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Original research article

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FROM AN ELEMENT TO A COMPOSITION: RECONSTRUCTION OF A VAULT OF TERRACOTTA TUBES FROM TIMACUM MINUS, SERBIA

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Abstract. – The renewal of the archaeological excavations of Timacum Minus in 2019 initiated extensive analyses and an additional interpretation of the results of previous excavations of its buildings. One of the buildings outside the fortification has attracted special attention, because of both its constructive solutions and its dimensions. Although the archaeological research of "the building with a hypocaust" has never been completed, there are enough discovered segments that indicate the applied building techniques and constructions. In addition to under-floor and wall heating systems, this building had vaults built of terracotta tubes. The rarely discovered and insufficiently documented examples of this type of vaulted structure in Roman architecture in south-eastern Europe necessitate a deeper analysis of their remains in Timacum Minus, with the aim of obtaining relevant information important not only for the reconstruction of the construction process and appearance of "the building with a hypocaust", but also for future architectural analyses of Roman buildings in the territory of Serbia and in the surrounding region.

Key words. – Vaults, vaulting tubes, terracotta tubes, tubi fittili, Timacum Minus, building techniques, Roman architecture, late antique architecture, Severan period, south-eastern Europe

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Terracotta vaulting tubes represent specific elements, all shaped according to the same model, created as part of mass production intended for the construction industry of ancient Rome. The formation of the series of tubes enables the execution of rows, which are built next to each other, that is, multiplied, forming the vault. The tubes are shaped so that they can be placed on each other to follow the projected curve of the vault, with the mortar used for their mutual bonding. Before the 4th century, interconnected tubes were used to form the surface of the intrados (inner surface) of the vault, while concrete was then poured over them (Fig. 1a)[1]. From the 4th to the 6th century, in late antique architecture, rows of tubes placed longitudinally were more often employed, instead of rows placed transversally along the vault, which were more common in earlier periods. During this later period, the rows of tubes were also often doubled, with large volumes of concrete no longer applied over them (Fig. 1b). The technique of vault building using terracotta tubes is one of the few that, in the ancient period, enabled the absence of the use of wooden formwork. This avoided unnecessary processes and costs in the procurement, processing, installation and removal of formwork during the preparation for the construction of the vaults.[2]

In the relevant literature in English regarding the use of vaulting tubes, there is a parallel use of the terms *terracotta vaulting tubes* and the Latin term *tubi fittili*. In French literature, the tubes are defined as *tubes emboîtés* or *tubes de voûte,* in German, they are called *Tonröhren*, while Spanish researchers call them *tubos afusados* and the Italians, *tubuli fittili*.[3]

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1 Lancaster 2015, 116, 126.
2 Bjelić 2020, 124.
3 Lancaster 2012; Arslan 1965; Storz 1994; Lancaster 2015, 213.

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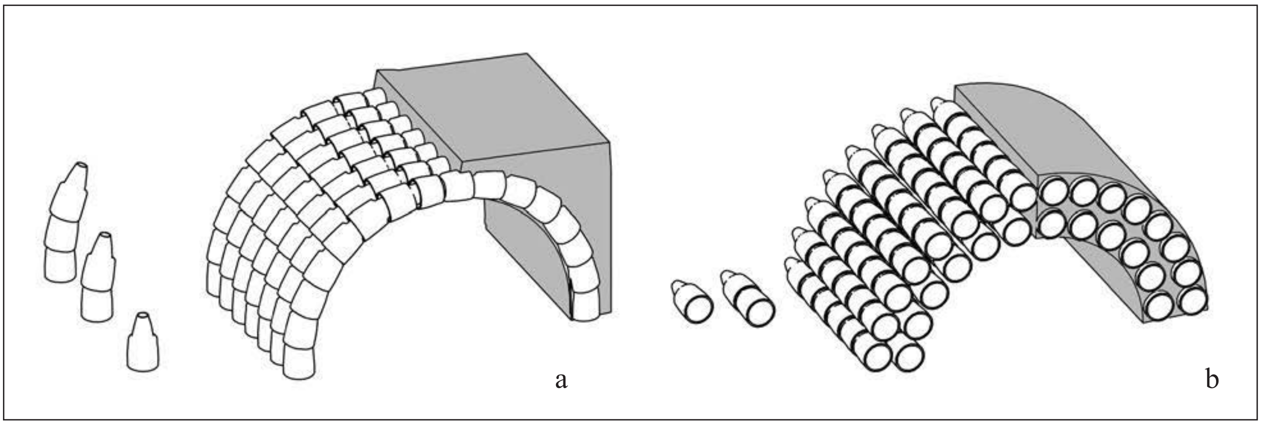

Fig. l. Variants of vaulting tube stringing within the mass of the semicircular vault: a) rows of tubes placed transversally along the vault during the 3rd century; b) rows of tubes placed longitudinally along the vault during the period 4th–6th century (Drawing: Igor Bjelić)

Сл. 1. Варијанте низања цеви за сводове унутар масе свода полуобличастог свода: a) редови цеви постављени трансверзално дуж свода током III века; b) редови цеви постављени лонгитудинално дуж свода током периода IV–VI века (Цртеж: Игор Бјелић)

The study of terracotta vaulting tubes has been ongoing for three decades. In south-eastern Europe, however, this topic has not been the subject of in-depth analysis. The main reasons for the insufficient research of this building technique in south-eastern Europe are the lack of recognition of these specific building elements during their discovery, i.e. the small number of experts who are familiar with the existence and function of vaulting tubes, as well as insufficient interest of researchers in specific architectural problems of the historic buildings and their interpretation.

These tubes are mainly intermixed by researchers with heating tubes or water pipes, giving them the role of these elements. However, this problem is not only a local one, it has been observed worldwide. For this reason, this paper will also give a brief explanation of the importance of the proper differentiation between several types of terracotta tubes, since it directly affects the acquaintance of researchers of Roman archaeology with specific building elements, such as vaulting tubes.

The renewal of the excavations of the Roman archaeological site of *Timacum Minus* in 2019[4] initiated extensive analyses and a reinterpretation of the results of previous excavations of its buildings, that is, their specific elements, of which vaulting tubes caught the attention most of the authors of this paper. Their identification was carried out, their function within the architectural complex was analysed, and then the elements necessary for the visual reconstruction of one of the researched buildings at this site near the village of Ravna in Serbia were proposed.

A brief overview of previous research on terracotta vaulting tubes

Terracotta tubes for the construction of vaults have been recorded in the literature since the 19th century[5]. However, the first extensive systematisation of this important type of building element was performed only at the end of the 20th century, by R. J. A. Wilson and S. Storz.[6] At the beginning of the second decade of the 21st century, L. Lancaster consolidated their knowledge and expanded it, on the basis of the works of other authors and her own research.[7] Also

[4] Petković, in print.

[5] Among the 19thcentury authors, J. Overbeck and R. Bergau are significant. In 1856, in his study of Pompeii, Overbeck noted the construction of domes from these tubes in the Roman city, and gave a drawing of the dome of a furnace built from them (Overbeck 1856, 259). Then, in 1867, Bergau published a short text on the use of amphorae to lighten vaults, but also on the use of vaulting tubes, giving drawings of shapes known to him at that time (Bergau 1867, 405–408, Tao d'agg L). Lynn Lancaster, however, writes that only one of the tubes shown in Bergau 1867 had the function of a vaulting tube (Lancaster 2015, 213).

[6] Wilson 1992, 97–129; Storz 1994.

[7] Lancaster 2012; Lancaster 2015.

significant are publications dealing with the appearance of terracotta vaulting tubes at individual sites across the former borders of the Roman Empire, among which are the works of E. A. Arslan and F. Tomaselo, which deal with the appearance of tubes on Italian territory.[8]

According to previous research, the appearance of vaulting tubes is significant in the areas of the western Mediterranean, while in other parts of the Empire their occurrence is rare.[9] The oldest tubes for vaults, mutually connected with gypsum mortar, recorded so far, are those within the North Bath of Morgantina in Sicily, which dates from the 3rd century BC.[10] Despite sporadic phenomena in the region of the western Mediterranean, there was no significant spread of the technique of constructing vaults using the tubes until the end of the 2nd century AD.[11] The most pronounced appearance of vaulting tubes from that time was recorded on the soil of North Africa, the southern coast of today's France, the eastern coast of Spain, on Sicily, as well as on the entire Apennine Peninsula. The real eruption in the application of terracotta tubes for vaults came in the 3rd century, during the rule of the Severan dynasty, in the province of *Africa Proconsularis*. Attention has to be also drawn to the fact that, according to the available literature, their appearance has not been recorded on Greek soil so far. The late appearance of these elements was registered during the 5th and 6th centuries in isolated regions of Byzantium, such as today's northern Italy.[12] Among the well known vaulting tube constructions from this period, the domes of buildings in Ravenna – the Church of San Vitale and the Baptistery of Neon, certainly stand out.[13]

This type of vault in the territory of south-eastern Europe has not been significantly treated, and mention of the vaulting tubes themselves is sporadic. According to the collected data from older authors, L. Lancaster has registered seven individual sites in south-eastern Europe: *Pietas Iulia* (Pula), *Orsera* (Vrsar) and *Sibinicum* (Šibenik) in Croatia, *Domavia* (Srebrenica) in BiH, Gârbou (Csáki Gorbó in Hungarian) in Romania, and *Sirmium* (Sremska Mitrovica) and *Timacum Minus* (Ravna) in Serbia.[14] Let us add here that, in addition to the listed sites, examples of such tubes were found in Bulgaria at *Novae* (Svishtov), in Romania at *Drobeta* (Drobeta–Turnu Severin), *Apulum* (Alba Iulia), *Colonia Dacica Sarmizegetusa* (Sarmizegetusa), *Potaissa* (Turda) and *Jidova* (Câmpulung), in North Macedonia at *Lychnidus* (Ohrid), as well as in Serbia at the site of *Viminacium* (Kostolac) (Fig. 2).

In the territory of Romania, near Trajan's castrum of *Drobeta* on the Danube, there is a bath that was built in the 2nd century and renovated several times during the 3rd century, in which vaulting tubes were identified.[15] However, they are used in the building presentation and arranged as wall heating tubes along a room wall.[16] During the excavations of a public building, probably erected in the second half of the 2nd century, also used during the time of Septimius Severus and later through the 3rd century, and situated in *Municipum Septimium Apulense*, near the fortress of *Apulum*, Romanian archaeologists found specimens

[8] Arslan 1965, 45–52; Tomasello 2005, 145–155.

[9] Lancaster 2015, 101, Figs. 66; The appearance of vaulting tubes has been registered in many sites in North Africa (Bulla Regia – Lézine 1954, 168–181, Sabratha – Dodge 1989, 249–251, Mlakou – Bukhenouf, Iaichouchen 2020, 51–60, Sbeitla – Duval 1971, Wilson 1992, 98–99, etc.), Italy (several localities in Sicily, including Morgantina – Allen 1972, 379, Piazza Armerina – Arslan 1965, 48, Syracuse – De Angelis 2009, 148, then Rimini – Arslan 1965: 47–50, Pompeii – Scurati – Manzoni 1997, 9–18, Florencia – Shepherd 2014, 257–265, etc.), Spain (Cercadilla – Hidalgo Prieto 1996, 126–127, Granada, Cabrera de Mar – Alcaide et al. 2019, 131–156, etc.) and France (Perpignan, Trans-en-Provence, Olbia, et al. – Lancaster 2015, 101, Fig. 66), as well as in individual localities on the east coast of the Mediterranean (among them is Caesarea Maritima – Vann 1993, 29–34), Britain (in several military fortifications: Chester – Mason 1990, 215–222, Heke 2017, 13–61, Chester – Wilson 2002, 180–185, Carlisle – Mills 2013, 459, York – Whitwell 1976, 45, Caerleon – Heke 2017, 18–19, 24). In this context, the appearance of tubes in the shipwrecks of the Mediterranean is also interesting (Bound 1997, 187–200, Anastasi, Capelli Distav 2016). Examples from south-eastern Europe are listed individually in the text.

[10] Willson 1992, 106; Lucore 2009, 43–59; Allen 1972, 361–383.

[11] Lancaster 2015, 116, 126; Willson 1992, 104–105.

[12] Verzone 1938, 7–12.

[13] For the appearance of the vaults in Ravenna, see in: Bovini 1960, 78–99 and Russo 1996, 285–329.

[14] The location of the seven sites in south-eastern Europe, where the vaulting tubes were identified, is correct on the Lynn Lancaster map. However, in the text for the site of Csáki–Gorbó, Lancaster writes that it is in Hungary, and in fact, it is in Romania (the village of Csáki–Gorbó in Hungarian, or Gârbou in Romanian). The vaulting tubes were found in a building named "Roman Baths" in the very village of Csáki–Gorbó (Lancaster 2015, 112; Buday 1914, 45–62), while a Roman fort is situated in the nearby village of Buciumi (Gyemant, Gudea 1984).

[15] Tudor 1965, 41, Tab VIII. These tubes were not recognised as vaulting tubes in the literature.

[16] When looking at tourist photographs of the colleague M. Muminović, from the Knjaževac Homeland Museum, during a visit to the ancient monuments in Drobeta–Turnu Severin, an author of this article recognised the tubes in one of the buildings; See in: Association 2017, 66.

of these tubes with lime mortar remains, whose function they connected to the vaults.[17] G. Băeştean writes about the difficulty of distinguishing vault tubes from water pipes, in the case of the *Sarmizegetusa* baths, where the origin of a large number of found tubes is unknown.[18] In *Potaissa*, terracotta vaulting tubes were found during the excavation of the baths in the legionary fortress.[19] The baths' erection was dated to 168, and renovation to the Severan period.[20] Băeştean assumes that in *Potaissa* these were originally water pipes, but later used in the construction of the vaults of the baths.[21] In *Jidova*, terracotta vaulting tubes were found in the Severan layer, in the rubble of the hypocaust space of a small building next to the *praetorium*.[22] As for the tubes from *Novae*, they were discovered during excavations in the area of a large early Christian basilica, when, according to Biernacki, a complex of baths was discovered dating back to the third quarter of the 2nd century, the use of which continued until the beginning of the 4th century.[23] In *Domavia*, tubes were found in a room within the building designated as a curia and in several rooms of the public baths and had a prismatic part that narrows up to a pyramidal nozzle. There is no mention of the function of these tubes related to the vaults.[24] However, the tubes found in the family tomb that formed two small vaults, at the site of Vidobišta of *Lychnidus,* have almost the same shape, although a closed nozzle, and are designated as vaulting tubes by its researchers. The erection of the tomb was dated to the first half of the 3rd century, while at the end of the same century or in the first half of the 4th century it was expanded.[25]

The finds of vaulting tubes at the aforementioned sites are not well documented, which is why the prevalence of terracotta tubes on the territory of south-eastern Europe should still be taken with caution (Fig. 2). The general state of research that is present on this issue in the region requires special attention in the consideration of the vaulting tubes at individual sites in Serbia.

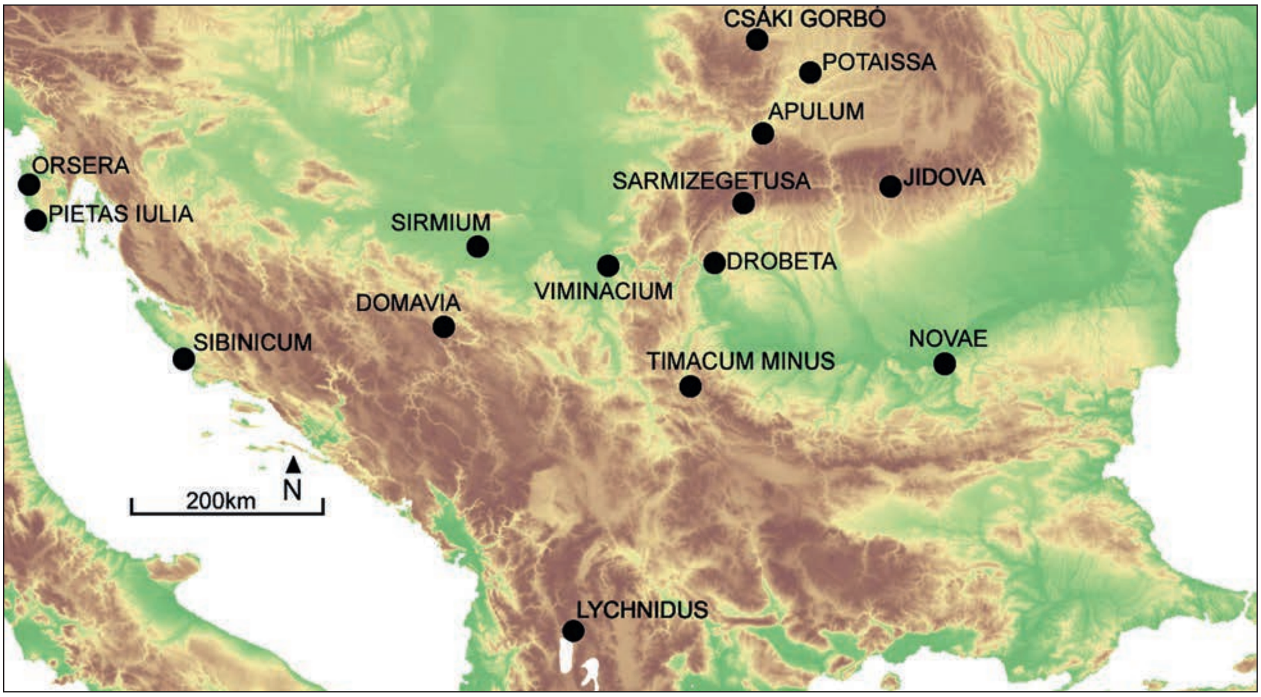

Fig. 2. Prevalence of the findings of terracotta tubes for the construction of vaults on the territory of south-eastern Europe (Map: captions by Igor Bjelić on "Elevation Map of Europe", Owner: European Environment Agency (EEA), CC BY 2.5 DK, https://www.eea.europa.eu/legal/copyright).

Сл. 2. Расūросūрањеносū налаза керамичких цеви за изīрадњу сводова на ūлу јуīоисūочне Евроūе (Маūа: ознаке Иīора Бјелића на „Elevation Map of Europe", Owner: European Environment Agency (EEA), Creative commons license: CC BY 2.5 DK, Copyright holder: European Environment Agency (EEA), https://www.eea.europa.eu/legal/copyright).

The first author who published data on the vaulting tubes on the territory of today's Serbia was the architect Miroslav Jeremić (1943–2016).[26] Prior to the publication of his paper from 2006, there was not a single article in the Serbian scientific literature that dealt with this topic.[27] At the same time, Jeremić is credited with recognising these elements in the function of building vaults at the only two sites where they were registered in Serbia until then, and where they were previously treated differently. Using the data of older authors, as well as of M. Jeremić, L. Lancaster was the first to show the distribution of vaulting tubes on the territory of the former Roman Empire. Covering the territory of south-eastern Europe, she mapped individual examples, thus creating the preconditions for comparison between them. However, Lancaster also pointed out the general problem concerning all individual examples of vaulting tubes on the territory of today's Serbia, as well as on the territory of the whole of south-eastern Europe – poor documentation.[28]

When it comes to examples of vaulting tubes found on the territory of today's Serbia, i.e. in *Sirmium* and *Timacum Minus*, the observations of M. Jeremić are very important. Some of the rare specimens from today's Sremska Mitrovica come from site no. 68, and were found in the immediate area of a basin which was a part of a building from the 4th century whose function is unknown, but for which it is assumed that it represented public baths and that the tubes belonged to the vault above the basin.[29] The possibilities for determining the context of the vaulting tubes in *Timacum Minus*, as well as the former positions within the building to which they belonged, are much greater. However, in the existing archaeological documentation, as well as in the work of M. Jeremić, there were several points of confusion, which we will highlight later. The type of tubes in *Timacum Minus* is characterised by the existence of the cylindrical and conical parts of a tube, corresponding to similar types in the Roman Empire, and is characteristic for the period from the beginning of the 2nd century to the end of the 6th century.[30] As for *Viminacium*, the found vaulting tubes belonged to the building of the public baths, and they were found in the rubble of the hypocaust space of the middle and younger phase of the building, i.e. the period of the 3rd and 4th century. Unfortunately, their exact position was not documented during the excavations.[31] Apart from the probable similarity in the technique of making vaults, there is no other closer connection that could be reliably established between the terracotta vaulting tubes at the three sites in Serbia.

The problem of recognising vaulting tubes

Initially, the terminological indeterminacy of the use of special terracotta elements for the construction of vaults often led to the intermixing of vaults made of tubes with the use of ceramic vessels (usually amphorae) in concrete in order to lighten the weight of the vault near its springers.[32] The two techniques of vault construction, however, have nothing in common in performance or in terms of statics, since the vessels

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17 Ota 2012, 146, Planşa XV; Ota, Lascu 2011, 205, 212–213, 224.

18 Băeştean 1998, 255–258, 260. In our opinion, based on the whole context of the find, the described tubes represent water pipes. However, in the Deva museum there is a tube with mortar and wall paint on it (Băeştean 1998, 257).

19 Barbulescu 1999, 432, 439, Fig. 8; Barbulescu 2019, 111–114.

20 Grec 2011, 187.

21 Băeştean 2008, 171.

22 Petolescu et al. 2018, 25–27, 282, Fig. 4; Petolescu et al. in print.

23 Biernacki, 2003, 9.

24 In the curia, the tubes were found *in situ*, within the wall itself, placed in transverse rows. In the baths, they were found installed in two rooms in longitudinal rows. The first opinion of the author V. Radimsky was that the tubes found in the curia were an insulating layer against moisture in the wall, but he later defined them as heating tubes, which, from the beginning, was his opinion on those found in the baths. I. Bojanovski also defined the elements from the bathroom as heating tubes. In our opinion, the registered tubes at these sites, based on to the context in which they were registered, did not serve as elements for the vaults (Radimsky 1892, 14, 15; Radimsky 1894, 8, 14, 15. Tabla II; Bojanovski 1980, 54–55).

25 Kuzman 2015, 134: Figs. 4, 5, 140, Fig. 18, 135, 144–145, 161, 174–175, 184, 187.

26 Jeremić 2006.

27 In 2004, Ana Radivojević only mentioned the use of this technique as part of the general overview of constructions and construction techniques of ancient Rome (Radivojević 2004, 84–85), and then again, with more detailed information, in a 2018 book dealing with bricks in Late Antiquity (Radivojević 2018, 43).

28 Lancaster 2015, 111.

29 Jeremić 2006, 90.

30 Following the typology of tubes established by Lancaster, we notice that other types belong to the bullet-shaped type (3rd century BC), while later the tubes similar to water pipes were used (House of Fabius Rufus, *Pompeii*, 1st century AD), or ceramic vessels in the shape of a bowl (the Rhine area, 1st–3rd century AD). According to this typology, the appearance of our type of tube can be followed in a wide period range, from 100 AD until the end of the 6th century (Lancaster 2015, 103, Fig.68).

31 Milovanović et al. in print.

32 Lancaster 2015, 99.

do not have a constructive role. Furthermore, distinguishing vaulting tubes from other types of terracotta tubes proved to be the biggest problem in Serbia and in the surrounding region. In that sense, it is of the greatest importance to keep track of the development of these terracotta elements.

The use of terracotta tubes in architecture was certainly not first applied in the field of vault construction. According to Wilson, the use of terracotta tubes for vaults resulted from the previous use of tubes and vessels for forming kilns. Kilns made of terracotta elements have long been used in the frontier area of the Rhine, but early examples of those kilns were discovered during research in the 19th century in *Pompeii*. These kiln vaulted constructions are rarely preserved, but their recognition can be based on the remains of mortar around the bottom of the found vessels. On the surface of the mortar, an imprint is noticeable, which fits with the inner surface of an identical vessel that was placed before in a series of vessels mutually bonded with mortar.[33]

Vaulting tubes are very different in relation to other types of terracotta elements used in ancient buildings. However, the evolution of the shape of these elementary parts for vaults was carried out in Antiquity through several stages. It was probably concluded very early that these terracotta elements did not require the formation of a base, so it was enough for them to be shaped almost like hollow pipes.[34] Thus, it can be also said that these vaulting elements can be actually similar to water pipes. After all, early examples of the appearance of vaulting tubes, such as those in the House of M. Fabius Rufus, testify to the use of water pipes for vaulting purposes.[35] In later examples of the use of vaulting tubes, especially those from the 3rd century, there is a more pronounced difference in shape in relation to water pipes. The degree of narrowing of the top of the vaulting tube becomes so great that it could cause uneven pressure from the source to the endpoint of the liquid delivery. The main difference in relation to heating tubes, i.e. the *tubuli*, is that a cylindrical part[36] and a concave nozzle that goes into the next tube can be seen in the structure of a vaulting tube, while the *tubulus* has a constant width and no nozzle. The nozzle implies a narrowing of the vaulting tubes, so any use of them in the function of heating is not possible because with each subsequent narrowing, the amount of heated air decreases in the next tube. Both kinds of terracotta tubes – *tubuli* and vaulting tubes, have been found in *Timacum Minus*.

The problem of recognising vaulting tubes was also present in the research of *Timacum Minus.* In archaeological diaries, the use of certain terms was not precise enough. Finds of hollow tubes were registered in two buildings: at the baths northeast of the fortification, and during the excavation of “the building with a hypocaust”, southwest of the fortification. On that occasion, no distinction was made between terracotta tubes of different functions (spacers, *tubuli* for wall heating, water pipes or vaulting tubes). After the process of detailed verification of the findings during 2019, we came to the conclusion that the vaulting tubes in the diaries older than 1988, i.e. before the field visit by M. Jeremić, were treated as heating tubes.[37]

Vaulting tubes of Timacum Minus

The context of found tubes

Timacum Minus is located in eastern Serbia, 8 km north of the town of Knjaževac, near the village of Ravna. The first data on the existence of *Timacum Minus* is related to the stay of the cohort *I Thracum Syriaca* during the 1st century when a fortification with wooden-earthen ramparts was built. From the middle of the 2nd century until the end of the 3rd century, cohort *II Aurelia Dardanorum* was situated in it. The castrum and the settlement around it experienced greatest prosperity, and many masonry buildings were erected. The settlement developed along the bank of the river Timok, and within it, the thermal baths and “the building with a hypocaust” have been archaeologically explored. During the 4th century, *Pseudocomitatenses Timacenses Auxiliarii* resided in it. During the third quarter of the 3rd century until 378, *Timacum Minus* was attacked by the Goths, and then by the Huns in 445, after whose attack it never recovered.[38]

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33 Wilson 1992, 107–108.

34 Such tubes were registered as early as the 3rd century BC in the North Bath of Morgantina, in Sicily (Lucore 2009, 43, Fig. 4).

35 Scurati–Manzoni 1997, 9–11, Fig.5.

36 Or prismatic shape in rare known cases, such as those in *Domavia* and *Lychnidus.*

37 M. Jeremić recognised the function of tubes for vaulting immediately during a visit to the *Timacum Minus* site in 1979, but they were recorded as heating tubes in archaeological diaries until 1988 (Jeremić 2006, 90, Note 27, Documentation of the Archaeological Institute (AI), inv 368: Diary of archaeological excavations 1988).

38 Петровић 1975, 46–47; Petrović 1995. 33–34; Petković et al. 2005. 13–19.

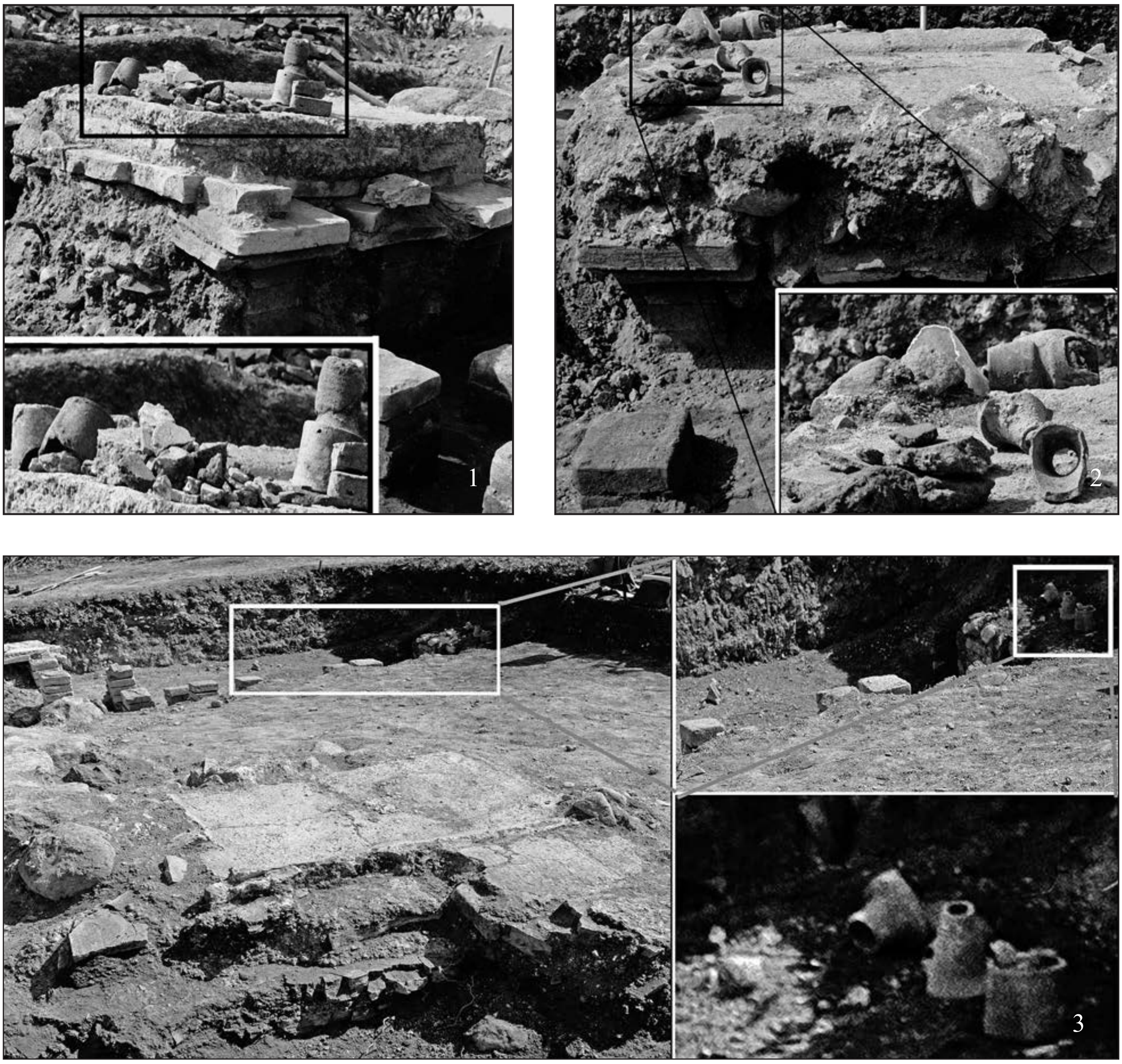

Fig. 3. Vaulting tube finds inside the rooms of “the building with hypocaust”:
1) “room 2” – detail of the regular tube for vaults;
2) “room 2” – detail of the central element for vaults;
3) “room 1” – detail of the regular element for vaults;
4) “room 3” – floor layer over the hypocaust pillars and fragments of terracotta vaulting tubes
(Photo-documentation of the Institute of Archaeology, Belgrade)

Сл. 3. Налази цеви за сводове унутар просторија „објекта са хипокаустом”: 1) просторија 2 – детаљ регуларних цеви за сводове; 2) просторија 2 – детаљ централног елемента за сводове; 3) просторија 1 – детаљ регуларних елемената за сводове; 4) просторија 3 – слој пода преко стубића хипокауста и уломака керамичких цеви за сводове (Фото-документација Археолошки институт, Београд)

The context of the findings of terracotta vaulting tubes at *Timacum Minus* was initially debatable.[39] The early death of prominent researchers of *Timacum Minus* was an additional factor in the slow identification of these tubes.[40] In the work of M. Jeremić, it is stated that the tubes originated from the building named "the Small Baths" outside the walls of *Timacum Minus*.[41] There are two buildings on the site that have been identified by older researchers as the baths, situated outside the fortification, northeast and southwest of it. None of the archaeological diaries, technical documentation or published works related to *Timacum Minus* have identified the site under the name given by M. Jeremić. Only "Thermae I" and "Thermae II" – which is also known as "the building with a hypocaust", are mentioned.

There are no drawings of complete tubes originating from the site in the technical documentation.[42] Such drawings were later made by M. Jeremić, during the writing of his paper, based on specimens that had already been dislocated from the site itself. There are no fragments of vaulting tubes at the site near the excavated parts of the mentioned buildings. However, the building where a large quantity of one type of vaulting tubes was excavated was identified using photo documentation of the Institute of Archaeology, in Belgrade and the Homeland Museum, in Knjaževac. It is "the building with a hypocaust ("Thermae II") (Fig. 3). The tubes were found in all discovered rooms of the building.

As presented above, the largest number of tubes was found as part of the research of "the building with a hypocaust". It was researched in the period from 1978 to 1980 and again in 1988. During the research, the methodology of excavation and documentation was changed several times.[43] Unfortunately, none of the four rooms of the building has been fully explored (Fig. 4). Initially, the central part of " room 1" was explored, and during the next research campaign the research was extended to the west, i.e. to the north-eastern part of "room 2". During the third campaign, in 1980, the previous excavations were completed, and expanded to the southern part of the building, when two conches were discovered. In 1988, during the last excavations, the central part of "room 3" was explored, and excavations of "room 4" were started. In most of the space, stone extraction from the walls of the building was noticed, so the remains of the building were heavily damaged and, in some sections, the entire mass of the walls was almost gone, with either only very low remains or only remains in the negative found.

Judging by the area explored so far, the perimeter walls of the rooms were placed orthogonally to each other. It is noticeable that the walls of "room 2" stand next to the walls of "room 1". The northern walls of the two rooms are not on the same course, but on two courses very close to each other, so it seems that they do not belong to the same spatial concept of the building. The scope of research of "room 2" does not allow us to fully understand its plan. Walls 4, 9 and 10 belonging to "room 1" and "room 2" are about 0.90 m wide. The walls of the praefurnium are adjacent to the northern walls of "room 1" and "room 2". Inside all four rooms, pillars of hypocaust suspensions were found. Some of the pillars were quite highly preserved, at a height of ten rows of square bricks, above which were bricks of a format in standard use in most of the Roman sites on the territory of today's Serbia (28 × 40 × 5 cm), then bipedals (60 × 60 × 7 cm), and finally two floor layers, each of 8 cm. Along the northern walls 4 and 10 of "room 1" and "room 2", *tegulae mammatae* were placed, through which the wall heating functioned. A large number of these tegulae were found along walls 6, 7 and 8, which essentially belong to one course of a wall only 0.5 m wide.[44] Walls 6, 7 and 8 are separated by two channels which are the same width as the praefurniums, and which

39 Some specimens of the tubes from the excavations of *Timacum Minus* are today in the Archaeo-ethno Park Ravna, available to researchers for analysis.

40 Petar Petrović, the director of the excavations at *Timacum Minus* and the former director of the Institute of Archaeology in Belgrade, passed away in 1997. Svetozar Jovanović, once the only archaeologist of the local Homeland Museum in Knjaževac, on whose territory Ravna – *Timacum Minus* is located, passed away in 2000. Miroslav Jeremić, who correctly pointed out the identification of these elements on the site, passed away in 2016.

41 Jeremić 2006, 88.

42 Among the rare drawings of these tubes in the archaeological diary for 1978 (Inv. No. 1), there is a drawing of two fragments of conical tips of tubes. They were discovered in the area southwest of "Thermae I" within the walls that do not belong to the baths. Judging by the drawing, there are no similar examples of vaulting tubes in the preserved inventory of the Homeland Museum in Knjaževac.

43 The marking and orientation of the square grid have been changed several times. In the initial years, the archaeological diaries recorded the observations of archaeologists in great detail, and during 1980 and 1988, they were much reduced.

44 Documentation of Institute of Archaeology, Belgrade, inv 368: Diary of archaeological excavations 28.9.1978.

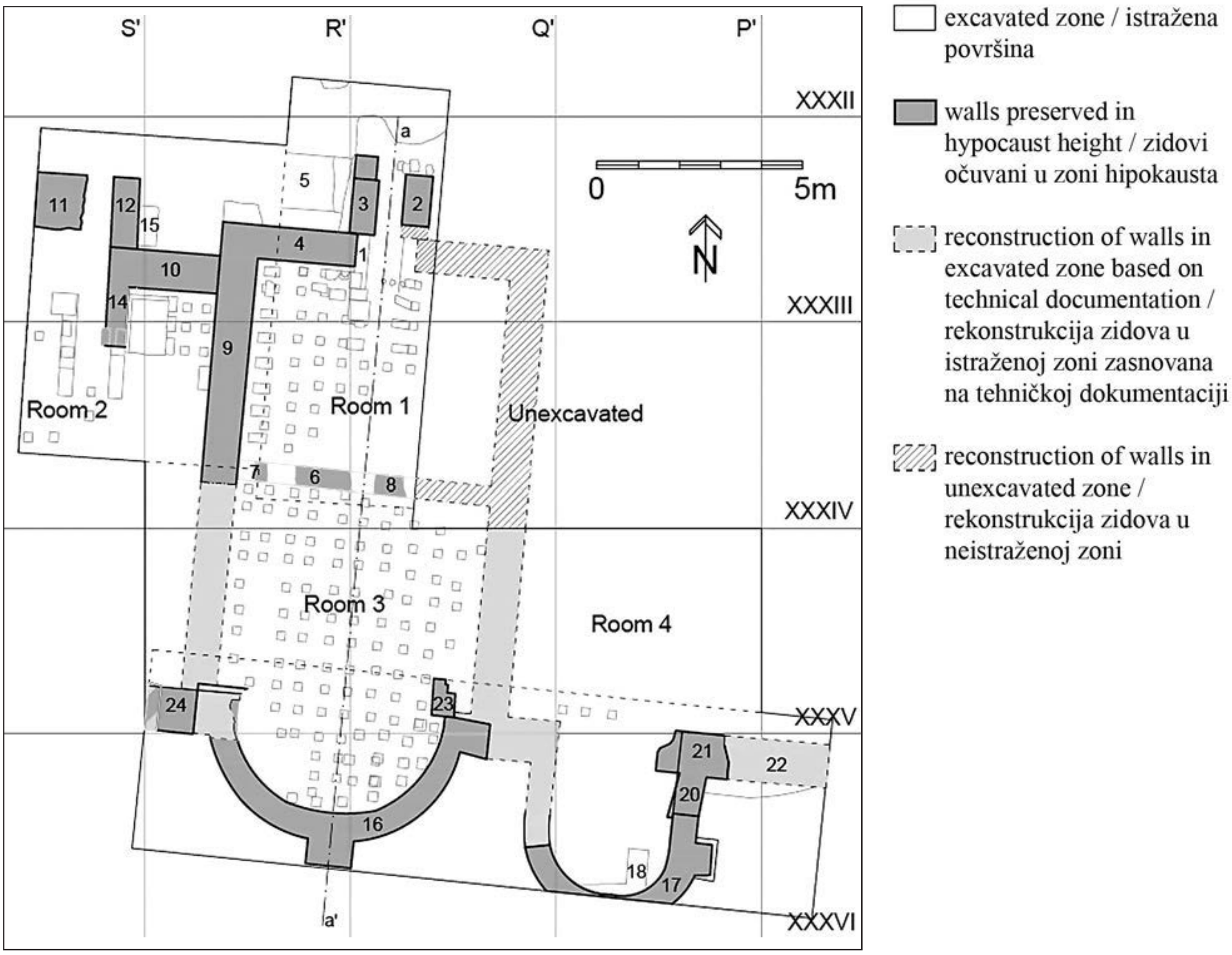

Fig. 4. Plan of "the building with a hypocaust" with the indicated route of the registered walls (dark grey), the route of the removed walls (light grey), and the reconstructed route of the walls (hatch) (Drawing: Igor Bjelić)

Сл. 4. Основа „објекта са хипокаустом" са назначеном трасом регистрованих зидова (тамно-сива), трасом повађених зидова (светло-сива) и реконструисаном трасом зидова (шрафура) (Цртеж: Игор Бјелић)

were once vaulted. For the channel between parts of walls 6 and 8, it is explicitly stated in the diary that its interior faces are on the same course as the interior faces of the praefurnium of "room 1".[45]

In "room 3" and "room 4" in the south, the walls of the south conches of the building are the best-preserved (walls 16 and 17). A buttress was registered in the axis of the conch in "room 3". Other walls (walls 20–24) are only partially preserved. There is no data in the documentation for the west wall of "room 3", but its beginning at the northern end was registered when following the course of the extension of the wall. Its further course was determined on the basis of preserved photo documentation.[46] Judging by the position of the hypocaust pillars of this room and the thickness of the wall at the northern end, the eastern face of the wall was on the same course as within "room 1". According to this data, it is certain that the thickness of the western wall of "room 3" was the same as in its extension. On the east side of "room 3"

[45] Documentation of Institute of Archaeology, Belgrade, inv 368: Diary of archaeological excavations 27.9.1978.

[46] The diary of archaeological excavations for 1988 is unfortunately not preserved in its entirety. The fortunate circumstance is that photographs were preserved with which it was possible to identify the spots from which the photographs were taken, and then to identify the excavated parts of the walls.

during the research, a wall in the negative was registered, of which, to some extent, fragments of mortar and stone on the course between the conches remained.[47] Traces of this wall are of great importance for defining the boundaries of at least one of the rooms within "the building with a hypocaust", i.e. "room 1", because they define the span of the vault which covered it. The position of the hypocaust pillars helps to better define the course of this wall.

If we look at the plan of "room 1" and "room 3", it is noticeable that the position of the praefurnium channel in the north and the channel in wall 6–8 is on the course of the axis a–a', as well as the axis of the conch in "room 3" which is otherwise emphasised by the buttress position. The position and size of the hypocaust pillars inside the northern part of "room 1" are also designed almost symmetrically with respect to the a–a' axis. According to the data presented so far, the course of the east wall of "room 3" also fits into the whole of the spatial concept. It seems certain that in relation to the course a–a' symmetrically to the massive wall of "room 1" and "room 3" on the west side, there was an equally massive wall on the east side of these rooms.

Several other factors that are of interest for our research topic have been subjected to the presented reconstruction proposal. It was stated above that the walls of "room 2" were unconstructively leaning against the walls of "room 1". The thickness of the walls 4, 9, 16, 17, and 21–24 indicates that these walls could have carried a heavier load, which corresponds to the finding of a huge number of terracotta vaulting tubes and roof tiles in these rooms.[48]

When considering the possible spans of the vaults of "room 1" and "room 3", whose boundaries are the clearest so far, it was noticed that the shorter span of "room 1" is defined in a south-north direction. The initial possibility for defining the supports of the vaults along the course of wall 4 and walls 6–8 had to be discounted, however. It is clear that the walls 6–8, with a thickness of 0.5 m and weakened in their lower part by channels, could not play the role of vault supports. This is especially pronounced taking into account the possibility that concrete was poured over the vaults of the tubes and that they also partially carried the load of the roof construction and covering. Therefore, the forces due to the load from the vaults of the tubes had to be transferred to the west and east walls of "room 1". The load transmission had to be realised in the same way in "room 3", and the walls 6–8 with the east-west direction was a thin partition wall between the mentioned rooms. This again justifies the assumption that the eastern walls of the rooms must have been as strong as the western ones.

The shape of the vaults above "room 1" and "room 3" is defined precisely by the possibility of load transfer to the mentioned walls. A semicircular vault above the rooms is most certain here. Its shape would also fit well with the position of the conch in the south of "room 3". Above it, a gabled roof could have been easily built, having the same orientation as the vault itself. The roof is also in line with the position of the praefurnium of "room 1" since all atmospheric waters would be diverted outside the course in which it is located.

During the construction of "room 1", a mortar base for hypocaust suspensura (floor no. III) was constructed, as well as the floor itself (floor no. II). At the time of the destruction of the building in a later period, the vaults made of tubes fell and broke the floor. On that occasion, terracotta vaulting tubes got among the pillars of the hypocaust along with other collapsed material (bricks, fragments of wall paintings, etc.). In the renovation of the building, a new floor (floor no. I) of bricks and larger pebbles was laid in "room 3" over the collapsed structures of the vaults and the hypocaust.[49] In that way, the entity to which the hypocaust and vaulted constructions of the earlier phase of the use of the building belonged was closed.

Regarding the function of "the building with a hypocaust", Miroslav Jeremić cautiously suggests that it is a thermal building from the 4th century. The only finds of the 4th century in the area of the building are coins from the time of *Constantius II* and, stratigraphically speaking, they belong to later pits.[50] The identification of the building as baths has never been con-

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[47] Documentation of Institute of Archaeology, Belgrade, inv 368: Diary of archaeological excavations 1988. 1–2.

[48] Analysis on the relationship between the wall thickness and the vault span in the architecture of Roman public baths in Algeria is given in Bahloul Guerbabi 2016, while interpreting different possibilities of the spaces covered with wooden roofs and vaults (235–250). Barbulescu et al. 2019 used the results of the study to interpret the types of vaults over the baths in the legionary fortress of *Potaissa* (111–120).

[49] In order to avoid confusion during the work of future researchers, the numbering of floors in this paper has not changed in relation to the diary of archaeological excavations from 1988.

[50] Documentation of Institute of Archaeology, Belgrade, inv 368: Diary of archaeological excavations 18.9.1978.

firmed with any certainty. Namely, four large rooms with hypocaust were excavated, without the rooms that would correspond to the *frigidarium*, *palaestra*, *apodyterium* or other contents.[51]

Among the building material, it is important to point out the bricks and tiles on which the stamp of *Cohors Aurelia II Dardanorum* (COHAURIIDARD) is printed. In "room 1", such specimens were registered among the floor bipedals, the bricks for the hypocaust pillars and the roof tiles.[52] In "room 2", a fragment of a brick with a part of an inscription COH and an imprint of a tile in the mortar with a stamp imprint were found.[53] The letters in the mortar cannot be distinguished, but the length of the stamp corresponds to stamps of the previously mentioned cohort. In "room 3" and "room 4", in the layer of collapsed structures with the vaulting tubes, between the floor constructions (II and III), fifteen pieces of bricks with the same stamps were found.

The appearance of *Cohors Aurelia II Dardanorum* in *Timacum Minus* is related to the period from the first half of the 2nd century to the end of the 3rd century, while, according to *Notitia Dignitatum*, *Pseudocomitatenses Timacenses Auxiliarii* appears in this area from the beginning of the 4th century.[54] Due to the appearance of the stamp of the previous cohort, the present dating of "the building with a hypocaust" must be moved at least a century forward, i.e. into the period of the 3rd century. Since, in other provinces, there was a real rarity of the appearance of vaulting tubes in the period of the end of the 2nd century and the beginning of the 4th century, the dating of "the building with hypocaust" to the 3rd century coincides with the period of expansion of the technique of making vaults using terracotta tubes.

The characteristics of tubes

The shapes of the vaulting tubes found in *Timacum Minus* are diverse. The tubes belong to the type with a cylindrical part on one side and a conical part on the other side (Fig. 5). However, different sorts are present within this type (Fig. 6). This classification was performed according to the specifics of the conical and cylindrical part, since the shapes, dimensions, colours and textures can also vary among individual specimens. The average dimensions differ in the largest range of values of 5 cm (± 2.5 cm), which is a consequence of the fast manual work of a large number of specimens, the quality of the clay, the firing temperature, and drying of individual specimens. The colour varies from dark (black) to red, which corresponds to brick products and is also affected by the quality of the clay and the firing temperature.[55]

Among the very rare types of vaulting tubes from *Timacum Minus,* the context of which has not yet been discovered, is a tube that has a slight concave transition between the cylindrical and conical part (Fig. 6a).[56] The tube is smooth on the outside, while a ribbed surface is recognisable on the inside. The tube is characterised by its red colour. This sort belongs to larger types of tubes with a length of 23.4 cm and a diameter of the outer edge of the cylindrical part of 10 cm.

In *Timacum Minus*, a sort of tube which has a ribbed outer surface was also discovered. A larger such tube, 19 cm long and 9.6 cm in diameter (Fig. 6b), has a conical part that is slightly convexly shaped (in the shape of a bullet), and a ribbed outer surface is present on the cylindrical part. The smaller tube has a length of 16.5 cm and a diameter of 8.4 cm, while more pronounced ribbed outer surfaces are present on both the conical and cylindrical parts (Fig. 6c). This sort of tube is characterised by its red colour. Unfortunately, the context of the finds has not been identified.

The previous sorts of tubes belong to the usual forms of vaulting tubes in the Roman Empire. However, the most present sort of tube in *Timacum Minus* is characterised by having a conical part of a smaller diameter and a cylindrical part of a slightly larger diameter, and a clearly accentuated transition between them. The outer surface of these tubes is smooth. A ribbed surface is registered on the inside of the tubes. The colour varies from dark red, through grey, all the way to black. The length varies from 17.5 cm to 22 cm,

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51 On the other hand, most of the buildings in which the vaulting tubes are registered in the territory of south-eastern Europe are designated as baths related to military fortifications.

52 Documentation of Institute of Archaeology, Belgrade, inv 368: Diary of archaeological excavations 25.9.1978, Documentation of AI, inv 368: Diary of archaeological excavations 26.9.1978.

53 Documentation of Institute of Archaeology, Belgrade, inv 368: Diary of archaeological excavations 21.9.1979.

54 ND, Or. IX, 40; Petrović 1995, 34.

55 Small variations in colour and dimensions, according to Wilson, are primarily a consequence of the different firing temperature of a particular series of tubes, and were not of great importance since the rows of tubes in the interior of the room were covered with plaster, over which decoration in the form of paintings or mosaics were laid (Wilson 1992, 98).

56 In Jeremić 2006, this species is listed as type (b) (89, Fig. 11).

Fig. 5. The appearance of a terracotta vaulting tube found at Timacum Minus inside "the building with a hypocaust" (Photo-documentation of the Institute of Archaeology, Belgrade)

Сл. 5. Изглед једне од керамичких цеви за сводове пронађених на Тимакум Минусу унутар „објекта са хипокаустом" (Фото-документација Археолошког института Београд)

and the diameter is in the range from 9.1 cm to 11.4 cm.[57] In most specimens, the length of the conical part in relation to the cylindrical one is the same (Fig. 6f), and it is not uncommon for some specimens to have even a slightly longer length of the conical part (Fig. 6g).

Among the found vaulting tubes, a special one was also discovered. It is characterised by a cylindrical shape and a characteristic convex narrowing in the middle of the tube (Fig. 6d). Its belonging to the mentioned group of finds is certain, based on the texture and colour of firing. It is characterised by a smooth outer and ribbed inner surface. It is 25.0 cm long and 11.6 cm wide. This is the only known find of this sort in *Timacum Minus*.[58] Its shape is characterised by the absence of a conical part, i.e. the presence of a duplicated cylindrical part and, thus, the possibility to pull rows of tubes into such an element from two opposite directions determines its function in a series of tubes. Based on that, we conclude that this element played the role of a "keystone" in the arched constructions of rows of tubes.[59]

The found "keystone" tube is more proof of the existence of a semicircular vault above the mentioned rooms.[60] It is of the great importance because it shows us that the tubes were lined up in transversal arched rows, and that there was a system of load transmission from one tube to another (Fig. 1a). The tubes, therefore, played a constructive role. In the case of rows of tubes placed longitudinally along a semi-cylindrical vault, there is no load transmission between individual tubes, but they play the role of formwork through which the mortar with coarse rubble aggregate (concrete) is poured (Fig. 1b).

As for the construction above the conch of "room 3", the covering construction was probably made using terracotta tubes and was certainly based on the principle of establishing arched transversal rows, but since the rows go in the direction to the top, the cen-

57 In Jeremić's paper, this type is listed as type (a), but constant values of 22 cm in length and 11.36 cm in width have been attributed to it. However, only the largest of the specimens are distinguished by these values (Jeremić 2006, 89, Fig. 11).

58 M. Jeremić listed this finding as type (c). It is not clear from where in the paper the different dimensions of 2 to 3 cm in the drawing of this find come, since this is the only find of its type on the site (Jeremić 2006 89, Fig.11).

59 Jeremić 2006, 89.

60 In the case of domed vaults made of tubes, especially in their upper part where the diameter of the meridian of the sphere becomes narrower, the tubes had to be arranged in horizontal rows. In the Ravenna domes, the spherical shape is made of two rows of tubes that lie on top of each other and are arranged in a spiral, at an angle close to the meridians, at the same time following the shape of the dome. Thus, it is not necessary to have a central element that would connect the tubes from two directions.

61 Kassab Tezgör, Özsalar 2010.

62 According to Wilson 1992, 98.

tral element is not applied. Such a system of arranging tubes was previously noticed in the dome forms of Roman pottery kilns in Turkey.[61]

The execution of a row of tubes in the form of an arch with a central element was also characterised by some specific interventions. Namely, the whole procedure was conditioned by stringing the elements from the beginnings of the arch to its top, with them being connected to each other with mortar. S. Stortz noticed that the tubes were lined up to the top of one such arch by pulling another filled with mortar on the previous one.[62] However, this procedure could last until four to five elements remained on each side of the central element at the top of the arch itself. These elements

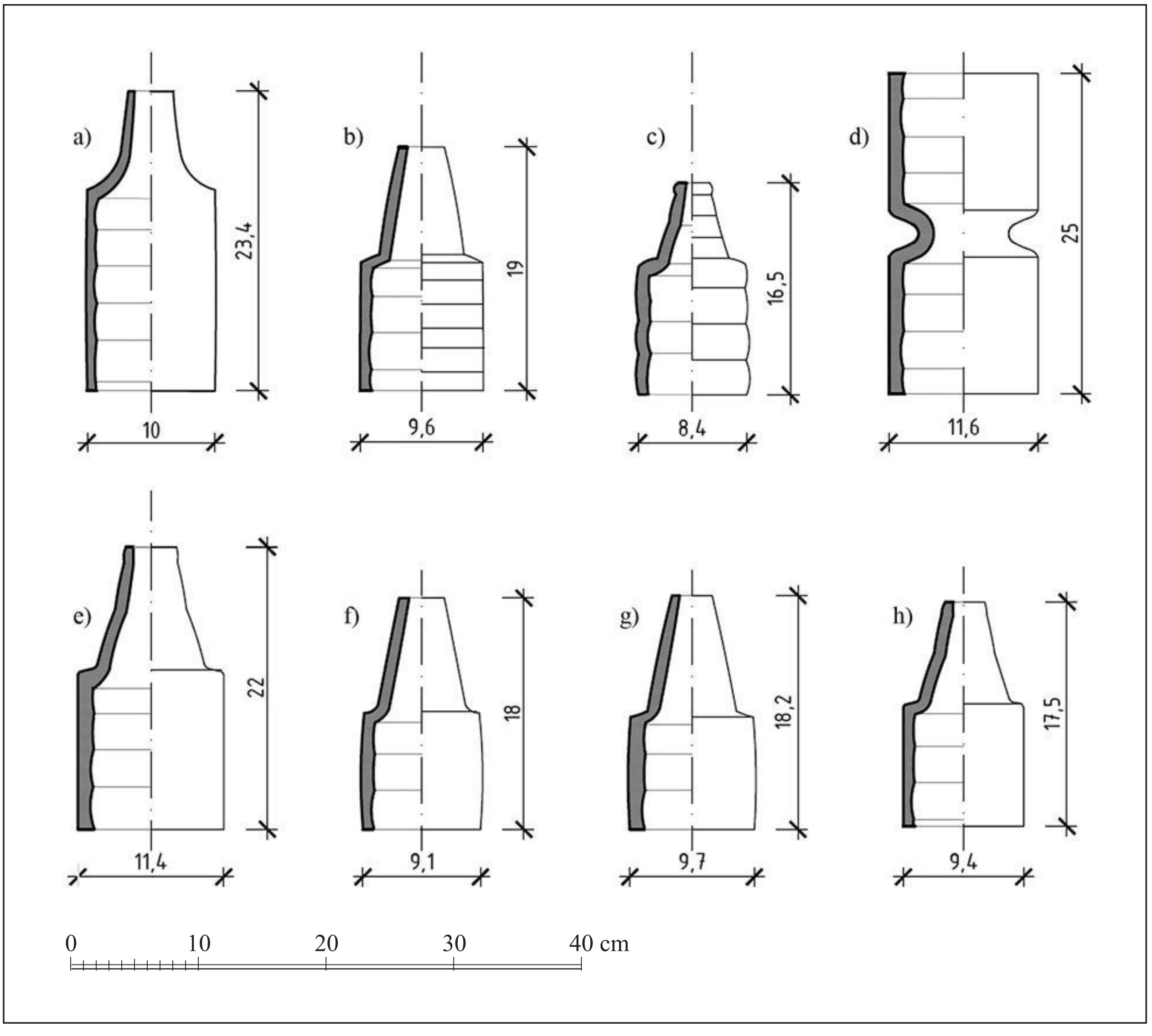

Fig. 6. The types of vaulting tubes found in Timacum Minus:
a) tube with a smooth surface and a larger cylindrical part; b) larger tube with a pronounced ribbed surface;
c) smaller tube with a very pronounced ribbed surface; d) central element for the apex of the vaults;
e–h) the most common sort of terracotta vaulting tubes (Drawing: Igor Bjelić)

Сл. 6. Врсте цеви за сводове пронађене у Тимакум Минусу:
а) цев са глатком површином и већим цилиндричним делом; b) већа цев са благо израженом ребрастом површином;
c) мања цев са веома израженом ребрастом површином; d) централни елемент за теме сводова;
e–h) најчешћа врста керамичких цеви за сводове (Цртеж: Игор Бјелић)

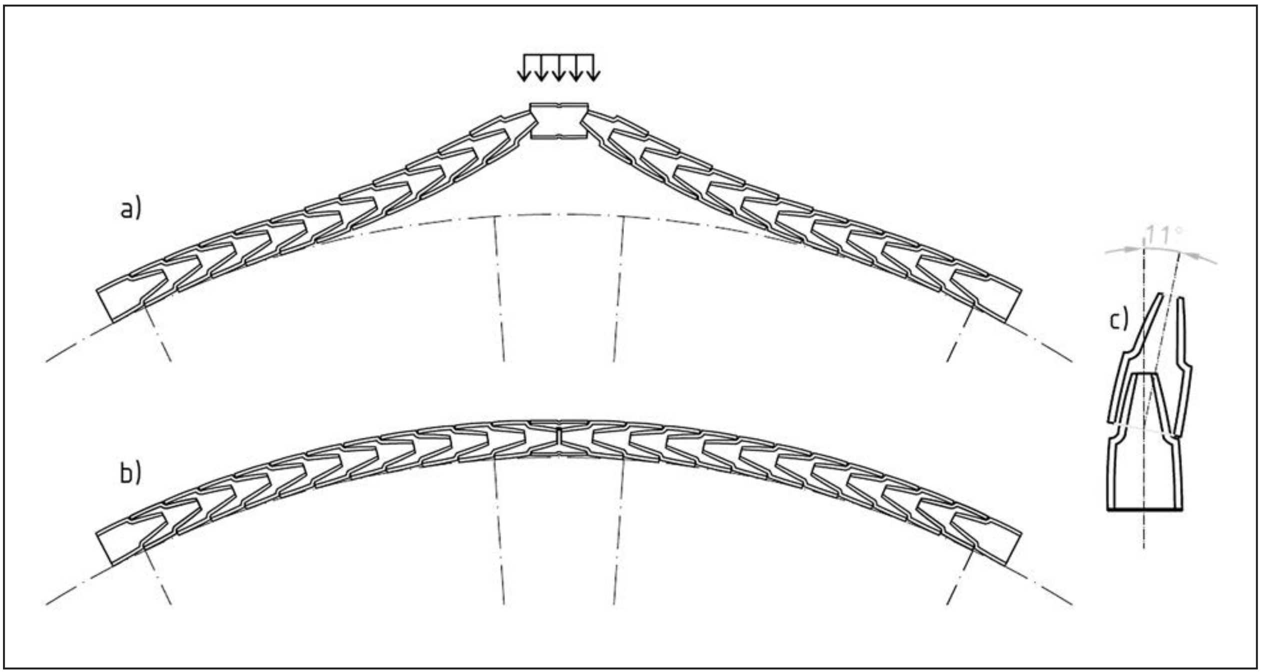

Fig. 7. The procedure of arranging terracotta tubes in the apex of the vault: a) placing the central element at the ends of the rows of tubes; b) placing the tube on the correct route of the curve of the vault (Drawing: Igor Bjelić)

Сл. 7. Поступак ређања керамичких цеви у темену свода: а) постављање централног елемента на крајеве низова цеви; b) постављање цеви на правилну трасу кривине свода (Цртеж: Игор Бјелић)

were lined up on top of each other without being interconnected with mortar and curved into the central element on each side (Fig. 7a). Then the whole set of elements was pushed down (Fig. 7b). In case the length of the row of these elements did not correspond to the curvature of the arch, the whole procedure took place again, choosing slightly longer or shorter elements until the appropriate curvature was reached. If the length of the elements in the row satisfied the curvature of the row at the same time, the procedure was repeated, but this time the mortar was finally introduced.

Traces of mortar found on the mentioned tubes are equally important for the analyses of vault shapes. In most cases, from examples in North Africa to Chester in Britain, the composition of mortars that joined individual elements corresponded to gypsum mortars, which basically consist of calcium sulphate.[63] Also, it was not uncommon to use lime mortars, which could be waterproof. By adding crushed or ground, baked bricks, which are characterised by a high content of silicate, as an artificial material that could have pozzolanic properties, to pure lime mortar, calcium-silicate-hydrate was obtained. It initiates the setting speed, and gives water resistance and strength to the mortar, giving it the characteristics of hydraulic mortars. For the joining of tubes in *Timacum Minus,* lime mortar with the addition of crushed brick was applied. Unevenly distributed fragments of bricks in the composition of the mortar were up to 0.5 cm. Brick, however, was only one of the possible additives to give the mortar the mentioned properties. Often, the mortar that connected the vaulting tubes in Roman buildings also included other materials that could have pozzolanic properties, such as coal and ash obtained by burning straw,[64] which, however, was not noticed in the mortars of *Timacum Minus*. Whether hydraulic lime mortar was formed with the addition or exclusive use of materials of natural or artificial origin with pozzolanic properties as a binder or aggregate, whether the lime used was formed by firing impure limestone,

[63] The reasons for the greater use of gypsum mortars are explained in: Lancaster 2015.

[64] Lancaster 2012.

or even part of the aggregate had mild pozzolanic properties, cannot be easily concluded.[65] As for the lime mortar with coarse rubble aggregate, which could have been poured over the terracotta tubes in *Timacum Minus*, it is important to say that, in this region, quality natural materials with pozzolanic properties are not easily available, so this mortar could never have achieved the properties of Roman concrete where volcanic materials with pozzolanic properties were used, which enabled the construction of monumental structures in the Roman Empire. Brick was the most used pozzolanic additive that could improve the properties of lime mortar in the eastern part of the Roman Empire, and in the territory of today's Serbia.[66] Inside the tubes themselves, mortar of the same visual composition as on the tubes was found. It was also found inside fragments of the conical parts of the terracotta tubes, being deposited there during the pulling of the next tube with the inserted mortar on it. The ribbed surface in the cylindrical part improved the mutual contact of the mortar and the tube.

According to the considered properties of the plan of the rooms and the analysis of the tubes, it was concluded that there was a semicircular vault above "room 1" and "room 3". However, when it comes to "room 2" and "room 4", given the degree of their research, we have not been able to reconstruct the vault above them.[67]

Analyses of the dimensional characteristics of the vault

Although various theories are represented in the field of analysis of masonry structures, the structural theory of masonry has been proved to be the most practical model for obtaining the acceptable results in the analyses of arches and vaults.[68] It relies on the plastic theory, which theorises the possible extreme conditions under which the structure could collapse. Based on the type of construction, arches are considered, within the framework of plastic theory, as statically indeterminate constructions that are sensitive to small movements.[69] In relation to the structural theory of masonry and plastic theory, the following assumptions are adopted for arches and vaults. The first assumption is that the value of the frictional force between the voussoirs is so great that any tendency to slide is prevented (Fig. 8a and 8b). Another assumption is that masonry structures are not resistant in any way to tensile forces. The third assumption is that the masonry structures of the arches have a high compressive strength and that the stresses are so low that there is no crushing of the mortar.[70]

By transmitting the load from the vault to the walls and further to the ground, the action of horizontal thrust occurs, which can affect the mutual spacing of the upper ends of the walls and the alter the geometry of the vault, i.e. the appearance of cracks within the vault structure. The minimum thrust value at which cracks occur is observed. The mutual influence of horizontal thrust within the structure in relation to the gravitational action of the mass of vaults and walls can be represented by the graphostatic method, with a thrust line in the form of an inverted chain[71] (Fig. 8). It, in

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[65] Nikolić, Rogić 2018, 40–45. Future laboratory analyzes will show the characteristics of this mortar and some indications will be obtained about the materials used for its preparation. With the research of available natural materials in the vicinity of *Timacum Minus*, valuable conclusions about their exploitation will be obtained.

[66] Radivojević, Kurtović-Folić 2006, 693–694.

[67] Since this space measures only 1.45 × 2.15 m, the first question was whether this space could have been covered with a vault of tubes at all. Namely, since in the mentioned tube type the flat conical part is quite pronounced in relation to the usual design of this type, the greatest slope between individual tubes was questioned, which gives a given minimum radius of the semicircular vault. Measurings showed that the slope was about 11° (Fig. 7c), and that it provides a minimum radius of only 84 cm. Therefore, it is certain that the mentioned space was also covered with a vault of tubes since a great amount of tubes was discovered between the pillars of the hypocaust inside that space over which the floor collapsed. According to the dimensions, i.e. to the shape of the space itself, it would be impractical to envisage a spherical or cross vault over such a space, which could also be made of vaulting tubes. It is thus, the most likely that there was a semicircular vault over this space.

[68] The "classical" approach based on the field of strength of materials does not lead to results that are close to the actual behaviour of masonry vaults, and more confidence should be given to observing the stability of rigid disks that turn into a mechanism. For the whole assembly, the equilibrium equations do not contain enough data to determine the positions of the support line within a single arch (Bošnjak-Klečina, Lozančić 2010, 409–410; Heyman 1995, 6).

[69] One of the basic laws of the plastic theory applied in the consideration of statically indeterminate construction systems is that which states that the structure is safe if one state of equilibrium in a particular structural element can be determined (Heyman 1995, 22).

[70] Heyman 1995, 114

[71] The line of action of the tensile force in a chain is the analogue to the thrust line of the arch in arched structures. For the arch, the thrust line is, in its appearance, vertically inverted from the shape of the chain, i.e. from the appearance of the line of tensile force in it. At the same time, it is important to note that the chain cannot be defined precisely enough as a parabola, so for that reason, this analogy is used – the shape of a hung chain.

its form, must fit somewhere within the mass of the vault (Fig. 8c). Depending on the variation of actions and the intensity of the load, the thrust line can change its shape. Instability occurs if the intensity of a force on the construction of the vault at one point of the extrados or intrados of the arch is too great. In that case, instead of touching the edges of the outer and inner curve at three points, the thrust line also has contact at a fourth point, so instead of a stable three-hinged arch mechanism, an unstable "four-hinged arch" mechanism is created (Fig. 8e–f). Changing the direction of the thrust line outside the arch mass or contact

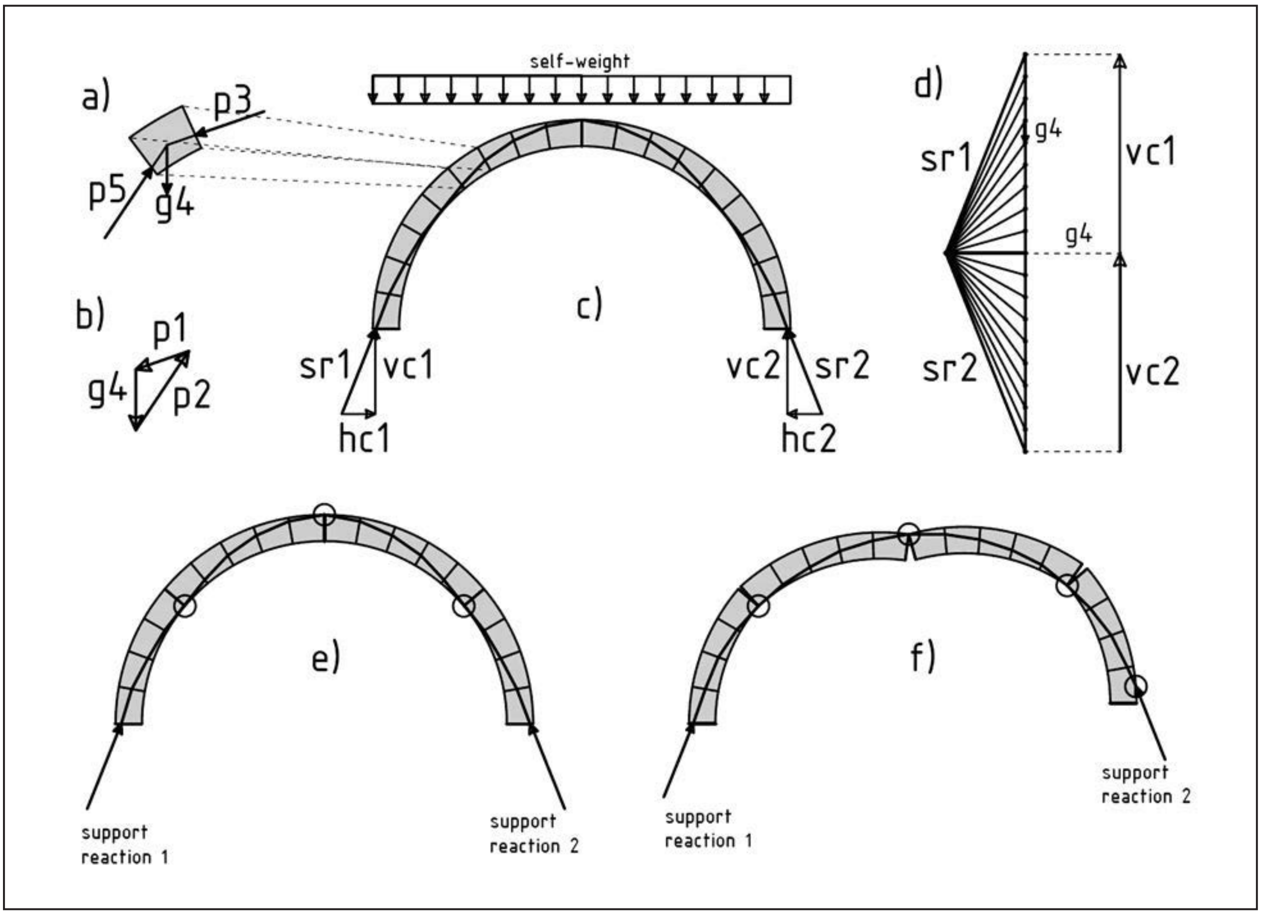

Fig. 8. Graphostatic method for the analysis of thrust-line position within an arch: a) A separated element of the arch (voussoir) with its self-weight and supporting reactions; b) The equilibrium state within one element of the arch; c) The mass of the arch elements „breaks" the thrust-line in certain places along the directions of the vertical axes in which the centroids of gravity of the individual arch elements lie (the supporting reactions (sr) of the whole arch are divided into their vertical (vc) and horizontal (hc) components; d) The polygon of forces where the values of the reactive forces for each element in relation to their individual weights are calculated (the thicker line indicates the support reactions); e) a stable "three-hinged arch" mechanism; f) an unstable structure of a "four-hinged arch".

Сл. 8. Графо-статички метод за анализу положаја потпорне линије унутар једног лука: а) Издвојени елемент лука (сводар) са назначеним гравитационим оптерећењем и силама реакције услед оптерећења унутар лука; b) Стање еквилибријума унутар једног елемента лука; c) Маса елемената лука „прелама" потпорну линију на одређеним местима по правцима вертикалних оса у којима леже тежишта засебних елемената лука (силе реакције у ослонцима (sr) за читав лук су подељене у одговарајуће вертикалне (vc) и хоризонталне (hc) компоненте); d) Полигон сила где су срачунате вредности сила реакција за сваки елемент у односу на њихове појединачне тежине (дебљом линијом су означене потпорне реакције); е) механизам лука „на три зглоба"; f) нестабилна структура лука „на четири зглоба".

of the thrust line with the intrados or extrados of the arch in more than four positions inevitably leads to the collapse of the arch. Thus, the design of the arch depends on how the thickness is determined for a given span (i.e. the stiffness of the arch) and the thrust that the arch should withstand. The proportions of an arch are an important factor in its load-bearing capacity, and these proportions in the form of an arch could only be reached empirically by Roman builders.

According to the data obtained from the archaeological excavations in *Timacum Minus*, a theoretical model was made on the basis of which the proportions of the assembly of walls, vaults and their load-bearing capacity in relation to the load of the entire assembly were analysed. The setting of the theoretical model for the analysis of vaults with the use of terracotta tubes is characterised by some specifics. We can recall here that the tubes were arranged in a radial row by pulling on each other, and that they were filled with mortar. According to the findings from *Timacum Minus*, the composition of the mortar inside the tubes did not differ from the mortar that was poured with coarse rubble aggregate over the vault of tubes.

In the type of vaults made of terracotta tubes in the 3rd century, the concrete was laid radially.[72] The way the rows of tubes and the concrete were laid, as well as the uniform composition of the mortar, meant that the vault can be viewed as a single-layer construction composed of radially arranged elements. The model is conservative in terms of safety since the same value for unit mass per unit volume was taken for the vault layers and load-bearing walls. The conservatism of the model is reflected in the determination of the mass of the vaults greater than it would be in reality in relation to the mass of the walls. In practice, it is more certain that the walls were more massive per unit volume than the vault itself, which positively affected the stability of the vault, especially bearing in mind the partial filling of the tubes with mortar with coarse rubble aggregate. It is also interesting to consider the mass of layers inside the vaults, primarily from the point of view of force transmission. Due to the need to observe the theoretical model in this paper as conservatively as possible, an approximate equalisation of the unit masses of the two layers – terracotta tubes and the poured over mortar, were performed. Namely, it is clear that the top layer had to be more massive than the layer of tubes that had a maximum diameter of 11 cm. In our model, it was adopted that those layers have the same mass, so the thrusts of the entire vault on the walls would be higher. In this way, the model was brought to the fracture limit state in terms of unit masses of its elements – the vaults and walls, in order to examine the optimal dimensional characteristics of the walls and vaults [73] By reducing the mass of the vault layers in *Timacum Minus* to the same value, and equalising that mass with the mass of the walls, the optimal values of the dimensions of the assembly were examined.

The cross-section through the semicircular vault (with the geometrical centre in point O, radius *r,* and the thickness *t*) and load-bearing walls (with the straight height *h* from the level of point B to the point A) was observed, since the transmission of forces through the semicircular vault most closely takes place according to the model of force transmission within one arch to piers of a certain thickness (Fig. 9). The height of the masonry, i.e. the part of the walls above the vault supports (from the level of point A to the level of point C), was determined to fit into the projected slope of the roof planes of 23° above the extrados of the vault. This slope of the roof was common for Roman architecture.[74] In relation to the mentioned height of the masonry, the position of point D was determined, which represents one of the three hinges on which the stability of the remains of the vault construction rests. Theoretically, it is at this point that the appearance of a crack is possible when the supports are spaced apart and the arch geometry is adjusted to the previous circumstance. The second point is symmetrical to the previous one, while the third is determined at the top of the extrados of the vault.

The Rankine factor and the percentage of the abutment were selected as relevant indicators of assembly stability, according to the model used by L. Lancaster.[75] The Rankine factor implies a geometric safety factor that relies on the position of the thrust

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[72] Lancaster 2015, 116.

[73] Although in numerous examples in North Africa, terracotta tubes fell from the back of the vaults, the vaults themselves survived. In the case of “the building with a hypocaust” in *Timacum Minus*, according to archaeological finds and situations, it is clear that the tubes were an integral part of the vaults until their general fall. Lancaster pointed out that within vaults of this type, tubes could not be an element that facilitated the mass of the vaults (Lancaster 2015, 116–117; 182–183).

[74] Ulrich 2007, 124.

[75] Lancaster 2015, 182–183.

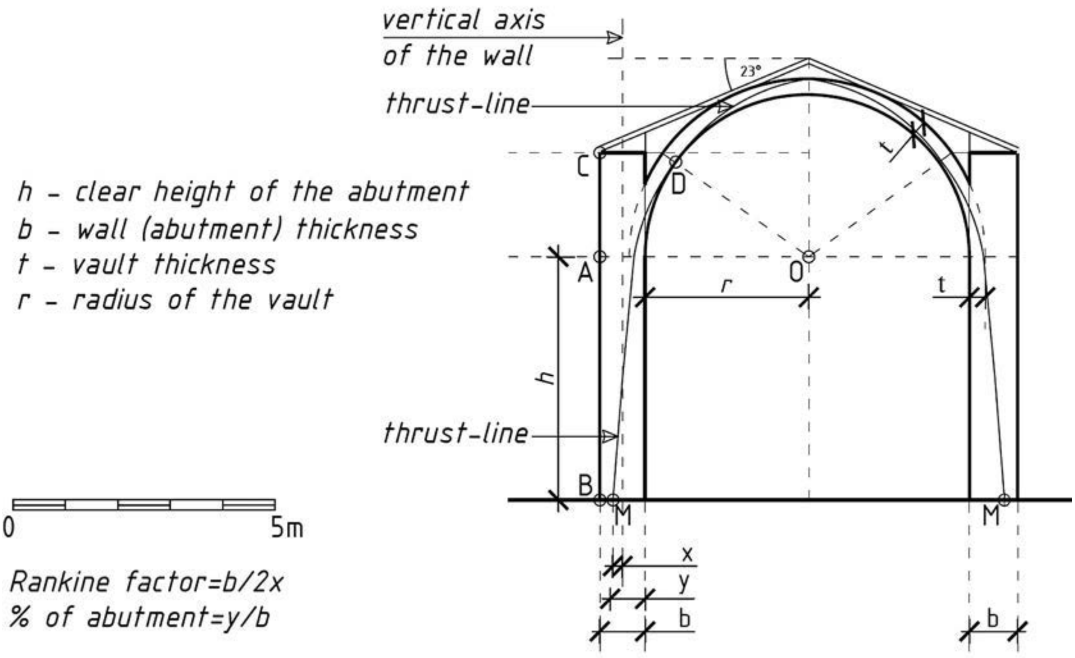

Fig. 9. The basic relationship between load-bearing walls and surcharges to the slope of roof planes and the span of the vault (Drawing: Igor Bjelić)

Сл. 9. Начелни однос носећих зидова и назидака према паду кровних равни и распону свода (Цртеж: Игор Бјелић)

line. According to W. J. M. Rankine,[76] the thrust line must be located within the middle third of the cross-section of the abutment, so that no tensile forces develop in relation to the applied thrusts of the vault.[77] For the Rankine factor, the formula *b/2x* was used, where *b* is the thickness of the load-bearing wall, and *x* is the distance from the vertical axis of the wall to the point of load application M (Fig. 9). In our analysis, the thickness of the wall is constant (0.91 m). This point is in the plane of the wall support, and is affected by the thrust line of the vault and wall. The same point is located on the other side of the vertical axis of the assembly. A Rankine factor of 1 or less defines assemblies whose stability is impossible, while for values above 3, the assembly is considered stable. Between these values, the stability of the assembly is uncertain, which means that any external factor (additional overload of the assembly, earthquake, sinking or sliding of the foundation) can affect it. The closer the thrust line is to the outer edge of the wall, the more pronounced the possibility of assembly collapse. In relation to this possibility, the percentage of abutment is determined, where collapse occurs when the percentage of abutment is equal to the value of 100%. Percentages less than 67% were considered safe according to Rankine's rule. The value of the percentage of abutment is determined as *y/b*, where *y* is determined as the length from the inner edge of the load-bearing wall to the previously defined point M. Cases where these two factors could not be defined, show that the assembly of walls and vaults tends to collapse.

At the beginning of the analyses, a value of 0.30 m was taken for the approximate thickness of the vault, based on examples of damaged vaults of this type or their fallen segments registered in Britain and North Africa.[78] In relation to this value, the first basic group of cases was researched, where subgroups according

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[76] W. J. M. Rankin (1820–1872) was a 19th century mechanical engineer. L. Lancaster used his work: Rankine, W. J. 1858 for the development of her model.

[77] This attitude tends to prevent the case where tensile forces would occur, to which the masonry structures of arches and vaults are not immune, according to the second assumption of the boundary equilibrium method presented above.

[78] Lancaster 2015, 109.

to wall height values were defined: a) the height of the walls is 3.08 m, equal to the vault radius (the real measurement taken from the site as the half distance between the walls), b) the height of the walls is 4.50 m, c) the height of the walls is 6.16 m, equal to the vault diameter.[79] The second group of cases involved strengthening the vaults to a thickness of 0.50 m and the mentioned wall heights for examining subgroups of cases. In addition to these cases, the possibilities of force transmission within the assemblies where the thickness of the vault is smaller (for the values of vault thickness 0.11 m, 0.20 m, 0.25 m and 0.30 m) were examined, as well as those cases where the span of the vault is larger (for values of vault diameters of 7.00 m and 7.50 m) (Fig. 10).[80]

For a defined value of the vault thickness of 0.30 m, the first group of cases was analysed. The possibility of approaching point M to the bearing wall axis due to the increase of the bearing wall mass, i.e. the resulting force as a product of the wall mass and gravitational force, was investigated. Within this group, the first case in which the height of the load-bearing walls is equal to the radius of the vault (Fig. 10.1) determines a Rankine factor of 1.43, and the percentage of abutment in the value of 85%. Already with these measurements, it is noticeable that the values of the indicators belong to the group where there is uncertainty about the stability of the whole assembly.[81] By increasing the height of the load-bearing walls to 4.50 m, and having the same vault thickness of 0.30 m, the value of the Rankine factor decreases and the percentage of abutment increases. Finally, for a height value equal to the vault diameter, the position of point M is at the outer edge of the load-bearing wall (Fig. 10.2). Therefore, the Rankine factor and the percentage of abutment could not be defined. It is noticeable that by increasing the height of the walls, the stability of the assembly is increasingly endangered.

In the second group of cases, the mentioned wall height values were tested for a value of the vault thickness of 0.50 m.[82] The possibility of a better load-bearing capacity of the entire assembly was examined, provided that the vault was strengthened with a larger thickness. For a value of wall height equal to the radius of the vault, the Rankin factor is equal to 1.20, while the percentage of abutment is equal to 92% (Fig. 10.3). At the same time, the position of point M is much closer to the outer edge of the wall than was the case for the value of the vault thickness of 0.30 m. For the value of the wall height equal to 4.50 m, or the diameter of the vault, the unfavourable values of the indicators were more pronounced. It is obvious that an increase in the thickness of the vault directly initiates its greater mass and, thus, an increase in the resulting forces of horizontal thrusts, which have a less favourable effect on the supports than was the case with the first group of examined cases. Such a conclusion prompted the examination of the following group of cases.

In the following cases, the load-bearing capacity of the assembly where the thickness of the vault is smaller was examined. From the previous tests, the most favourable possibilities were adopted, where the height of the load-bearing walls is equal to the radius of the vault, since it has been proven for the others how much more unstable they are. The diameter of the tubes themselves, about 11 cm, was taken as the smallest value of the vault thickness (Fig. 10.5). It is noticeable that the thrust line, in that case, extends beyond the boundaries of the vault itself, which would otherwise cause its fracture at the point where the thrust line protrudes most beyond the boundaries of the vault in cross-section. Therefore, the Rankine factor and the percentage of abutment could not be defined.

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[79] Since we cannot talk about static-computational analyses in the period of Antiquity, Roman builders came to them empirically. In doing so, they were tied to the proportions of the architectural elements determined in the plan of the building, which in the case of arches and vaults was primarily their range.

[80] Although the number of examined cases was higher, the cases presented here are only those which, in relation to the entered data of dimensions of thickness and height of the walls and vaults, as well as the diameter of the vaults, give relevant indicators regarding the stability of the assembly.

[81] The values of the indicators are, at the same time, a consequence of the conservatism of the theoretical model because the most unfavourable circumstance was determined for the massiveness of the arches and walls. The validity of the obtained results in this theoretical model can be compared with that of Lancaster, who studied the same type of arches. For the span of the vault (arch) of 5.25 m, the thickness of the load-bearing walls of 0.91 m, and the height of the walls, which is one and a half times larger than the radius of the vault, a Rankine factor of 1.3 and a percentage of abutment of 89% of the base of the wall (pier) were obtained, where the unit masses of the walls and vaults are also equalised (Lancaster 2015, 183).

[82] The dimensions of the elements of Roman architecture were mostly determined according to a foot. Accordingly, the second group of cases should be analysed so that the thickness of the vault is two Roman feet (about 60 cm). According to the results obtained in the second group of tests, it was confirmed that a vault 0.5 m thick adversely affects the stability of the assembly, so the adverse effect of a vault thickness of two Roman feet would be even more pronounced.

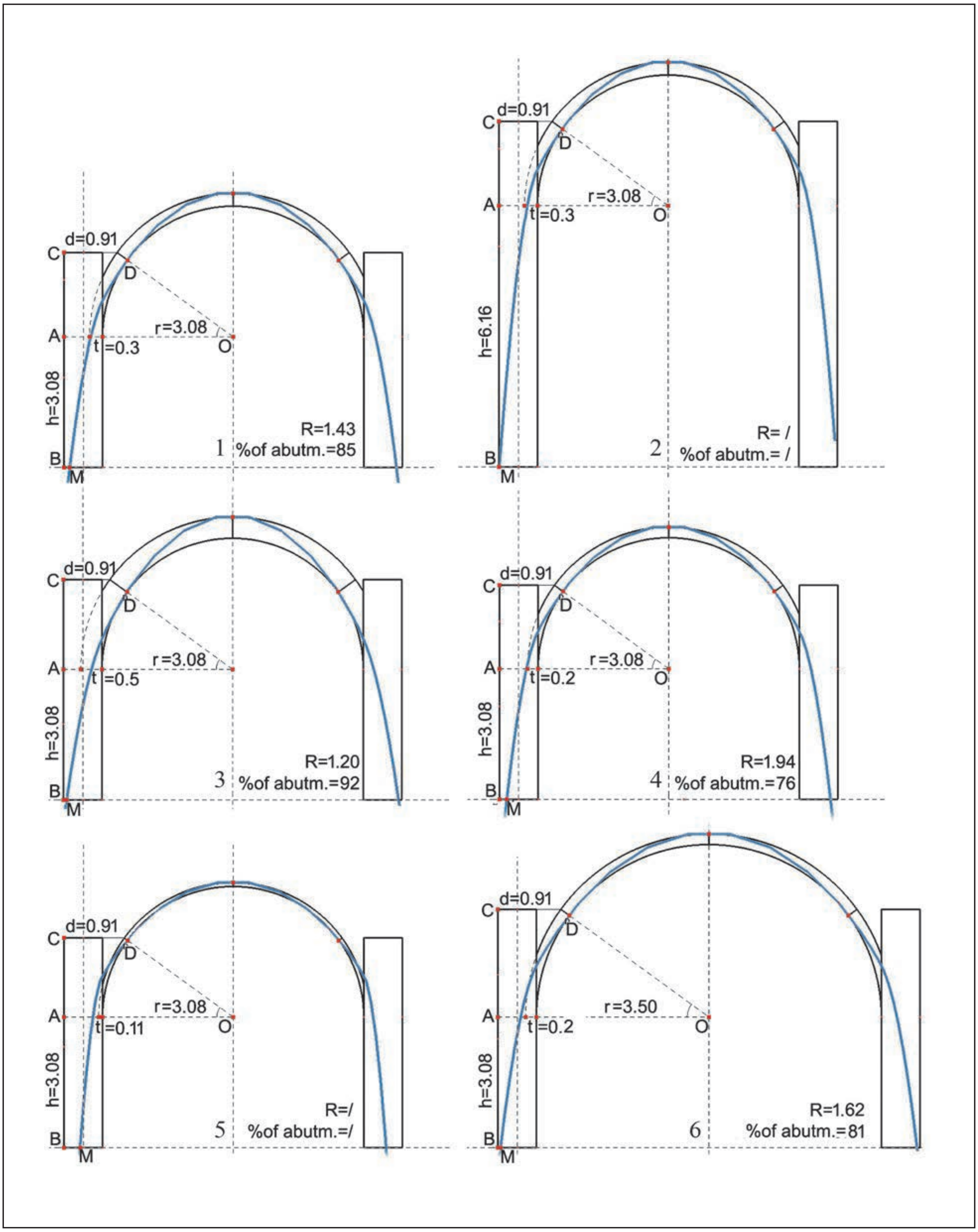

Fig. 10. Analysis of different dimensions of walls and vaults and their mutual relationships (Drawing: Igor Bjelić)

Сл. 10. Анализа различитих димензија зидова и сводова и њихових међусобних односа (Цртеж: Игор Бјелић)

For a vault thickness value of 0.20 m, the thrust line is within the vault boundaries, and the Rankine factor has a value of 1.94, while the percentage of abutment is equal to 76% (Fig. 10.4). For a vault thickness of 0.25 cm, the indicators are characterised by less favourable values.

In the last group of examinations, cases where the span of the vault is larger were considered. Since the previous tests considered the range of values of load-bearing wall height dimensions and vault thickness that adversely affects the stability of the assembly, for further analysis, more favourable options for vault thickness (0.30 m) and load-bearing wall height (3.08 m) were adopted. These factors were selected based on the results obtained so far from the Rankine factor and the percentage of the abutment (Fig. 10.6). In the first case, a radius of 3.50 m was adopted, corresponding to a span of 7.00 m, which affects the value of the Rankine factor to be 1.23, while the percentage of the abutment is 91%. As the span increases, the percentage of the abutment increases, i.e. the Rankine factor decreases.[83] According to the measurements of the indicators, it is noticeable that the factor by which the span is increased also adversely affects the stability of the vault and, thus, the entire assembly, even if the thickness of the vault and the height of the load-bearing walls are the most favourable.

The analysis of the theoretical model of the vault and load-bearing walls assembly gives several important results. During the first and second groups of tests, the unfavourable influence of the increase in the height of the bearing walls and the thickness of the vault was highlighted. The first circumstance indicates that the building could not be extended in height since it had walls 0.91 m thick and a span of at least 6.16 m according to the reconstructed plan. As the most optimal possibility, the analysis singled out the case where the walls are of the same height as the radius of the span above "room 1" and "room 3". Within the examination of the third group of cases, it was proved that the vault could not have been made only of tubes, but mortar together with coarse rubble aggregate was laid over, which increased the thickness of the vault to the minimum required of 0.20 m, in order to transfer the thrust line of forces within the mass of the vault. The analysis, therefore, proved that such a vault could not survive without putting mortar with rubble coarse aggregate over the tubes. Within the last group of tests, it has been proven that by further increasing the span of the vault larger than 6.16 m, its stability is increasingly adversely affected. It is certain that reducing its range would have a more favourable effect on the stability of the assembly, but this was not the case according to the plan of the rooms with the positions of the hypocaust pillars. Therefore, the conclusion of the analysis gives the thickness of the vault from 0.20 m to 0.30 m, the height of the walls of 3.08 m and the vault span of 6.16 m, i.e. shows the probability of the reconstruction of the geometry and dimensions of the vault as shown in Fig. 10.4. With the stated values of the dimensions of the load-bearing walls and vaults, the Rankine factor has a value of 1.94, while the percentage of the abutment is equal to 76%. In this way, the most favourable values of the dimensions of the load-bearing walls and vaults within the conservative model with predetermined strict criteria of the massiveness of the assembly are obtained.

The correctness of the reconstructed plan of "room 1" and "room 3", i.e. the proposal to cover these rooms with a semicircular vault, is best proven by a static analysis of the theoretical model.[84]

Conclusions

South-eastern Europe has so far not been recognised as an area where the use of vaulting tubes was frequent in the late antiquity period. Until now, according to previous international literature, only seven sites in Serbia and the countries with which it borders were known. By researching this topic, we have managed to greatly increase the number of the sites where

[83] This case was also examined for the possibility of increasing the thickness of the vault from 0.30 m to 0.50 m. The result is the same – the indicators are characterized by more pronounced unfavourable values for the stability of the assembly, and the position of the thrust line is even further away from the axis of the load-bearing walls. The span of the vault of "the room 3" certainly could not be more than 8.13 m because, at a greater distance from that, measured from the west wall of this room, there is a trace of the hypocaust columns of "the room 4", as shown in the technical documentation of the Homeland Museum in Knjaževac.

[84] In the previous analyses, the support of a heavy roof cover should also be taken into account. In the presence of factors that adversely affect the stability of the assembly, this factor would further contribute to the endangerment of the entire structure. By adopting a conservative theoretical model at the beginning of the research, a wide range of cases was obtained where the values of the output indicators indicate the initial endangerment of the structure in relation to the registered thickness of the load-bearing walls and the reconstructed vault span. Based on that, in each of the examined cases, a range of values of a certain dimension was singled out, which favourably affects the load-bearing capacity of the vault assembly and load-bearing walls.

the presence of vaulting tubes has been registered. It is important to point out that this research has also included examples of tubes whose real function was not recognised until know, which all indicate that the finds of vaulting tubes may be even more frequent in the area of south-eastern Europe.

The shape of the terracotta tubes in *Timacum Minus* is diverse, but they all belong to the type with a clearly distinguished conical part for insertion into the next tube. The presence of at least three different sorts of the same type indicates that these tubes were not the product of just one master. In shape, they are most similar to the specimens from *Novae* in Bulgaria and *Jidova* in Romania. This indicates that there could have been a connection between these places, either in terms of trade or the transfer of knowledge regarding the manufacture of the vaulting tubes, and even the technique of their construction. At the current level of research at both sites, it is almost impossible to determine if any of these is true.

The dimensions of the vaulting tubes vary at Timacum Minus. In the most numerous group of specimens, the conical part is as long as the cylindrical part. Such a relationship between the two parts of this group of tubes enabled the conical part of one tube to be completely immersed in the cylindrical part of the next tube, which was not the case with most specimens from other provinces of the Empire. Since the span of the vault was defined for "room 1" and "room 3", it was possible to determine, according to the dimensions of the tube, how many elements were used to cover one room with this vault.

Considering that their dimensions varied from 17.5 cm to 22 cm, 73 to 105 terracotta vaulting tubes would have been needed for the construction of one arched row of a 6.16 m span. The number of elements was most probably odd considering that there was a central element. On each side of the central element, from 36 to 52 specimens of the tube with a conical part could fit. Considering that the length of "room 1" in the other direction was 5 m, as well as "room 3", and the maximum diameter of the tube was 11 cm, it was necessary to construct 45 or 46 rows to cover these two rooms. These values should be understood as approximations, since they were calculated assuming the rows were placed next to each other. Also, the diameter of the tube could be 9 cm instead of 11 cm, so in the considered calculation, 4 cm of space would remain for the mortar between each arched row. Between 3,285 and 4,738 tubes would have been needed to construct the vault over one of these two rooms. Considering that there were two more rooms in which their remains were discovered, this number could have been at least three times higher.

The size of the tube is too small for applying a stamp indicating the presence of a certain cohort. However, the bricks and tiles with the cohort *Aurelia II Dardanorum* stamp placed in the lower parts of the walls of "the building with a hypocaust" directly place the construction of this building in the 3rd century. This circumstance has a deeper significance. Older researchers of the construction of vaulting tubes have indicated that the large number of elements required their production near the construction site. Since there was a developed activity of ceramic production in Timacum Minus, it is possible that elements of vaulting tubes could also have been produced here as part of it. This possibility also opens up directions for future research on this topic.

Of special importance is the finding of the central element, which had the role of a "keystone" in the apex of an individual transversal arched row of tubes in the vault. In addition to the fact that such an element is a rare find among the collapsed material of vaults, it directly resolves many issues related to the characteristics of the vaults. In the first place, it shows that the rows of the vaults were built as transversal arched rows on both sides, in the connection of which such an element was located. This resolves the issues of vault construction, the transmission of forces from the apex to the supports and the general constructive role of vaulting tubes. Furthermore, the existence of transversal arched rows indicates that a semicircular vault was most practical above "room 1" and "room 3". In that sense, the architectural analysis using one single building element can provide precious solutions for the reconstruction of the entire structure.

The application of static analysis of the theoretical model can help us to obtain answers to some more questions and further clarify the somewhat unclear archaeological situation. Thus, the approximate value of the height of the load-bearing walls that could carry the vault made of vaulting tubes was examined. It was highlighted that the harmonised proportions of the arch and the dimensions of the load-bearing walls were the basic factors of the stability of the assembly. Determining the height of the load-bearing walls at 1.5 times the value of the radius of the vaults endangered the stability of the assembly, which was even more pronounced at twice the value of the radius, as indicated by the data obtained by the graphostatic method. Therefore, the height of the supporting walls of the vault had to be adjusted to the entire assembly, so they were certainly equal to the radius of the span of the vault.

Finally, by applying the graphostatic method to a conservative theoretical model, it was shown that a vault with the use of terracotta tubes was most stable for a vault thickness value of 20–30 cm, where the thrust line for a given span of 6.16 m (i.e. radius of 3.08 m) can fit within the vault boundaries, and where the value of the height of the load-bearing walls is 3.08 m with a given thickness of 0.91 m. Accordingly, the height of the rooms at the apex of the vault was 6.16 m. Verification of the reconstructed plan of "room 1" and "room 3", considering the degree of damage to the walls and the material remains of the vault, could not be possible without analysing the characteristics of the assembly of the vault and walls. Although a precise reconstruction of these rooms cannot be achieved, the analysis of their static characteristics using the graphostatic method was the most practical way to gain at least a rough insight into their former appearance within "the building with hypocaust".

With this research, we have tried to highlight the importance of findings that are often given little attention, such as terracotta tubes. We have also drawn attention to the importance of architectural analysis in the process of interpreting a series of site problems whose solutions complement the image of a particular structure, its place within the building, and finally the context in which it was applied at a site. In that way, unclear situations can be resolved after archaeological excavations, especially when the buildings have not been fully archaeologically researched, which is the case with "the building with a hypocaust" at *Timacum Minus*. We hope that this case study can be an important reference for future archaeological and architectural research at sites where discoveries of the same type of finds of late antique construction activity, i.e. terracotta tubes for vaults, are possible.

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ОД ЕЛЕМЕНТА ДО КОМПОЗИЦИЈЕ: РЕКОНСТРУКЦИЈА СВОДА ОД КЕРАМИЧКИХ ЦЕВИ ИЗ ТИМАКУМ МИНУСА У СРБИЈИ

Кључне речи. – сводови, цеви за сводове, керамичке цеви, *tubi fittili*, *Timacum Minus*, технике грађења, римска архитектура, касноантичка архитектура, северијански период, југоисточна Европа

Обновом археолошких ископавања античког кастела Тимакум Минус 2019. године створиле су се нове могућности за тумачења његових грађевина које су истраживане пре више деценија. Међу остацима грађевина око античког кастела *Timacum Minus*-а посебну пажњу привлачи делимично истражен „објекат са хипокаустом", нарочито у погледу његових конструктивних карактеристика. Поред иначе честих античких конструкција хипокауста и зидног грејања, међу остацима ове грађевине уочена је и посебна врста грађевинских елемената – керамичке цеви за сводове. Велика количина откривених цеви указала је на то да је ова грађевина заиста имала сводове израђене од њих.

Иако је појава цеви за сводове приликом истраживања античких локалитета на тлу југоисточне Европе регистрована, она није довољно документована, као што ни сама функција цеви често није препозната. Један од разлога за то јесте недовољна упућеност истраживача у специфичне карактеристике цеви за сводове и њихову функцију, услед чега се оне мешају са водоводним цевима, тубулусима или калемовима везаним за зидно грејање – будући да сваки од тих елемената припада керамичким производима који су намењени грађевинарству.

У раду су разматране карактеристике цеви за сводове на Тимакум Минусу, као и контекст у коме су пронађене унутар „објекта са хипокаустом". На основу налаза печата кохорте Аурелије II Дараданорум одређено је да „објекат са хипокаустом" и конструкција сводова од керамичких цеви потичу из III века – у коме је и иначе појава тих сводова широм Римског царства била честа.

Приликом систематизације врста керамичких цеви на Тимакум Минусу посебно је издвојена она које је било највише у „објекту са хипокаустом". У склопу ње је препознат и сасвим специфичан централни елемент који је омогућавао да се два низа цеви на истом правцу, али из супротних смерова, међусобно споје. Тај елемент је дефинисао облик свода којим су биле покривене просторије чију је реконструкцију основе било могуће извршити.

Архитектонске анализе „објекта са хипокаустом", као и карактеристике уочене на самим цевима указале су на то да су просторије биле покривене полуобличастим сводом, изграђеним од лучних вертикалних низова цеви које су у темену биле „закључане" централним елементом. Реконструкција изгледа цеви и начина њиховог ређања уклапа се у хронологију извођења објекта и свода током III века. Даљим статичким анализама дошло се до још неколико сазнања. Показало се да је преко свода морао бити нанесен одређен слој малтерне масе да би дебљина свода досегла оптималну вредност у опсегу 20–30 cm. На основу пропорција објекта које су одређене у његовој основи испитана је висина објекта, где је група случајева такође дефинисана пропорционално. Према нашим анализама, зидови просторија „објекта са хипокаустом" у којима су цеви регистроване могли су досезати висину до 3,08 m, док је висина просторија у темену свода могла бити 6,16 m.

Овим истраживањем покушали смо да укажемо на велики значај појединачних архитектонско-грађевинских елемената, а међу њима и керамичких цеви за сводове, којима се често не придаје довољна пажња. Налази керамичких цеви за сводове у Тимакум Минусу, уз извршене архитектонске анализе, употпуњују слику откривеног „објекта са хипокаустом" из више аспеката. Посебно је значајно дефинисање његове висине, које је веома тешко за античке грађевине профане архитектуре на нашем тлу будући да су најчешће сачуване у приземној или темељној зони. Значај налаза керамичких цеви за сводове у Тимакум Минусу велики је стога што је он омогућио како конкретно дефинисање контекста њиховог налаза тако и реконструкцију облика одређених делова грађевине помоћу тог елемента, што до сада није истраживано приликом анализа античке архитектуре на тлу југоисточне Европе.