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STUDY OF TERRACOTTA VAULTING TUBES FROM A NEW ARCHAEOLOGICAL SITE IN MLAKOU, ALGERIA

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Abstract

Several archaeological excavation projects have been initiated over the last decade at ancient sites in many regions of Algeria. One of the newly excavated sites is referred to here as "Mlakou", a region in the department of Bejaia, Algeria. This paper reports on the unearthing of archaeological and architectural vaults built with terracotta vaulting tubes from the Roman period. The vaulting tube was a widespread construction material in Roman North Africa and was the subject of several studies spanning several Mediterranean countries, though very little of these were from Algeria. Vaulting tubes have been excavated from many sites across Algeria both on coastal sites (Souk Ahras, Setif, Guelma, Tebassa, Batna, Tipaza and Chélif) and deep in the desert (Biskara). The results of this work would contribute to the existing bulk of knowledge on the use and manufacturing techniques of vaulting tubes in Roman architecture. In addition, the study draws a comparative analysis with nine other vaulting tube types in terms of decoration technique, dimensions, shape and location.

Keywords*: Vaulting tubes; Arching tubes; Terracotta tube; Roman architecture; Archaeology*

Introduction

Ceramics in the form of bricks, tiles, terracotta vaulting tube, etc. are found in many ancient archaeological sites as ruins of architectural elements of buildings. The studies carried out particularly on vaulting tubes are varied and related to sites located on the north and south of the Mediterranean coast (e.g., Italy, Spain, France, Turkey, Tunisia and Algeria, etc.), as shown in figure 1. The analysis of data from excavation of these sites suggest that vaulting tubes were widely used in construction of building envelopes of Roman architecture from 3th century BC to 6th century AC [1, 2].

Terracotta tubes are known by many Latin designations such as tubuli, tubulae [3, 4] and Tubi fittili [5-9]. They are also referred to by technical terms including terracotta pipes, vaulting pipes, fictile tubules and ceramic rockets or ceramic bottles [10, 11]. The manufacturing technique of these vaulting tubes is considered common to that of making clay objects. In simple form, the tubes are small hollow clay cylinders with one large open end and a narrow-closed end (the socket), as shown in figure 2a. The building vault curvature is formed by loosely joining the socket of one tube into the larger end of another in series as shown in figure 2b. This then is repeated over several rows to form the depth of the arch. To remove the need for erecting scaffolding and rendering the vault rigid, the tubes were first filled with fast setting plaster so that successive tubes can be introduced in continuous manner to form the arching building structure [12].

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In buildings with elements designed to bear large loads (e.g., large baths in Mdaurouche) or obtain a wide span between the walls, the vault is constructed of two layers of tubes. Once the vault is formed, a layer of thick masonry composed of stiffer mortar and rubble is applied from outside of the arch followed by a finishing smooth mortar later to make the vault waterproof and ensure rigidity of the building elements. A layer of plaster composed of mortar and waterproof tiles 'opus signinum' is also applied on the inside of the arch [13].

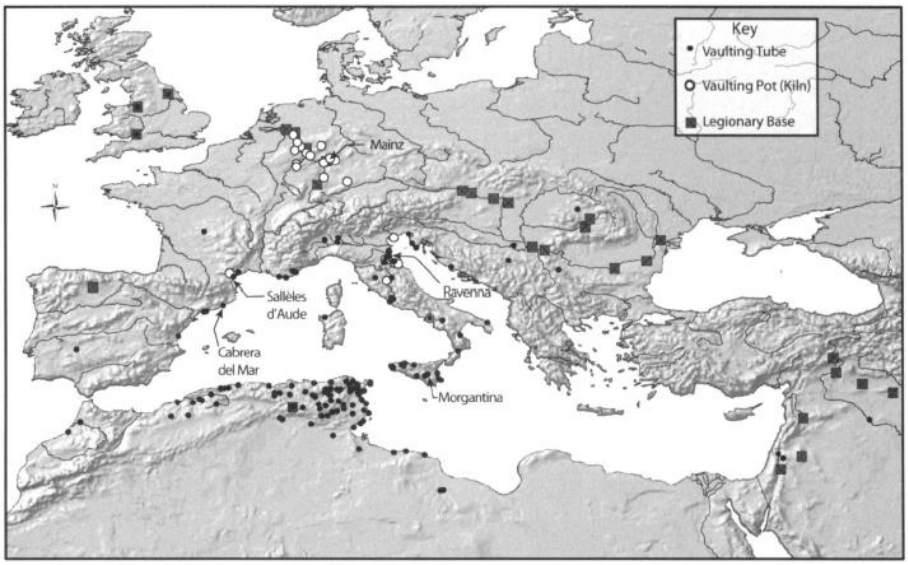


Fig. 1. Map of widespread location of vaulting tubes in Roman architecture [1]

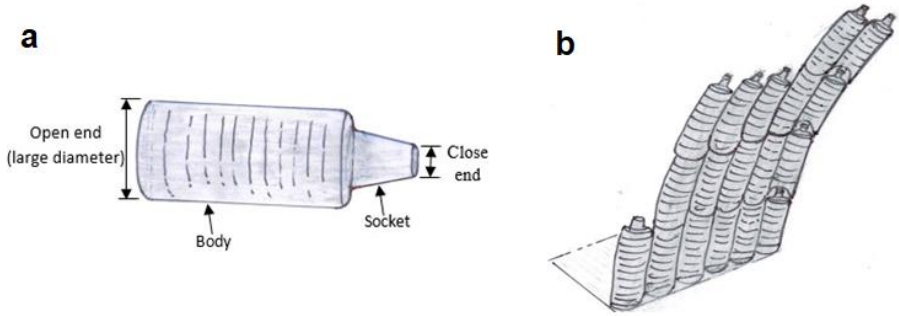


Fig. 2. (a) Schematic diagram of a vaulting tube **(b)** Vault formed of stacked vaulting tubes

This construction technique has several advantages including the speed of erecting the structures and the savings on timber frameworks. This is clearly demonstrated in the construction of roman buildings where vaulting tubes were used in for example Baths of Antonin Caracalla, Diocletian, and Basilica of Constantine (Rome, Italy) [14], the rural estate of Gerace (Enna province, Sicily, Italy) [15] and church of S. Ambrogio, S. Lorenzo and Duomo (Milan, Italy) [16]. In addition, vaulting tubes allow the construction of lighter vault structures and provide sound insulation through the air trapped inside the tubes (e.g., mosque of Ketchaoua, Algiers, Algeria).

Mapping of vaulting tubes sites in Algeria

Vaulting tubes were discovered in many ancient Roman sites across Algeria, as shown in figure 3 [17]. A collection sample of vaulting tubes can be found in museum of Djemila,

Department of Setif. The tubes measure 16.5cm in length and 7.0cm in diameter and the wall thickness of the tube is 0.5-0cm with smooth outer wall surface, as shown in figure 4a [5].

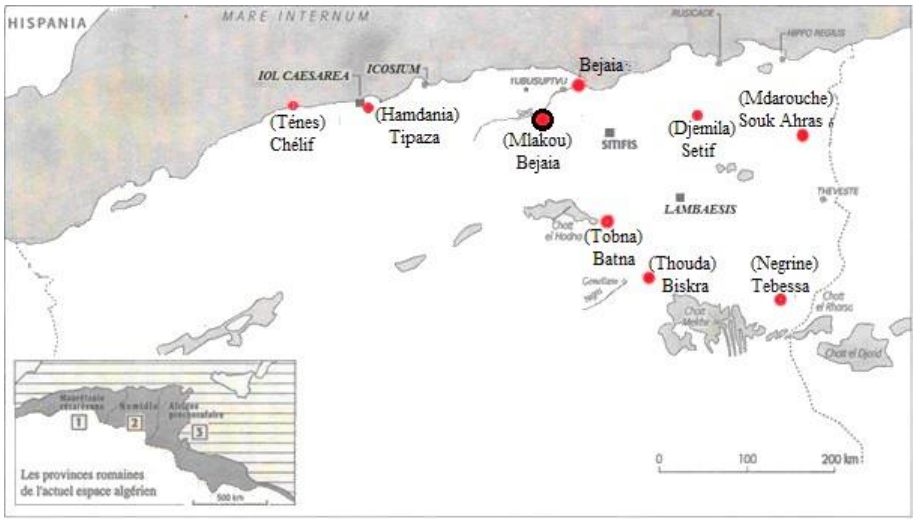


Fig. 3. Map showing the location of sites and deposits of vaulting tubes in Algeria - adapted from source [17]

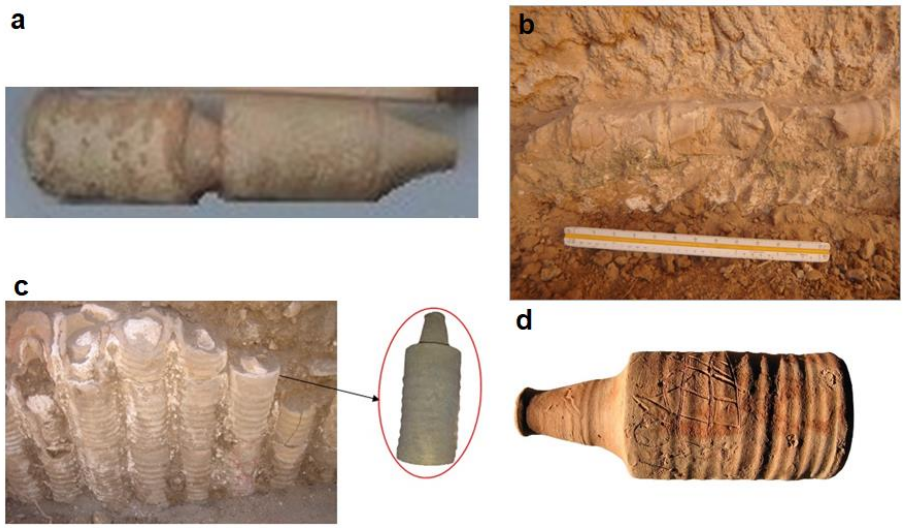


Fig. 4. Type and shape of vaulting tubes discovered in Algeria:
a) Vaulting tubes of the Djemila Museum, b) Vaulting tube of the Tobna site, c) Vaulting tube of the Mdaurouche site, d) Vaulting tube found at port of Ténès [5]

Vaulting tubes were also found at Tobna, the department of Batna, a region characterised by its semi-arid climate. This site formed a Roman military fort built for the surveillance of the southern border of the Roman Empire in North Africa. The vaulting tubes found at this site (Fig. 4b) were part of an inner wall forming the intrados of a vault in a buried bath building. The vault internal diameter is about 1.5m arranged in superimposed in horizontal rows.

In Mdaurouche, Department of Souk Ahras, vaulting tubes were discovered in several Roman public and private buildings dated from the end of the 4th century including a residence of the magistrates and in two water cisterns of the great baths. Figure 4c shows vaulting tubes

used to build water stores of two floors for rainwater collection and the tubes were in the form of vertical parallel lines.

In coastal areas, vaulting tubes were discovered in several sites including El Hamdania, department of Tipaza, Ténès, department of Chélif and unidentified collection is available in the museum of Bejaia (Saldea), which was a Roman colony founded at the beginning of the 1st century BC.

The vaulting tubes discovered in Ténès (Figure 4d) were located in the port of this city, which was an active commercial port in the southern shores of the Mediterranean sea in Roman period. There are no details about the origin or use of the tubes from this site, suggesting that the tubes may had been on transit for export to other cities of Roman Empire [18]. These tubes measure 20.5cm in length and have ridges in both parts (tube body and socket) as well as graphite on the body of the tube, which usually is applied before baking [5].

Vaulting tubes have also been found scattered above the ground on the north west of Negrine site in the Department of Tebessa. The vault structures of the sites are all buried in the sand due to the erosion process of desertification and there is no excavation work of the site. The overall vaulting tubes length is about 11 cm (the length of the body is 6cm and the socket is 5cm) while the outer diameter and thickness of the shard are 5.5cm and 0.4cm respectively.

Similar weather conditions affected vaulting tubes discovered in Thouda, Department of Biskra. There is currently an attempt to excavate the site, which was part of an ancient Roman baths. The vaulting tubes found in the site are of two sizes: the large ones have a length of 17.75cm and an external diameter of 7.5cm while the small one measure around 12.0cm in length and 5 cm in outside diameter with a pointing sleeve of 5cm long. The thickness of the wall of the shard is around 1.0cm.

The recent restoration work of mosque of Ketchoua, Algiers in 2016 shed further light on the use of terracotta pipes in the construction of the mosque vaults and domes [19]. The tubes used in this case do not have a socket for interlocking into one another, but simply stacked onto one another and the open ends of the tubes were plugged with plaster and the external surface smoothed out with a layer of mortar lime. The use of these vaulting tubes for the dome in the Ketchaoua mosque shows that this construction technique has continued to the medieval period in Algeria, drawing a parallel from the best-known example is the construction of the oldest religious buildings where vaulting pipes were used in the construction of Byzantine Churches [14].

Related to this work is the vaulting tubes excavated from Mlakou, Department of Bejaia, which the initial exploration work shows that the site is mainly associated with agro-industry activities and is described in detail later.

Manufacturing process of vaulting tubes

The manufacture of terracotta pipes undergoes a series of stages ranging from choosing the type of clay material, preparation, shaping, drying and baking at high temperature. The clay material is often mixed with sand to give the shell the required strength. The surface appearance of various tubes has a well-backed shard that emits high frequency sounds on a slightest tapping. It was also noticed that although the tube shell surface appears homogeneous, it has scratches and marks that were left on during the shaping and wheeling process. The authors have identified at least nine types of vaulting tubes with varied properties including dimensions, spiral reliefs outside or inside the body of the tube and shape (straight, narrow body in the middle, wide end and an extended socket).

Many authors believe that manufacturing of vaulting tubes flourished alongside the pottery industry in Roman North Africa [7, 9]. The production process may have involved some wheeling mechanisms in mass production workshops set up on or in proximity of the site where kiln space, raw clay materials and biomass fuel (wood) were in abundance. This is because building vaults of the type would require a large number of tubes. For example, the

reconstruction of Bulla Regia vault of 1.75×1.85m needed some 944 tubes while the 17m dome of San Vitale required around 77,000 tubes [1].

The development of vaulting tubes manufacturing into a full-fledged construction industry in North Africa has been hypothesised as due to its simplicity in that the construction of vaults and cupolas with the new material requires only a wooden formwork and a fast-setting binder made of plaster for plating and filling the bodies of the tubes for interlocking successive units [1]. It was also suggested the adoption of the new construction technique was a result of a shrinking forest areas and expansion of farming land, utilisation of wood for heating, industry and other construction applications [5].

Objective

Many works have been published on vaulting tubes from the Roman period originating from North Africa. In this context, this study attempts to add further to the existing body of knowledge in the use of vaulting tubes as a construction material in Roman architecture as discovered in a newly excavated site in Mlakou, Algeria. The excavated terracotta vaulting tubes design, size and materials were described in detail. Furthermore, a comparative analysis was conducted to identify design similarities with other vaulting tubes found in many sites across Algeria. It is envisaged that new materials and design details of the site will be reported in the future as the excavation work progresses further.

Mlakou site

Mlakou is situated in the territory of Akhenak village, some 7km to the East of Seddouk, a local district within the Department of Bejaia. Historically, the Romans established a castle in Mlakou, which was known as Petra. The castle was destroyed and possibly burnt down by the Roman army led by general Théodose who defeated Firmus, a local Chief, in the 4th century AC [20, 21]. The ruins of the site are still present and largely remain buried under ground. The excavation work of the site was initiated in 2015 by the authors following the authorisation of Algerian Ministry of Culture. Initial excavation work yielded many interesting archaeological artefacts among which are built up platforms, crafted stone blocks, clay tiles, pottery fragments, and vaulting tubes. Figure 5a shows excavation team at work while figure 5b shows the current work progress of clearing the top layer of the ground and delimiting the site's borders.

From the onset, it was apparent that the finding of various forms of vaulting tubes resonate with similar construction materials unearthed in other Roman sites in Algeria. This has led the authors to review other published works on vaulting tubes regarding origin, historical and architectural significance. A few publications discussed the existence of vaulting tubes in Roman sites in Algeria, but these were poorly reported and much of the details were missing. The data available on vaulting tubes from six archaeological sites in different parts of the country- section 2 was largely raw with little details.

The excavation work of the site of Mlakou shows that the vaults were destroyed and only a few upward wall structures still standing. In addition, the vaulting tubes collected from this site are of different configurations as shown in figure 6a, b, c and d. Figure 6a shows several vaulting tubes with one on the surface and the rest still buried underground. This type of vaulting tube has a smooth external surface and a short socket with a steep slope from the base to the tip. Figure 6b shows a partly broken vaulting tube with corrugations on the external surface. Figure 6c shows a vaulting tube with a body similar to that of figure 6a but with a longer socket profile. Figure 6d shows a different type of vaulting tube with a spiky socket shape. It can also be seen that the remains of a socket from another tube being fixed with a bonding mortar material. The vaulting tubes show that a high degree of manufacturing craftsmanship and precision may had been adopted as there is little apparent defects on the surface of the tubes.

Fig. 5. Excavation work progress at Mlakou site:
a - A group of students working on the site; b - Arial picture of the excavated site.

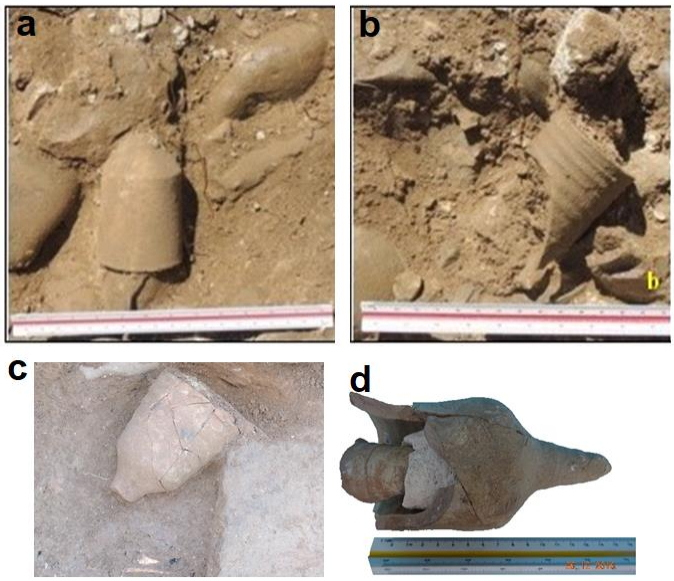
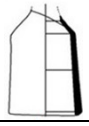
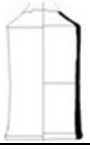


Fig. 6. Excavated vaulting tubes from Mlakou site: a) Smooth surface vaulting tube,
b) Corrugated surface vaulting tube, c) Spiky socket tip vaulting tube, d) Smooth outer surface with longer socket

The diverse typologies and forms of vaulting tubes excavated from Mlakou site and those found scattered in many other sites and museums across Algeria are presented in the Table 1.

Table 1. Comparative typology of vaulting tubes discovered in Algeria

Vaulting tube shape		Name of site	Total length (cm)	Body length (cm)	Thickness (cm)	Large diameter (cm)	Socket length (cm)	Socket end shape/ diameter (cm)
1		Mlakou, Bejaia, Algeria	≈ 17.90	11.90	1.20	10.90	≈ 6	Shape tip/ closed
2		Mlakou, Bejaia, Algeria	≈ 18.90	12.90	0.80	9.40	≈ 6	Shape tip/ closed
3		Mlakou, Bejaia, Algeria	13.80	7.60	0.8	6.20	6.20	Shape tip/ closed
4		Mlakou, Bejaia, Algeria	≈ 18.20	12.20	1.00	9.40	≈ 6	Shape tip/ closed
5		Mlakou, Bejaia, Algeria	≈ 14.90	8.90	0.90	10.20	≈ 6	Shape tip/ closed
6		Negrine, Tebessa, Algeria	11.00	6.00	0.40	6.90	5.00	Bullet tip/ closed
7		Thouda, Biskra, Algeria	17.75	11.85	1.00	12.50	5.90	Shape tip/ closed
8		Thouda, Biskra, Algeria	12.00	6.00	1.00	10.00	5.00	Shape tip/ closed
9		Hamdania, Tipaza, Algeria	≈ 17.50	12.50	1.10	8.00	≈ 6	Open end diameter ≈ 3,20
10	-	Ténès, Chélif , Algéria	20.50	10.50	-	9.50	≈ 6.75	Open end diameter ≈ 3,50
11	-	Djemila Setif Algeria	16.50	9.50	0.50	7.00	7.00	Shape tip/ closed

Discussion

This work highlights the trail of Roman presence in North African and in Algeria in particular through the specific construction material of a vaulting tube that is found throughout the Roman Empire. The paper documents and reports on the topology and configuration of these tubes used as a 'novel' construction material in vaults and arches of Roman buildings. It was shown that the tubes can also be found in many sites across the country's wider geographical area including coastal regions (Ténès, Hamdnai and Mlakou) as well as farther inland (Negrine, Thouda and Tobna).

The unearthing of vaulting tubes at Mlakou site complements existing research works on vaulting tubes found in the region and beyond and provides a tool to compare directly the manufacturing process of the vaulting tubes in terms of raw materials, surface texture, configuration and physical dimensions. Even though most of Mlakou site buildings were destroyed and looted over time, the excavation work points to the use of vaulting tubes in bath arches, residential and farm buildings.

Conclusion

The diversity of vaulting tubes typologies excavated from Mlakou site and found in many other sites and museums across Algeria (Table 1) suggests the existence of several dedicated production workshops and kilns with a highly skilled work force. It is thought that the widespread adoption of vaulting tubes as a construction material speeds up the construction process and gives better rigidity for load bearing building walls.

The excavation work at Mlakou site is on-going and these preliminary results unveil its historical and archaeological significance as a Roman agro-industrial and military complex. For example, the presence on the site of elevated and sloping concrete treading platforms, cascading reservoirs in the form of rectangular, circular and semi-circular vats suggests the building infrastructure is purposefully built to serve an important agro-industrial activity related to oil and/or wine processing, a characteristic of many Roman farm buildings [22]. The site is also strategically surrounded by fertile farming land and linking the east-west and north–south trading routes during the Roman time.

Finally, as the excavation work progresses, it is hoped that the initial indication of the use of the site for agro-industrial production of wine and olive oil in Roman time could further be evidenced.

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References

[1] L. Lancaster, *Terracotta vaulting tubes in Roman architecture: a case study of the interrelationship between technologies and trade in the Mediterranean*, **Construction History, 24,** 2009, pp. 3-18.

[2] M. Moreno Alcaide, J.M. Román Punzón, P. Ruiz Montes, *El uso de tubi fittili para cubiertas abovedadas en la Hispania romana. Revisión bibliográfica y estado de la cuestión*, **SPAL**, **28**(1), 2019, pp. 131-156. http://dx.doi.org/10.12795/spal.2019.i28.06.

[3] M. Bonifay, **Étude sur la céramique romaine tardive d'Afrique**, Bar international, Oxford 2004, pp. 441.

[4] A. Molinari, **Segesta II, Il castello e la moschea (scavi 1989 – 1995),** Palerme, 1997, pp. 149 – 151.

[5] M. Bound, *Tubi fittili (vaulting tubes) from the sea, the Roman wreck at Punta del Fenaio, Island of Giglio*, **International Journal of Nautical Archaeology and Underwater Exploration, 16,** 1987, pp.187-200.

[6] J.G. ROYAL, *The Levanzo I wreck and a reassessment for the distribution of tubi fittili in the central Mediterranean, Tradition and Tansition. Maritime studies in the Wake of the Byzantine Shipwreck at Yassada, Turkey*, **Symposium College Station,** (Texas), 2-4 November 2007.

[7] P. Mills, *The Supply and Distribution of Ceramic Building Material in Roman Britain*, **Late Antique Archaeology, 10,** 2013, pp. 451-469. https://doi.org/10.1163/22134522-12340039

[8] S. Storz, *La tecnica della costruzione delle volte con tubi fittili a S. Stefano rotondo a Roma*, **XLI Corso di cultura sull'arte ravennate e bizantina**, Ravenne1995, pp. 669-693.

[9], R.J.A. Wilson, *Terracotta vaulting tubes (tubi fittili): on their origin and distribution*, **Journal of Roman Archaeology, 5**, 1992, pp. 97-129.

[10] J.P. Adam, **La construction romaine; matériaux et techniques**, édition Picard, Paris 1984, p. 191.

[11] C. Scuro, S. Tiberti, R. Codispoti, G. Milani, R.S. Olivito, *Fictile tubules: A traditional Mediterranean construction technique for masonry vaulted systems*, **Construction and Building Materials, 193**, 2018, pp. 84-96.

[12] C.Scuro, F. Lamonaca, R. Codispoti, D. L. Carnì and R. S.Olivito, *Experimental and numerical analysis on masonry arch built with fictile tubules bricks*, **Measurement**, 130, 2018, pp 246-254

[13] C. Scuro, T. Simone, P. Saverio, R. Olivito, M. Gabriele, *Study of the interface behaviour between fictile tubules bricks and mortar: numerical and experimental analysis*, *in* **IOP Conference Series: Materials Science and Engineering**, 586, 2019. DOI: 10.1088/1757-899X/586/1/012027.

[14] E. Viollet-Le-Duc, **Le dictionnaire d'architecture**, textes réunis et présentés par Hubert Damisch, Pierre Mardaga Editeur, Hermann, Paris, p. 319.

[15] R.J.A. Wilson, T. Mukai, *UBC Excavations of the Roman Villa at Gerace, Sicily: Results of the 2016 Season* **Mouseion-Journal of the Classical Association of Canada, 15**(2), 2018, pp. 219-296. DOI: 10.3138/mous.15.2-2.

[16] A. Galli, L. Bonizzoni, M. Martini, E. Sibilia, *Archaeometric study of fictile tubes from three churches in Milan*, **Applied Physics A-Materials Science & Processing, 92**(1), 2008, pp. 117-121.DOI: 10.1007/s00339-008-4457-7

[17] E. Guernier, *Algérie et Sahara*, **Encyclopédie coloniale et maritime,** (tome1), Ed. Encyclopédie de l'Empire français, 1946, p. 47.

[18] R. Lorenzi, *From the trenches - Roman Ship's Secret Cargo*, **Archaeology**, 65(4), 2012. https://archive.archaeology.org/1207/trenches/rome_tunisia_tubi_fittili_fictile_tubes.html

[19] J. Modot, **Algérie: Guides bleus,** Hachette, Paris 1974, p. 153.

[20] A. Marcellin, **Histoire**, traduction de Guy Sabbah, livre XXIX, V, édition les belles lettres, 1986.

[21] A. Boukhenouf, O. Iaichouchen, *Bilan partiel de la fouille de Mlakou –Bejaia*, **Acte du IIe colloque national,** Université de Chélif, Revue n°14, Institut d'archéologie, Université Alger 2, 2016, pp. 50-60.

[22] J.J. Rossiter, *Wine and Oil Processing at Roman Farms in Italy*, **Phoenix**, **35**(4), 1981, pp. 345-361.

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