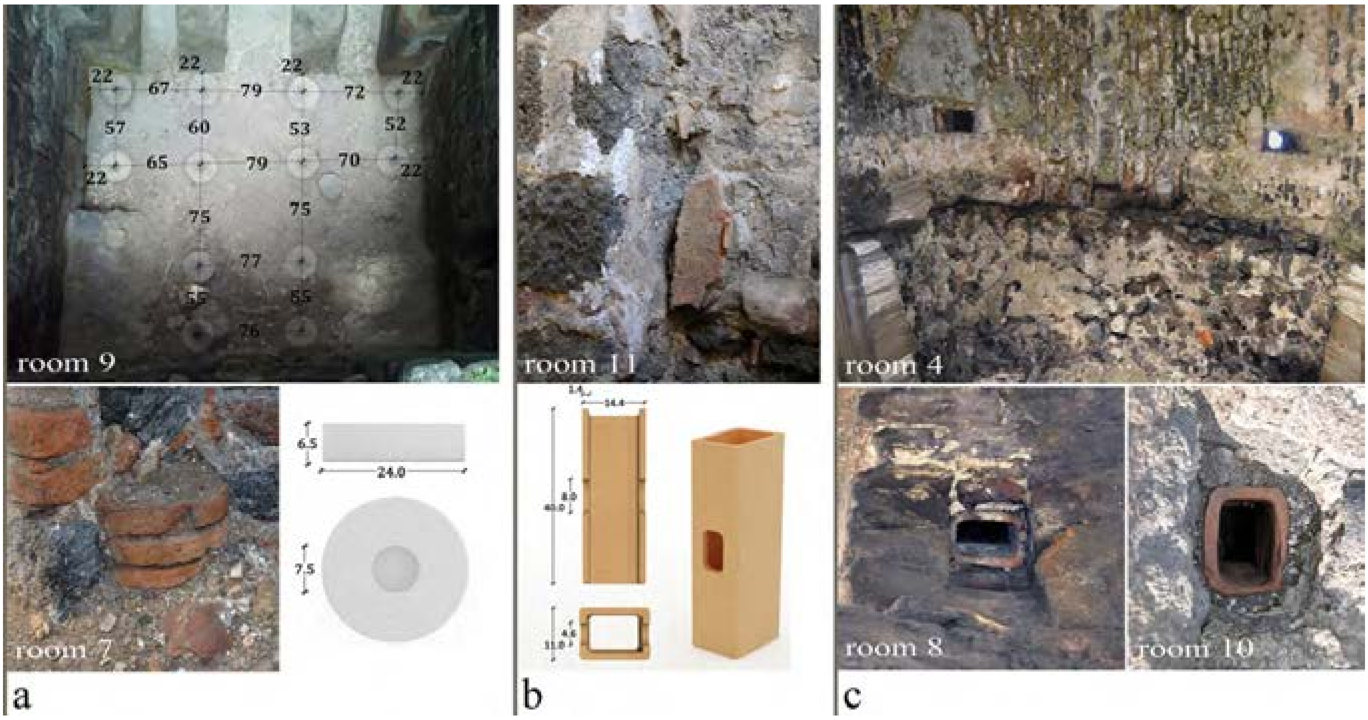

Fig. 8. *(a) pieces of evidence and details of pilae in rooms 7 and 9; (b) detail of the surviving wall tubulus in room 11; (c) remains of exhaust tubuli in rooms 4, 8, 10.*

wall elements, already reported in the XVIII and XIX century plans, were found during the last archaeological excavations (Fig. 2). They seem attributable to the Roman time, both for the height of the floor on which they are set, as well as the masonry used and the alignment of the dividing walls. This may support the hypothesis, put forward by the historian Francesco Ferrara [27] that the baths were originally part of a broader area that included other spaces designed for physical exercise.

Lacking further excavation evidence and owing to the transformations made to the monument in the XVIII century, it is nonetheless impossible to confirm the presence of more stokeholes and service areas on the eastern fringe of the complex.

4. THE HEATING SYSTEM

The *in-situ* analysis and 3D surveys were fundamental to reconstruct the heating system of the Indirizzo baths. To achieve this goal, experimental data were integrated and compared with historical drawings and with technical descriptions of Roman baths by Vitruvius [2], J.P. Adam [28], and F.K. Yegül [1].

As already mentioned, CFD simulations have been developed to investigate the operative temperatures and humidity in the heated rooms [16]. In particular, this study showed that the caldarium temperatures ranged around between 30 and 35 °C, the relative humidity around 60÷70%, while the thermal level of hot gases inside the hypocaust fluctuated from about 90 to 125 °C, according to the outdoor climate.

The Indirizzo heating system can be effectively summarized in five steps. The first one was to produce heat by wood combustion in the *praefurnia*. Perhaps there were seven *praefurnia* in all (Fig. 9a). However, *praefurnium* "*e*" is not entirely sure, and there is no archaeological evidence for *praefurnium "f"*. The *praefurnia* are all built with jambs and small brick arches (Fig. 14). The arched channel joining the hypocausts of rooms *5* and *6* (Fig. 14a) was built with the same construction technique. This would imply that in the first phase, this channel *"a"* was directly connected with a furnace before the construction of room *6*, and it was later replaced by the *praefurnium "a'"* (Fig. 9a).

The horizontal distribution of heat through the hypocaust was the second step (Fig. 9b). We have assumed the *hypocaust* was as high as 75 cm, with *pilae* made of

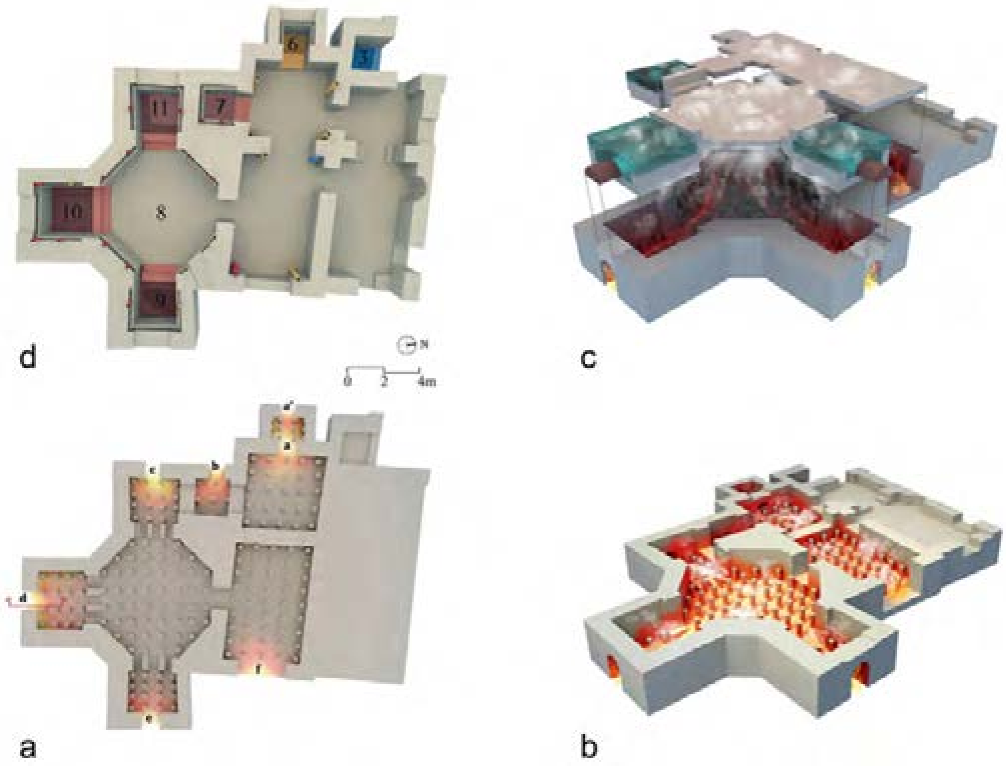

Fig. 9. *Operation of the heating system: (a) plan of the baths with evidence of praefurnia and probable hypocausts; (b) horizontal distribution of the heat through the hypocaustum; (c) heating of suspensurae through the hypocaustum and of the hot baths by bronze boilers; (d) perspective plan of the baths with evidence of the six identified alvea.*

eleven round bricks supporting the *suspensurae*, which were constructed with *tegulae bipedales* (Fig. 10).

The third was the heating of the *suspensurae* through the hypocaust and of the hot pools (*alvea*) by bronze boilers (*testudo alveolorum*) (Fig. 9c-d). These boilers probably fitted right under the arches of the *praefurnia* (Fig. 10). A cistern of about 20 m^3 was probably located on top of rooms *12* and *13* to supply the baths.

The fourth step was the vertical distribution of the heat through the wall *tubuli* (Fig. 11a). The warm and

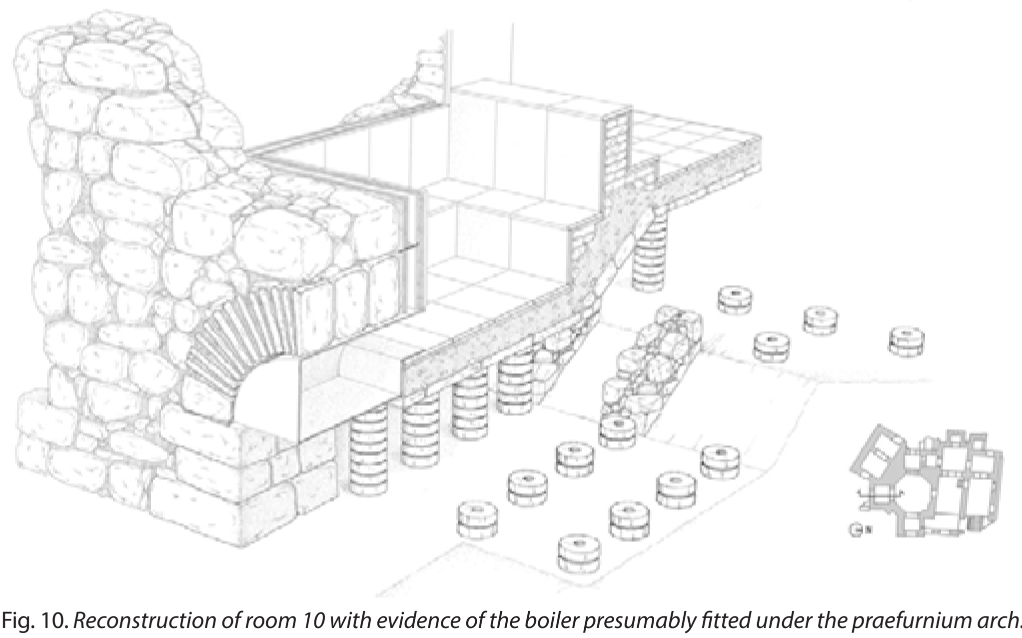

Fig. 10. *Reconstruction of room 10 with evidence of the boiler presumably fitted under the praefurnium arch.*

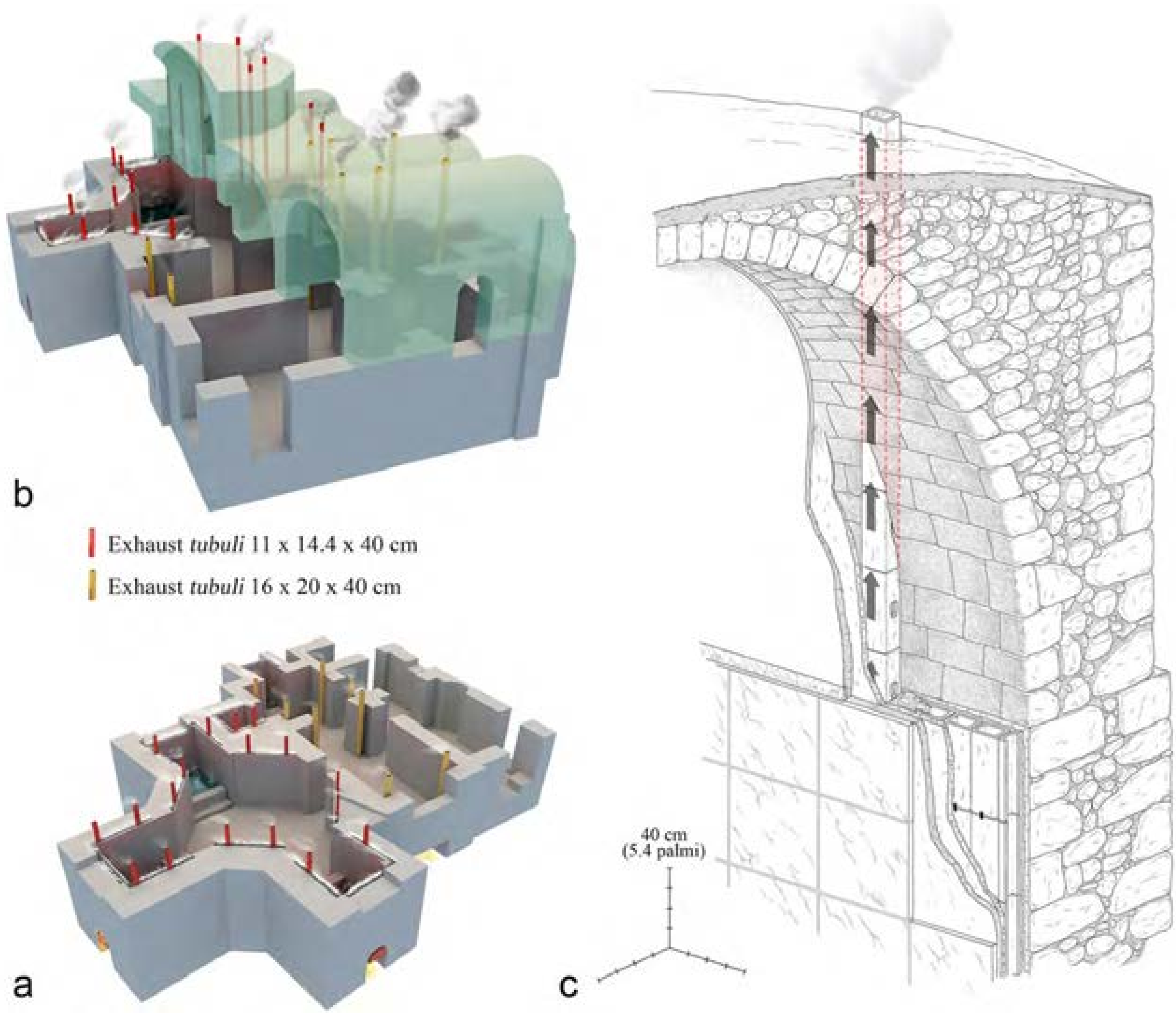

Fig. 11. *Operation of the heating system: (a) vertical distribution of the heat through the detected exhaust tubuli and probable location of the original wall tubuli; (b) expulsion of the flue gas through exhaust tubuli; (c) detail of an exhaust tubulus in room 8.*

hot pools (rooms *6*, *7*, and *9-11*; Fig. 9d), and probably also part of the *caldarium* were covered by hollow tiles. According to the archaeological remains and Ittar's drawings (Fig. 3b), the *tubuli* had side holes that allowed the horizontal propagation of heat (Fig. 8b). Again, based on his drawings, the *tubuli* were coated with stucco decorated with a herringbone pattern (Fig. 3b).

Finally, the last step was the expulsion of the hot air and smoke through exhaust flues. These flues were usually the same *tubuli* used for the wall heating system. Originally there were at least eighteen exhaust *tubuli* in the heated rooms (rooms *6-11*) and eight in the tepid rooms (rooms *4* and *5*) (Figs. 8c and 11). The two *tepidaria* have *tubuli* with a wider cross-section, probably to improve the draft of the hot gases.

5. CONSTRUCTION TECHNIQUES

5.1. WALLS

The wall masonry of the first phase of the thermal complex is around 73-75 cm thick and consists of two outer wythes (*crustae*), made of roughly shaped stones, and a core (*fartura*) in the middle, made from rock and brick fragments and small stones (*caementa*) arranged with abundant mortar (*materia*) (Fig. 12a-c).

The external face of this masonry appears to be *opus incertum*, though both *crustae* and *fartura* actually differ from this construction technique. At the Indirizzo baths, the *crustae* have a significant thickness (on average 20-25 cm) and an indisputable bearing role. Instead, in the typical Roman *opus incertum* their size is generally negligible compared to the overall masonry thickness, as they mostly served as permanent formwork and veneer. Moreover, the *fartura* (10-35 cm) is not made in *opus caementicium*, with elements random cast between the *crustae*, since this technique is more common for thick Roman walls (over 1 m), while it is not appropriate for thin ones [29]. Actually, every single stone or fragment (on average 10-15 cm) was placed by hand, normally in the most stable positioning, i.e., with its largest face laid horizontally (Fig. 12a-b, d). As to the abundant quantity of mortar used inside the masonry core, this is due to the irregular form of the stones and fragments that have been adopted.

The materials used are mostly the local black basalt, as well as sporadic Syracuse limestone or sandstone, and some bricks, generally in the form of fragments, except those used for arches. The mortar is constituted of burnt lime, crushed basalt rocks (up to 10 mm), volcanic ash, and sporadic crushed bricks. Despite the presence of some lime granules, which are still not hydrated, this mortar still remains quite hard, maybe due to the hydraulic properties afforded mostly by the volcanic ash.

The *crustae* are built with lithic blocks, more or less regularly dressed according to their positioning, and tightened with terracotta fragments and basalt spalls. The biggest and best-squared stones, sometimes ashlars coming from former constructions, are set in the most structurally strained elements, such as buttresses, wall intersections, jambs, quoins, as well as in door lintels and arches (Figs. 4 and 13a-b). The connection between *crustae* and *fartura* is achieved through header stones that are alternatively positioned on both sides with a certain regularity. Since these

Fig. 12. *Wall section in room 2 (a) and 11 (b); crusta in room 1 (c); detail of the fartura in the western wall of room 2, where the crusta is missing (d).*

stones are generally up to 40-cm long, they do not extend through the whole thickness of the wall and do not directly bind the *crustae* to each other. Nevertheless, they are well engaged inside the *fartura* and represent for the masonry an effective tying element. The vertical joints are generally staggered in order to get a proper bond (Fig. 12c). Many putlog holes of the original scaffolding are currently open, both in the inner and outer leaf.

The walls show leveling courses, i.e., horizontal bands, at an average distance of 60 cm (about two Roman feet), which cover the whole thickness of the masonry. These courses, which are not always fully visible, presumably correspond to the portion of stonework built from day to day by the masons, and they certainly contribute to the wall stability by allowing a proper transmission of vertical loads.

The walling construction of the later rooms (i.e., rooms *3*, *6*, *12*, and *13*) is similar to that of the original complex, while only the thickness is generally different (70 and 75 cm for room *3*, 55 and 59 cm for room *6*, 71 and 112 cm for room *12* and *13*). The overall quality of all masonries is, anyway, rather slipshod since the walls are often not perpendicular, the courses are generally uneven, and the stones are usually just roughly dressed (with the exceptions already mentioned, i.e., buttresses, quoins, etc.).

The masonry construction adopted at the Indirizzo baths can be found in other Roman thermal edifices of Catania province, such as the baths of Erba Bianca in Misterbianco (II-III century) [26], or the baths of Santa Venera al Pozzo near Aci Catena (III-IV century) [30].

5.2. ARCHES AND VAULTS

Arches generally show a more careful construction than the walls.

Stokehole arches are made of large bricks (from 6 to 8-cm thick, up to 34-cm wide, up to 49.5 cm long), laid in a more solid position, often on basalt springers (rooms *7*, *10*, and *11*) (Fig. 14c). Window arches instead, especially those of room *8*, are composed of large Syracuse limestone voussoirs. Door arches, as well as relieving arches, are generally in *opus vittatum* (Fig. 13a, d, f).

Fig. 13. *Evidence of two lintels in the northern (a) and the southern wall (b) of room 1; (c) rectangular flue connecting the hypocaust of rooms 5 and 7; (d) arch in opus vittatum in room 3; (e) remains of a vault on the exterior wall of the niche 11; (f) arch in opus vittatum in room 12.*

Fig. 14. *Confirmed praefurnia in rooms 5 (a), 6 (a'), 7 (b), 11 (c), 10 (d), 9 (e).*

Arches in *opus vittatum* are actually typical in the Roman architecture of Catania province [26], as well as in some later early Christian and Byzantine buildings with trefoil plan [31].

The arches are all semi-circular, except the relieving ones that are segmental. Sometimes the imposts are slightly set back from the jambs (e.g., stokehole arches, door or window arches of rooms *8* and *12*), probably to create a support for the centering on the top of the abutments (Figs. 13d-f, 14a and 14c-d).

All rooms are roofed by barrel vaults, except the large *caldarium* covered by a dome.

Barrel vaults are all made of basaltic tuff stones, whose porosity reduces the overall weight, thus effectively decreasing its outward thrust at the impost level. Those stones were unevenly cut to shape flat elements (25-50x8-10 cm), which were laid radially (Figs. 13d-e and 15a). Sometimes the falsework was directly placed on the top of the walls (rooms *1-3*), on the short setback created at the impost level (Fig. 13d, f). Especially in rooms *2* and *3*, the intrados plaster still shows some imprints of the original centering boards, revealing that masons first laid a bed of mortar on the falsework and then arranged the stones.

The caldarium's dome has a regular hemispheric geometry and a diameter as high as 5.87 m, making it the largest existing Roman cupola in Sicily (Fig. 16). It is composed mainly of neat basalt blocks (10-13 cm high and variable width between 15-50 cm), arranged in 32 circular courses with a dual fabric: in the first 13 courses, the blocks are placed with horizontal beds, using a corbelled vault technique, while in the last 19 courses they are laid with a conical inclination (Fig. 16). This peculiar compound technique that allowed avoiding formworks for the first portion of the dome can be observed in some later buildings of south-eastern Sicily, such as the Trigona di Vendicari near Vendicari (nearly VI century) [31] and "Bagno di Mare" near S. Croce Camerina (about VI-VII century) [25].

Some courses are composed of blocks of Syracuse limestone, instead of basalt, especially on the crown. The dome's circular base is connected with the octagonal base of the room by a course of corbelled bricks that protrude slightly out at the eight corners of the octagon

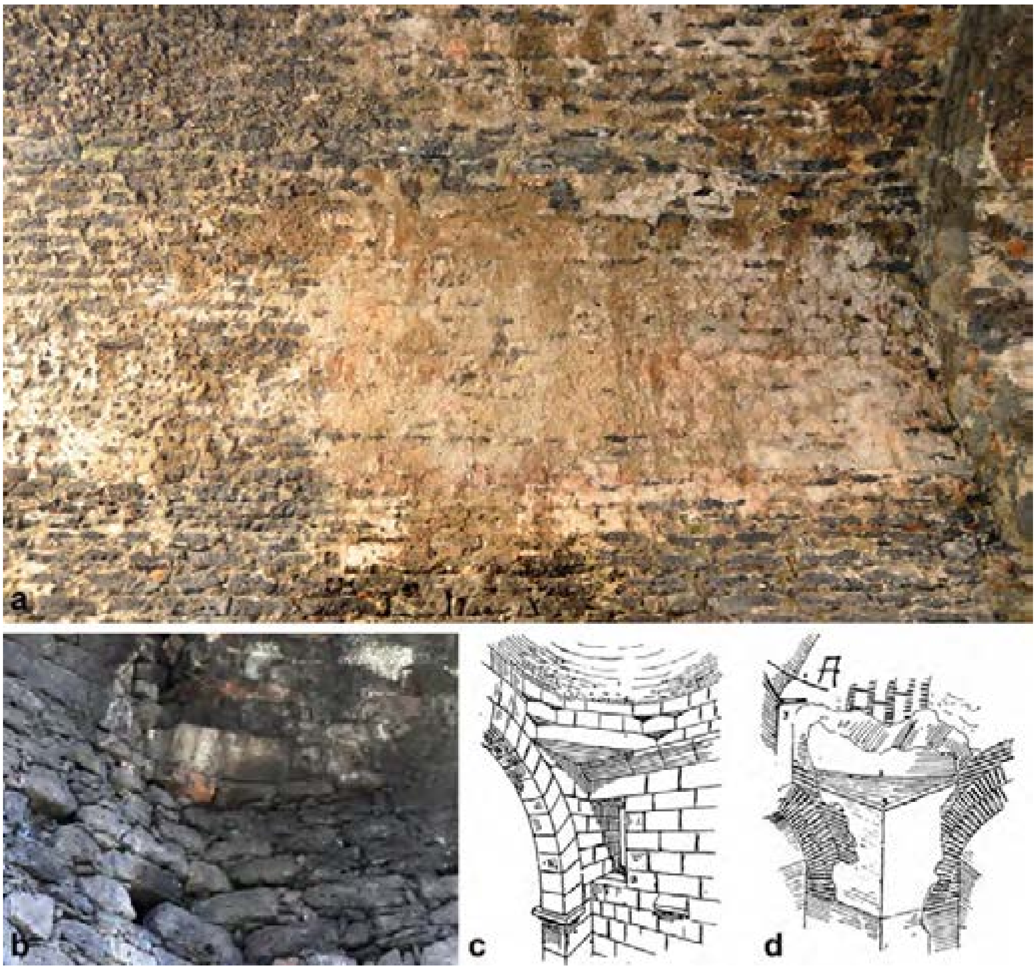

Fig. 15. *Barrel vault in room 1 (a); course of corbelled bricks at the impost of the dome in room 8 (b); corbelling system at the temple of Umm Iz-Zetun near Shahba in Syria (c) and the Nymphaeum of Minerva Medica in Rome (d) [32].*

(Fig. 15b), like in other Roman buildings in Syria and Rome (Fig. 15c-d).

The thrusts of the dome are contrasted by eight buttresses (Fig. 4), conveniently placed at the corners of the inner octagonal profile, where those buttresses lay on four massive substructures (Fig. 5).

6. TL AND OSL DATING

The detailed study of the spatial and functional layout, the construction techniques, and the heating system represent a fundamental prerequisite for addressing another problem, so far almost unsolved: the baths' dating. To this purpose, TL and OSL techniques have been adopt-

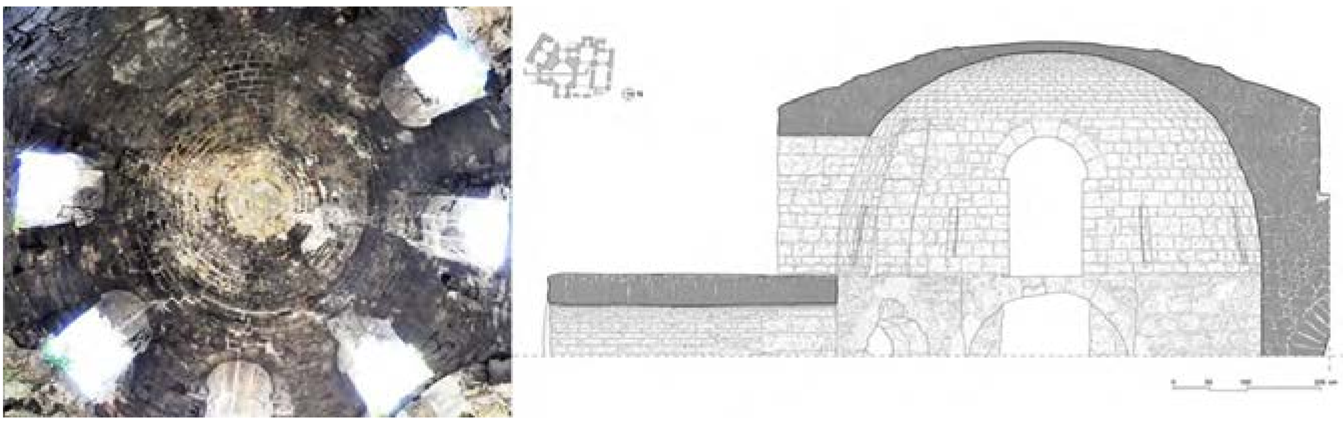

Fig. 16. *Caldarium dome (room 8): view of the intrados and orthometric section.*

ed for brick and mortar, respectively, with the aim to date the two main construction phases and determine the working life as baths and the dating of some successive transformations clearly visible in different rooms.

The TL and OSL methodologies are based on studying the luminescent signals derived from the minerals grains (essentially quartz and feldspars) contained in bricks and mortars. These crystalline inclusions are such as natural dosimeters [33, 34], and the starting assumption is that the amount of light emitted is proportional to the energy previously absorbed due to exposure to natural radioactivity. In turn, this energy is proportional to the time that has elapsed since the last time the minerals have been heated in the case of TL and exposed to light in the case of OSL. Thus, we can date the manufacturing phase for bricks and the last light exposition for mortars. For historical building dating, the chronology established from OSL of mortars is particularly important because the results are related to the mortar laying that is contemporary to the building phase. Instead, the bricks manufacture due to the usual practice of the past to reuse construction material is not always representative of the construction epoch [32].

The general equation used to determine the age, time from the last bleaching of the artifact until today, is the ratio between the Equivalent Dose (ED) and the annual Dose Rate (DR). The ED is the total absorbed dose with respect to the last heating at a high temperature for the bricks and the last exposure to intense light for mortars, measured using luminescence signals. Instead, the DR represents the rate at which energy is absorbed from natural radioactivity that is evaluated by independent techniques carrying out measurements both in the laboratory and on-site [35].

6.1. SAMPLING

The preliminary study of the baths allowed appropriately selecting the brick and mortar samples, i.e., to guarantee reliability and accuracy of results. As a general principle, and especially for the bricks, we have chosen samples from intact and well-preserved building components, well-integrated to the Roman building fabric, which may most likely be attributed to the two supposed construction phases of the baths, avoiding broken or deteriorated components, which may more likely belong to older, ruined edifices. Moreover, to preserve the monument and minimize the damage caused by the sampling activities, we generally did not remove bricks with their associated mortar.

In particular, concerning the brick samples, we have collected both “cold” bricks, which were presumably exposed to average room temperatures (approximately between 20 and 35 °C), and “hot” bricks, which belonged to the furnaces and were consequently exposed to high temperatures (up to 700 °C). Assuming that the selected bricks are coeval with the baths’ erection, the TL analysis of the “cold” samples allows dating the building construction; while the analysis of the “hot” ones dates the last exposure of the sample to the heat and, consequently, the last use of the monument as a thermal building.

As aforementioned, considering the practice of recycling construction materials from the previous building was very common in antiquity, to confirm TL results, we have collected mortar samples.

The selected samples have been grouped and named as follows:

- IC: bricks of the hypothetical I construction phase, exposed to very high temperatures (up to 700 °C);
- IIC: bricks of the hypothetical II construction phase, exposed to very high temperatures (up to 700 °C);
- IF: bricks of the hypothetical I construction phase, exposed to average room temperatures (around 20÷35 °C);
- IIF: bricks of the hypothetical II construction phase, exposed to average room temperatures (around 20÷35 °C);
- IM: mortars of the hypothetical I construction phase;
- IIM: mortars of the hypothetical II construction phase.

In particular, in the following table (Tab. 1), all samples are listed according to the Identification (ID) code, the typology, Brick (B) or Mortar (M), the position in the baths, and the corresponding building component (Figs. 5 and 7a). Furthermore, bricks are divided in two groups: Cold (CB) and Hot (HB).

IC and IIC samples, which were exposed to hot gases around 125°C [1], could be subjected to partial bleach-

Sample ID	Typology	Position (Room)	Building component
IC1	HB	*11* (Outside)	*Praefurnium*
IC2	HB	*11*	Rectangular *tubulus*
IC3	HB	*9*	*Pila*
IIC4	HB	*6* (Outside)	*Praefurnium*
IF1	CB	*10*	Drainpipe
IIF2	CB	*3* (Outside)	Archway
IIF5	CB	*7* (Outside)	Round *tubulus*
IM1	M	*10*	Near drainpipe
IM7	M	*8* (Outside)	Wall
IM9	M	*1*	Wall
IM10	M	*10*	Near drainpipe
IM11	M	*1*	Wall
IM12	M	*1*	Wall
IM13	M	*2*	Wall
IIM3	M	*8*	Barrel vault
IIM6	M	*3* (Outside)	Wall

Tab. 1. *The samples are listed according to their identification codes, typology, room in wich they have been collected and description.*

ing of the luminescence signals [33, 36]. The bleaching was supposed total for the *praefurnium* samples (IC1 and IIC4) during the baths' last use, as these samples were directly exposed to the kiln fire. On the contrary, for IF1 and IIF2 we assume that the last heating corresponds to the brick's manufacture and that they have not been subjected to particular humidity variations.

The samples collection was conducted following the procedure used in historical building dating campaigns [37–39]. All the samples were collected during spring, first scraping off the surface layer and then putting the samples in sealed opaque black plastic bags to prevent exposure to light and preserve their natural moisture content [18].

6.2. SAMPLES CHEMICAL-PHYSIC PREPARATION

For bricks, the polymineral fine grain fraction was obtained by PH3DRA standard procedure [35]. The outer two-millimeter layer was removed, and then the sample was crushed and sieved to select the fraction below 40 µm. After, a sequence of etching procedures was made: 10% HCl for 1h to remove the carbonate, 10% H_2O_2 for 48 hours to remove the organic component, 1% HF for 1 hour to remove clay mineral, and 10% HCl for 25 minutes to eliminate fluorosilicates. A polymineral fine grain fraction in the 4–11 µm range was obtained through a sedimentation procedure and then deposited onto specific discs.

For mortars, the Coarse Grain (CG) preparation procedure [40] was applied on 90-150 µm fraction (Quartz Inclusion, QI). This fraction was treated with hydrogen peroxide (10% for 2 days) to remove organic material, and then it was washed in HCl (20% for 40 minutes) to dissolve carbonates. By using a solution of sodium polytungstate and density separation method, the quartz fraction was separated from feldspars and other minerals before being etched in HF (40% for 45 minutes) to remove the alpha dose contribution to the outer layers and washed in HCl (10% for 25 minutes) to eliminate any fluorides produced. Luminescence measurements were performed with aliquots deposited onto stainless steel discs coated with silicone oil.

6.3. EQUIPMENT

All curves were recorded using semi-automated readers Risø TL-DA model for bricks [41] and Riso TL-DA-15 model for mortar samples [42]. TL glow curves were recorded using Corning 7-59 and Schott BG-12 optical filters. OSL and IRSL signals were obtained, respectively, with 41 blue LEDs (470±30 nm) and with a laser diode (830±10 nm). The stimulation units delivered ~30mWcm^{-2} for OSL and ~240mWcm^{-2} for IRSL at 90% power. Both OSL and IRSL emissions were detected using a Hoya U340 optical filter. The emissions were detected by EMI 9235QA phototubes selecting an overall detection spectral window extended from 380 to 480 nm. Artificial irradiation was carried out using ^{90}Sr-^{90}Y calibrated beta sources integrated in the readers.

6.4. AGE EQUATIONS

The two sample preparation techniques described in paragraph 3.4.2 involve the application of different age equations (Eqs. 1 and 2). In the case of fine-grain fraction, the age is calculated as reported below:

$$Age = ED/(k\dot{D}_\alpha + \dot{D}_\beta + \dot{D}_{env}) \quad \text{(Eq. 1)}$$

where ED is the Equivalent Dose, and k is the alpha efficiency, calculated through luminescence measurements. D_α and D_β are, respectively, the annual dose contributions derived from alpha and beta decay of the radioactive contents present in the sample and that together give the annual dose from the sample itself. D_{env} is the contribution to the annual dose resulting from both gamma dose rate emissions from the environment, including cosmic rays contribution.

In the case of coarse grain, the age equation is:

$$Age = ED/(f\cdot\dot{D}_\beta + \dot{D}_{env}) \quad \text{(Eq. 2)}$$

where f is the attenuation factor depending on grain size [43]. All dose contributions to the annual dose have to be corrected by factors taking into account the porosity and the average moisture level of the sample during its life.

6.5. ED DETERMINATION FOR BRICK SAMPLES

The Added Dose technique is applied for ED determination [33]. With this procedure, it is possible to determine the value of the equivalent dose to the total natural dose received by the sample from the evaluation of equivalent dose (Q) and of a corrective term associated with nonlinear behavior at low doses (q).

For Q determination, 24 aliquots of each sample were measured; the first 6 were subjected to the natural thermoluminescence reading, and the others, divided into groups of 6, were irradiated with increasing doses, and then the thermoluminescent signals were read. TL glow curves were recorded by heating the aliquots up to 500°C with a 5°C/s heating rate in a nitrogen environment. To eliminate the variation of luminescence intensity, due to the small different mass of grains deposed on the discs, a normalization sequence was made giving the same dose to all aliquots, and the plateau test was used for temperature range useful to TL intensity values [33].

In the TL intensity vs. added dose plot, the intercept of the linear fit on the dose axis represents the Q value. To evaluate the possible non-linearity sample behavior, q correction was determined from the intercept of the "second" growth curve behavior at low artificial beta doses. The aliquots were then exposed to small and incrementing beta doses, and a growth curve was constructed. The intercept of the curve on the dose axis is the correction value for supra-linear growth (q) [33].

From artificial luminescence signals induced by calibrated alpha doses, the luminescence efficiency coefficient *k* was determined comparing the artificial luminescence signals induced by calibrated beta and alpha sources [33]. Furthermore, no relevant effects are registered about fading tests performed to avoid underestimating the equivalent dose due to the presence of feldspars in the polymineral fine-grain fractions used [44].

6.6. ED DETERMINATION FOR MORTAR SAMPLES

After checking the purity of quartz fraction through the R-value coefficient calculated according to Mauz and Lang [45], the ED of each sample was determined by the modified Single-Aliquot Regenerative dose protocol (SAR) [46] using the parameters described in Table 2. The cycle of SAR was repeated 7 times using increasing regeneration doses from 0.5 to 7.5 Gy. Seven regenerative beta doses (including zero dose and a repeated test dose) were used, and the corresponding sensitivity-corrected OSL (regenerated OSL signal divided by the subsequent test-dose OSL signal) was used to construct a growth curve. The value of ED was estimated by interpolating the sensitivity-corrected natural OSL onto the growth curve.

Steps	Treatment	Observed
1	Give dose, *Di*	–
2	Preheat at 220°C for 10 s	–
3	OSL at 125°C for 40s	*Li*
4	Give test dose, D_t	–
5	Heat to 180°C	–
6	OSL at 125°C for 40s	*Ti*
7	OSL at 280°C for 40s	_
8	Return to 1	–

Tab. 2. *SAR protocol used for the mortars ED evaluation. For each step, the treatments and the related observed signal are listed. For natural sample i=0, and D_0=0 Gy with corresponding L_N and T_N values. Li and Ti (steps 3 and 6) were derived from the decay curve, taking the first 0.8 s minus a background estimated from the last 3.5 s integral of the OSL signal.*

At the end of each measurement cycle, an optical stimulation for 40 s at 280°C allows checking if any thermal transfer of charge occurred from levels insensitive to light to the OSL traps [46].

After the SAR sequence, the same regeneration dose of the first point of beta irradiation is given again to check whether the sensitivity corrected OSL is reproducible by the recycling ratio R. This value, moreover, identifies the presence of a possible systematic error in the interpolation of L_N/T_N onto the dose-response curves. On the same aliquots, the recovery test was performed [46].

For ED calculation, data are acceptable if the recovery test and recycling ratio are within ±10% of unity and recuperation test near zero [46].

6.7. ANNUAL DOSE RATE DETERMINATION

Concentration values of K, U, Th and Rb have been obtained by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). These values have been used to calculate the internal contribution D_α and D_β to the Annual Dose Rate (see Eqs 1 and 2). The factors re-evaluated by Liritzis et al. [47] were used to convert the radiochemical contents into the corresponding Dose Rate contributions. The environmental and cosmic ray doses are obtained using in situ Canberra InSpector 1000 detector.

6.8. RESULTS AND DISCUSSION

Table 3 shows the U, Th, K, and Rb contents of all samples with the corresponding Dose$_\alpha$ (D_α), Dose$_\beta$ (D_β) and the total contribution of the environment (D_{env}) after the corrections relating to water content experimentally estimated for each sample [33, 48–49].

Figure 17 shows, as an example, the result of the plateau test performed for the IC2 sample. The temperature range between 300–400 °C was selected to integrate the TL signals used for the growth curves elaboration and the ED determination. All the brick samples studied in this paper presented the same plateau test results.

Table 4 shows that the ED values with associated standard deviations are reported together with the DR total values obtained from alpha, beta, and environmental contributions. This table also lists the individual dating results (referred to 2020, the year of the TL/OSL measurements) and the corresponding calendar dates, and the century.

The dating of mortar samples belonging to the I construction phase (IM9, IM11, IM12, and IM13) allows speculating that the baths' construction dates back to the end of the IV century. The brick samples belonging to the II construction phase (IIF2, collected from the arch at the entrance of room *3*, and IIF5, collected from the covered structure over the *praefurnium* entrance of room *7*) also refer to the same period, suggesting that the II phase may correspond to transformations occurred shortly after the baths' opening or to possible changes already occurred during the building erection. Only IIM3, collected from the intrados mortar of the barrel vault in room *3*, dates back to the late seventh century (680 ± 80); however, this date, compared with those of the "hot" bricks, does not seem to be attributable to the II construction phase, but to later works, which probably were carried out when the monument

Sample	U (ppm)	Th (ppm)	K (%)	Rb (ppm)	D_α (mGy/a)	D_β (mGy/a)	D_{env} (mGy/a)
IC 1	2.3±0.1	10.5±0.3	2.44±0.05	95±1	12.9±0.3	2.41±0.04	0.8±0.01
IC 2	2.5±0.1	9.8±0.3	2.31±0.05	92±1	13.7±0.3	2.44±0.04	0.88±0.01
IC 3	2.3±0.1	9.9±0.3	1.72±0.04	83±1	13.7±0.3	2.01±0.04	0.83±0.01
IIC 4	3.4±0.1	10±0.3	1.48±0.04	53±1	14.5±0.3	1.74±0.03	0.84±0.01
IF1	2.8±0.1	10.8±0.3	1.80±0.04	91±1	15.5±0.3	2.15±0.03	0.98±0.01
IIF2	3.6±0.1	11.6±0.3	2.10±0.05	81±1	16.9±0.3	2.35±0.04	1.10±0.02
IIF5	2.1±0.1	9.6±0.3	1.80±0.04	26±1	12.7±0.3	2.05±0.02	0.71±0.01
IM1	2.2±0.1	5.4±0.2	1.57±0.04	30±1	-	1.58±0.03	1.10±0.02
IM7	2.5±0.1	5±0.2	1.16±0.03	19±1	-	1.31±0.03	0.97±0.02
IM9	3.8±0.1	4.9±0.2	1.83±0.04	24±1	-	1.97±0.04	1.05±0.02
IM10	2.4±0.1	3.8±0.2	1.49±0.04	24±1	-	1.44±0.03	0.98±0.02
IM11	3.4±0.1	5.2±0.2	1.81±0.04	30±1	-	1.86±0.04	1.05±0.02
IM12	3.6±0.1	4.8±0.2	1.84±0.04	40±1	-	1.76±0.04	1.05±0.02
IM13	3±0.1	4.2±0.2	1.71±0.04	48±1	-	1.58±0.02	1.05±0.02
IIM3	2.6±0.1	10.4±0.4	1.09±0.03	39±1	-	1.28±0.03	1.10±0.02
IIM6	1.9±0.1	5.2±0.1	1.81±0.04	30±1	-	0.91±0.02	1.00±0.01

Tab. 3. *Radiochemical composition and dose rate contributions for the examined samples.*

was not anymore used as thermal building. In fact, the dating of the "hot" brick samples (IC2, IC3, IIC4, and IC1) allows supposing that the baths were heated, i.e., used, until the VI-VII century. In particular, IC2 and IC3, which were exposed to the hypocaust temperature (90÷125 °C), belong to the VI century, while IIC4 and IC1, which were exposed to the much higher *praefurnium* temperature (up to 700 °C), belong to the VII century, considering for all samples the central age. This means that the *praefurnia* were exposed to fire until the VII century that, consequently, may refer to the last use of the complex as a thermal building.

Sample	ED (Gy)	DR (mGy/a)	Age (a)	Data (AD)	Centuries
IC1	6.29±0.16	4.65±0.13	1352±52	660±50	VII to early VIII
IC2	7.09±0.35	4.80±0.14	1479±85	540±80	V to early VII
IC3	6.36±0.25	4.27±0.14	1489±74	530±70	V to early VII
IIC4	5,82±0,30	4.13±0.15	1408±88	610±40	VI to VII
IF1	1.68±0.18	4.68±0.16	359±40	1660±90	late XVI to XVIII
IIF2	8.40±0.40	5.14±0.17	1634±95	380±90	late III to IV
IIF5	6.44±0.37	4.00±0.14	1609±109	410±110	IV to early VI
IM1	1.71±0.12	2.68±0.03	638±45	1380±50	XIV to early XV
IM7	1.44±0.12	2.28±0.03	632±53	1390±50	XIV to early XV
IM9	4.91±0.32	3.02±0.04	1625±108	390±110	late III to V
IM10	0.98±0.06	2.42±0.03	405±25	1610±30	XVII
IM11	4.72±0.29	2.91±0.04	1622±102	390±100	late III to V
IM12	4.62±0.28	2.81±0.04	1643±102	370±100	late III to V
IM13	4.28±0.26	2.63±0.04	1624±101	390±100	late III to V
IIM3	3.18±0.19	2.38±0.03	1337±82	680±80	VII to VIII
IIM6	1.18±0.08	1.91±0.02	619±43	1400±80	XV

Tab. 4. *The ED, DR, and the ages, obtained by TL for bricks and OSL for mortars and referred to 2020, with chronological data and the century are reported for brick and mortar samples.*

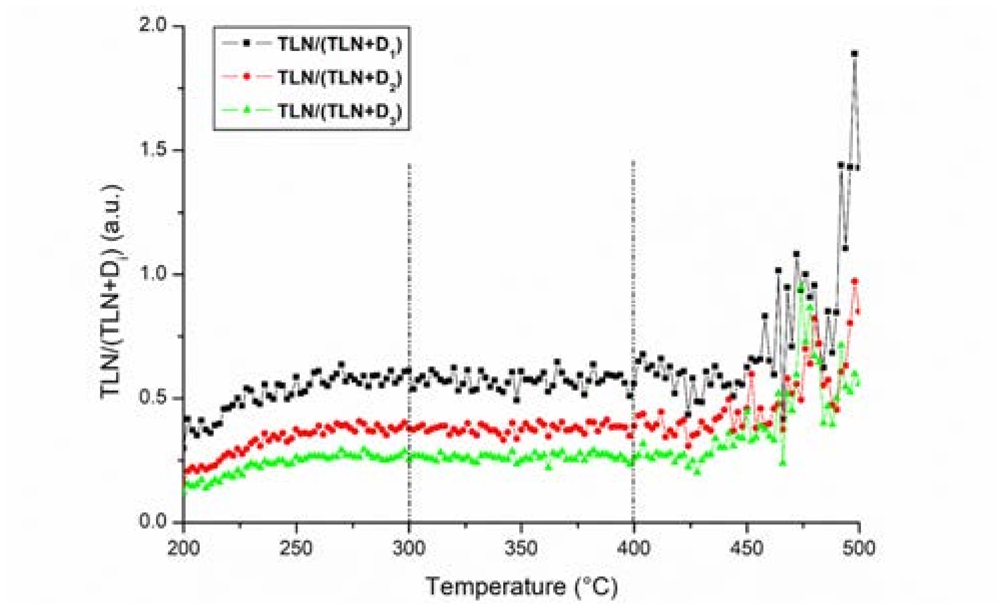

Fig. 17. *The plateau test for IC2 sample. The dots joined by the dashed line show the ratio of the Natural TL signal (TLN) and TL signal coming after irradiation with increasing beta dose in the laboratory (TLN+Di).*

Finally, all the samples with later dating (IM1, IM7, IIM6, IM10, and IF1) can be associated with transformations between the XIV and XVII centuries, when the building had been already used for other functions. Among these transformations, there is the insertion of an inclined drainpipe in the west wall of room *10*, where two mortars and one of the brick samples were collected close to each other (IM1, IM10, and IF1); the dating of these samples suggests that a first intervention goes back to the XIV century (IM1), followed by a second one in the XVII century (IM10 and IF1), corresponding to the installation or replacement of the existing drainpipe. It is worth to note that the insertion of this drainpipe was possible only after the removal of the wall *tubuli* and that the drainpipe was visible in the late XVIII century, as clearly documented by Houel's gouache representing rooms *10* and *8* (Fig. 1c).

7. CONCLUSIONS

The Indirizzo baths at Catania represent an outstanding expression of the Roman bathing culture in the empire's provinces. Although incredibly well-preserved and almost entirely roofed, this monument is only partially known since it is mainly inaccessible to the public, while only partial archaeological excavations have been conducted so far.

On the one hand, the surveys, analyses, and simulations have precisely and extensively specified the original use and functionality of the thirteen rooms that compose the thermal complex. On the other, they have considerably contributed to the correct planning and implementation of the dating campaign, whose outcomes represent one of this paper's primary results. In particular, brick and mortar specimens were selected considering those belonging to the Roman construction and the temperature of the sampling zones during the baths' operation (hot, warm, or cold).

The dating campaign has confirmed that the baths have been built at the end of the IV century, and this result is generally in line with the archaeologists' conjectures [15, 13, 19]. The bricks samples collected from the structurally detached walls from the main building (IIF2 in room *3* and IIF5 outside room *7*) also refer to the end of the IV and the beginning of the V century. As a consequence, there is no chronological evidence of different construction phases during the Roman time and, according to the presented outcomes, the rooms that are not structurally bonded to the rest of the complex (i.e., rooms *3*, *6*, and *12-13*) may correspond to additions made during the building construction or shortly after the baths' opening.

Moreover, the bricks collected from the *praefurnia* (IC1 and IIC4), whose luminescence signals were most likely bleached during the baths' use by the furnace's high temperature (up to 700 °C), belong to the VII century. Hence, the VII century may constitute the *terminus post quem* for the operation interruption of the thermal complex.

All the other more recent samples can be related to transformations that occurred between the XIV and XVII century when the building was used for different functions.

This study has achieved a twofold objective. On the one hand, the proposed interdisciplinary methodological approach has consistently contributed to deepening the knowledge of the Indirizzo baths. The presented outcomes are of great interest in view of future safeguarding, conservation, and exploitation activities that hopefully will soon concern this beautiful yet neglected monument. On the other, the successful validation of the experimental approach to one of the most complete and best-preserved Roman baths allows to effectively replicate it to study other Roman thermal complexes.

Author Contributions

Sections 1, 3: M. Liuzzo; Section 2: M. Liuzzo and G. Margani; Sections 4, 5, 7: G. Margani; Section 6.1, 6.4, 6.8: S. Pasquale, G. Politi and G. Stella; Section 6.2: S. Pasquale; Section 6.3, 6.5, 6.6: G. Stella; Section 6.7: G. Politi; Section 6.9: A.M. Gueli, M. Liuzzo and G. Margani; Supervision: A.M. Gueli, M. Liuzzo and G. Margani.

Funding

This research was supported by the Department of Civil Engineering and Architecture of the University of Catania ("FRUERE" research project), and by the Department of Physics and Astronomy "Ettore Majorana" of the University of Catania ("TECLA" research project).

Acknowledgments

We would like to thank: M.C. Lentini and F. Nicoletti for authorizing sample collection at the Indirizzo baths; V. Garro, who contributed to experimental phases; W. Pettinato (Figs. 7–11), S. Savarino (Fig. 5) and F. Settimo (Figs. 6, 16), for the indicated figures drew under the authors' supervision.

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