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Quantifying Ancient Building Economy

Panel 3.24

Michael Heinzelmann
Cathalin Recko (Eds.)

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Edited by

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PREFACE

On behalf of the 'Associazione Internazionale di Archaeologica Classica (AIAC)' the 19th International Congress for Classical Archaeology took place in Cologne and Bonn from 22 to 26 May 2018. It was jointly organized by the two Archaeological Institutes of the Universities of Cologne and Bonn, and the primary theme of the congress was 'Archaeology and Economy in the Ancient World'. In fact, economic aspects permeate all areas of public and private life in ancient societies, whether in urban development, religion, art, housing, or in death.

Research on ancient economies has long played a significant role in ancient history. Increasingly in the last decades, awareness has grown in archaeology that the material culture of ancient societies offers excellent opportunities for studying the structure, performance, and dynamics of ancient economic systems and economic processes. Therefore, the main objective of this congress was to understand economy as a central element of classical societies and to analyze its interaction with ecological, political, social, religious, and cultural factors. The theme of the congress was addressed to all disciplines that deal with the Greco-Roman civilization and their neighbouring cultures from the Aegean Bronze Age to the end of Late Antiquity.

The participation of more than 1.200 scholars from more than 40 countries demonstrates the great response to the topic of the congress. Altogether, more than 900 papers in 128 panels were presented, as were more than 110 posters. The publication of the congress is in two stages: larger panels are initially presented as independent volumes, such as this publication. Finally, at the end of the editing process, all contributions will be published in a joint conference volume.

We would like to take this opportunity to thank all participants and helpers of the congress who made it such a great success. Its realization would not have been possible without the generous support of many institutions, whom we would like to thank once again: the Universities of Bonn and Cologne, the Archaeological Society of Cologne, the Archaeology Foundation of Cologne, the Gerda Henkel Foundation, the Fritz Thyssen Foundation, the Sal. Oppenheim Foundation, the German Research Foundation (DFG), the German Academic Exchange Service (DAAD), the Romano-Germanic Museum Cologne and the LVR-LandesMuseum Bonn. Finally, our thanks go to all colleagues and panel organizers who were involved in the editing and printing process.

Bonn/Cologne, in August 2019

Martin Bentz & Michael Heinzelmann

Historical Sources, Labour Figures and Ancient Stone Working Costs

Simon Barker – Ben Russell

There can be little doubt that huge amounts of time and labour went into the production of architectural stone-work for ancient building projects, but what can we say about the cost of architectural carving? Occasionally ancient costs of individual architectural elements are preserved, but this is rare, making comparisons difficult.[1] The most obvious response to this problem, of course, is to think of cost not as a monetary figure but in terms of labour input expressed in man-hours.[2] To-date, a considerable amount of research on the economics of ancient building has made use of 19th-century building manuals.[3] This paper highlights a number of issues regarding their application in determining labour figures for Roman stone-working.

First and foremost, it is difficult to retrieve and apply the correct labour constants due to the minutiae of tables, archaic language and lack of explanations. It is clear that Pegoretti's manual, for example, assumes a level of specialist knowledge – i.e. a marble block intended for use in an ashlar wall if sawn at the roughing-out stage (*sbozzatura grossolana*) can pass straight to flat chisel work (*cesellatura*) for fine chisel work or rubbing (*orsatura*) for the first phase of polishing (*pulimento a lucido*); in contrast, a block roughed-out by hand, however, will have to pass through preparatory dressing (*apparecchio o taglio rustico*) with a point chisel and tooth chisel and bush hammer work (*martellinatura o gradinatura grossolana*); equally a block destined for polishing would not be worked with the bush hammer, since it might bruise the stone.[4] These choices would have been second nature to ancient (and post-antique) stone-carvers, but none of this is explained by Pegoretti; however, the inclusion or exclusion of these tasks in generating labour figures can affect the overall economic results.

Equally, the conversion of these labour figures into real data about ancient construction is not straightforward. The resultant man-hours can be converted into *denarii*, for example, using figures provided in Diocletian's Price Edict[5], or other commodities, such as *kastrenses modii* (KM) of wheat.[6] Here, labour costs can meaningfully compare the approximate costs of large-scale imperial buildings with other kinds of state or imperial expenditure. DeLaine's total outlay of 12–14 million KM of wheat on building the Baths of Caracalla was relatively small, by one if not two orders of magnitude, when compared to the 44–150 million KM that was paid out annually to the army.[7] A further option is to examine the economic implications of different types of architectural stone-work by examining the labour differentials in order to establish ratios of cost and the economic repercussions of different architectural stone. If we look at the figures for 20, 30, 40 and 50 Roman foot (RF) monolithic shaft in granodiorite we can see the impact of each 10 RF increase – 684 man-days for a 20 RF column, 1,024 man-days for a 30 RF column, 1,368 man-days for a 40 RF column, and 1,708 man-days for a 50 RF column.[8] These figures

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demonstrate that each additional 10 RF added roughly 340 man-days to the carving time in addition to the added difficulties associated with transporting and erecting columns of these sizes. Moreover, an investigation into the working costs of carving column shafts in different materials can reveal the economic impact of the shift from Late Republican temples executed in tufa to the fluted columns of white marble of the Augustan Age to the monolithic granite columns of the 2nd century AD. Using Pegoretti's figures for quarrying, roughing out, dressing and fluting, we see that a monolithic column shaft, 20 RF in length, in tufa would have taken a single carver roughly 48 man-days to complete, while a fluted column in a hard white marble would have taken the same carver 123 man-days. Finally, it would have taken a single carver 684 man-days to carve a smooth granodiorite column. These figures demonstrate among other things that, as would be expected, the different labour requirements between materials are significant. The gap between the costs of these three columns would have been further expanded based on the additional impact of sourcing and transporting these materials, with granodiorite costing a great deal more than tufa or even white marble. In this way, we can readily comprehend the economic impact of the developments in Rome from the mid-Republic with temples, such as Temple C (possibly identified as the Temple of Feronia) in Largo Argentina with its 14 peperino columns, to the marble upgrades in the Augustan period, such as the Temple of Mars Ultor (completed 2 BC) in the Forum of Augustus, or the Temple of Castor in the Roman Forum (AD 6–7), and finally to the spectacular columnar displays of later temples like the Pantheon.

Overall, this paper explores how 19th-century building manuals have been and can be used to better understand the economic implications of ancient construction. This paper, while reaffirming the usefulness of such sources, and consequently, the usefulness of this approach for the quantification of the economics of Roman construction, has also demonstrated some of the failings of these sources. Misinterpretation can lead to erroneous conclusions about the labour and, consequently the costs involved in the production of architectural ornamentation. These manuals, therefore, should be used with caution and alongside other forms of evidence. That being said, 19th-century building manuals in general, and Pegoretti's manual in particular, are important and useful resources for understanding ancient building projects in terms of how they relate to other aspects of the ancient economy and in assessing their broader economic implications.

Notes

[1] On this point, see Duncan-Jones 1982, 64.

[2] For a discussion, see DeLaine 2017. For approaches to labour figures for stone-working, see Barker – Russell 2012.

[3] The key text and standard reference point is Pegoretti 1843–1844.

[4] See Barker – Russell 2012, 87.

[5] Such as the calculations for the marble elements of the Julio-Claudian Temple of Augustus in the forum at Tarraco; Mar – Pensabene 2010.
[6] For this approach, see DeLaine 1997.
[7] DeLaine 1997, 221.
[8] Labour estimates for carving work relevant to the production of a column shaft in man-hours can be found in Pegoretti 1843–1844, 240–336.

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Logistics of Building Processes: The Stabian Baths in Pompeii

Monika Trümper

When Pompeii was buried by Vesuvius in 79 AD, the city boasted three large baths and a series of smaller establishments. The construction of these baths required significant efforts, in terms of logistics, building material and technological skills, especially with regard to the necessary water management, heating system and vaulting. While building processes and construction techniques have received significant attention in scholarship on Pompeii[1], these have not yet been discussed specifically for Pompeian baths. This paper attempts to fill this gap, focusing on the Stabian Baths that were longest used of all Pompeian establishments. They are also the target of a new research project that is being carried out within the frame of the Excellence Cluster Topoi in Berlin and investigates the development, function, and socio-cultural context of the Stabian and Republican Baths.[2] Following a brief overview of the state of research, this paper will discuss preliminary results of the new project. In his monograph from 1979, Hans Eschebach proposed a development of the Stabian Baths in six phases from the 5th century BC to the Imperial period (fig. 1).[3] Eschebach's phase VI includes all of the many building measures carried out in the Imperial period. He did not discuss building logistics and reconstructed phases, which would have entailed numerous major constructional changes. For example, the porticoes of the palaestra (fig. 2: B/C), including the styblobates, drainage channels, columns, and roofs would have been modified and moved repeatedly: the eastern portico four times and the southern and northern porticoes at least twice. Similarly, the many changes of the bathing rooms between his phases IV and VI would have required the extension of two barrel-vaults: by about 4 m in the women's caldarium (fig. 2: IX), and about 1.50–2 m in the men's tepidarium (fig. 2: III). Since the patching of barrel vaults seems difficult, the entire vaults must have been rebuilt when enlarging the rooms.

The ongoing Topoi project has shown that Eschebach's building history requires significant revisions. The baths were only built after 130/125 BC (fig. 2). It is possibly to distinguish three large remodeling phases, dated to the years after 80 BC, when Pompeii became a Roman colony; to the early Imperial period; and to the years after a major earthquake in 62 AD. Inscriptions suggest that the Stabian Baths were built at public initiative and remained public property and responsibility until AD 79.[4]

The building history of the Stabian Baths has been investigated using different methods, including stratigraphic excavation and a comprehensive survey and analysis of all standing remains. The survey of architectural elements and decoration assessed features such as the relationship of walls to one another, differences in materials, mortars, and techniques, and the types of pavements, wall paintings, and stucco decorations. The chronology of building materials and techniques and their significance for providing rough chronologies of Pompeian structures remains subject to discussion.[5] But the combination of different

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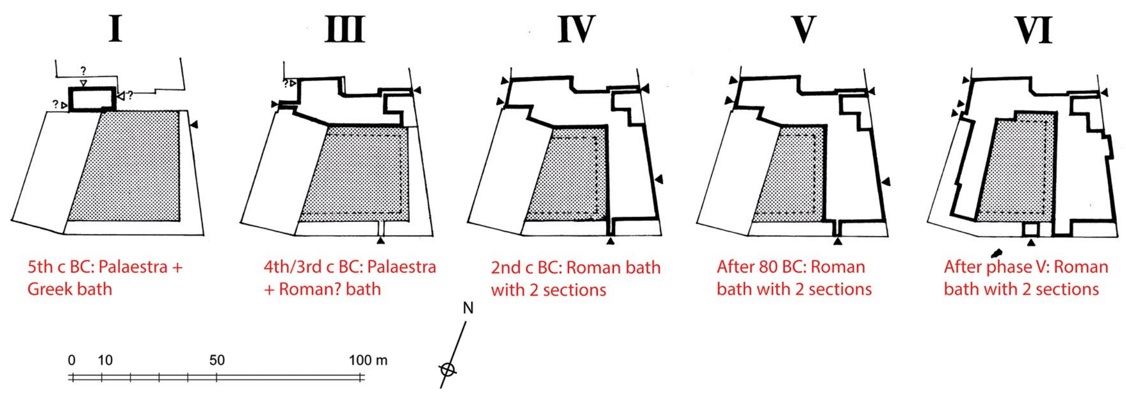

Fig. 1: Pompeii, Stabian Baths, development in 6 phases according to H. Eschebach (phase II is missing here).

methods, particularly including stratigraphic excavation, provides a solid foundation for reconstructing the major steps in the development of the Stabian Baths. Reconstructions also rely on the basic assumption that construction and particularly remodeling measures were planned economically and major changes avoided whenever possible. For various reasons, the building processes cannot be quantified any further, such as providing numbers regarding the required work force and man-hours, or required materials and their costs.[6] Important steps of the building process such as large-scale terracing and digging of foundations were identified in some trenches, but cannot be reliably estimated for the entire building in any of its phases. Standardized, calculable materials were only used in some phases and selected parts of the Stabian Baths. Materials were reused, from earlier phases of the baths and possibly also from other buildings, which makes it difficult, if not impossible, to calculate labor and costs. Finally, the methods and sources used for quantifying the economy of Roman construction remain debated and require a more comprehensive assessment than can be provided here.[7]

This discussion is therefore limited to an evaluation of the following general logistical questions for each of the large four phases of the Stabian Baths: How was the construction site accessed? Which materials (local, regional, imported) and techniques (with or without standardized materials) were employed? Which technologies and skills were required? Decoration is not systematically included because it cannot be fully assessed for the first three phases. It is clear, however, that most rebuilding measures required redecoration.

Construction

The baths were built after 130/125 BC at the southern end of insula VII 1. While they provided separate sections for men and women on a surface area of 2,400 m², the southwest corner of the lot was occupied by a house of 900 m² (fig. 3). Before construction of the

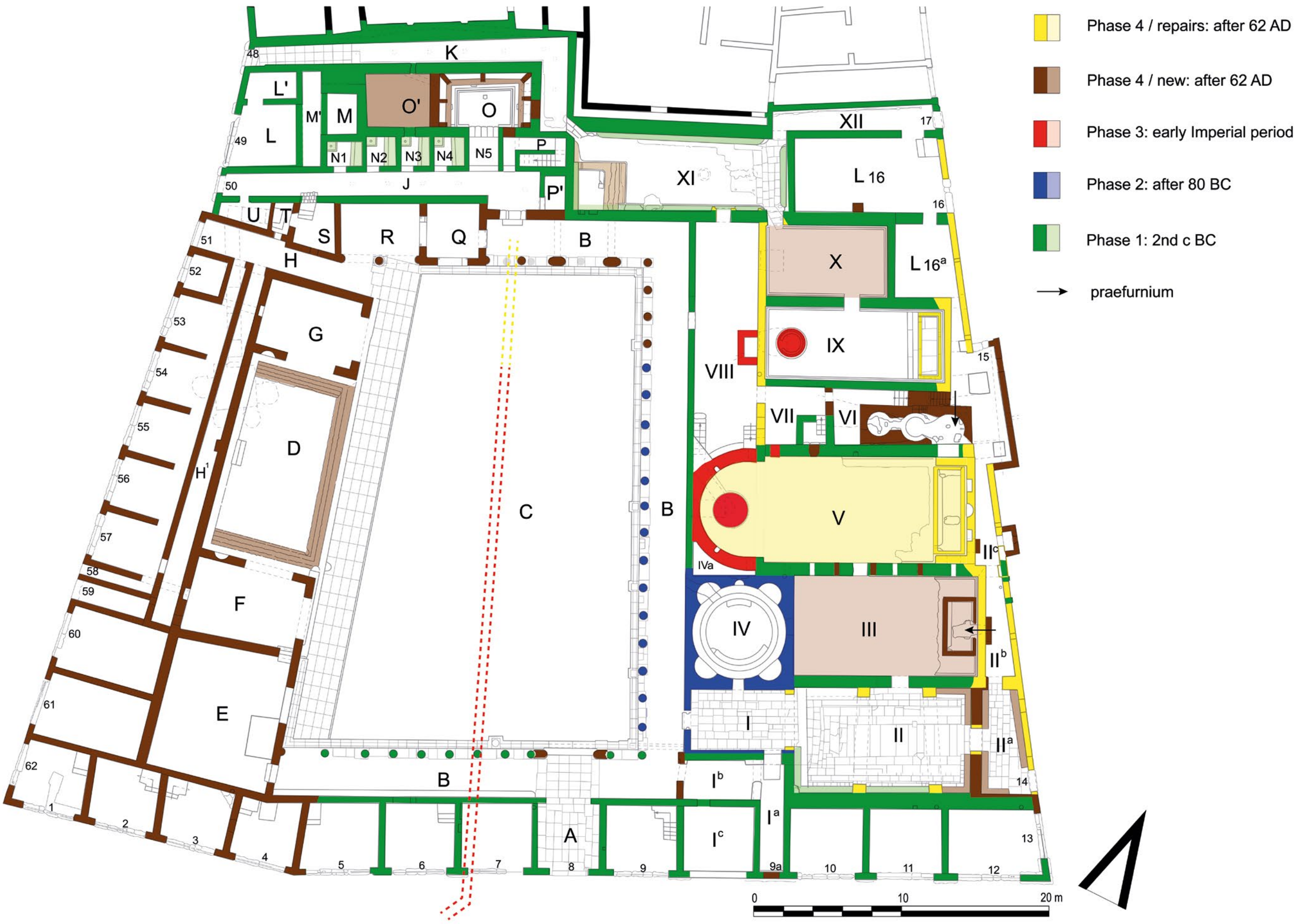

Fig. 2: Stabian Baths, phase plan.

baths, the terrain was barely developed, except for isolated water features. The lot was served by the two major arteries of the city, Via dell'Abbondanza and Via Stabiana. It was freely accessible from the west, south and east, while the lot to the north was already occupied by a house. As the terrain sloped from north to south and west to east, it was first systematically leveled and terraced. Then earth mortar foundations of up to 0.65 m depth were put in place for the major walls of the baths.[8] These earth mortar foundations were wider than the walls built on top of them, protruding for about 20–80 cm on both sides and dug into the levelled ground (fig. 4). The rising walls were predominantly made of opus incertum with locally available material, black lava and cruma di lava. Opus caementicium was also used for the large barrel vaults of the six bathing rooms (fig. 2: II, III, V, IX–XI), which were all maintained until AD 79. Architectural elements with a specific decorative function were made of high quality grey tuff that was quarried regionally, in the Sarno River plain.[9] This is true of the frames of the five entrance doors to the men's and women's sections (fig. 2: Ia, IIb, XII, K, J), large niches in the six bathing

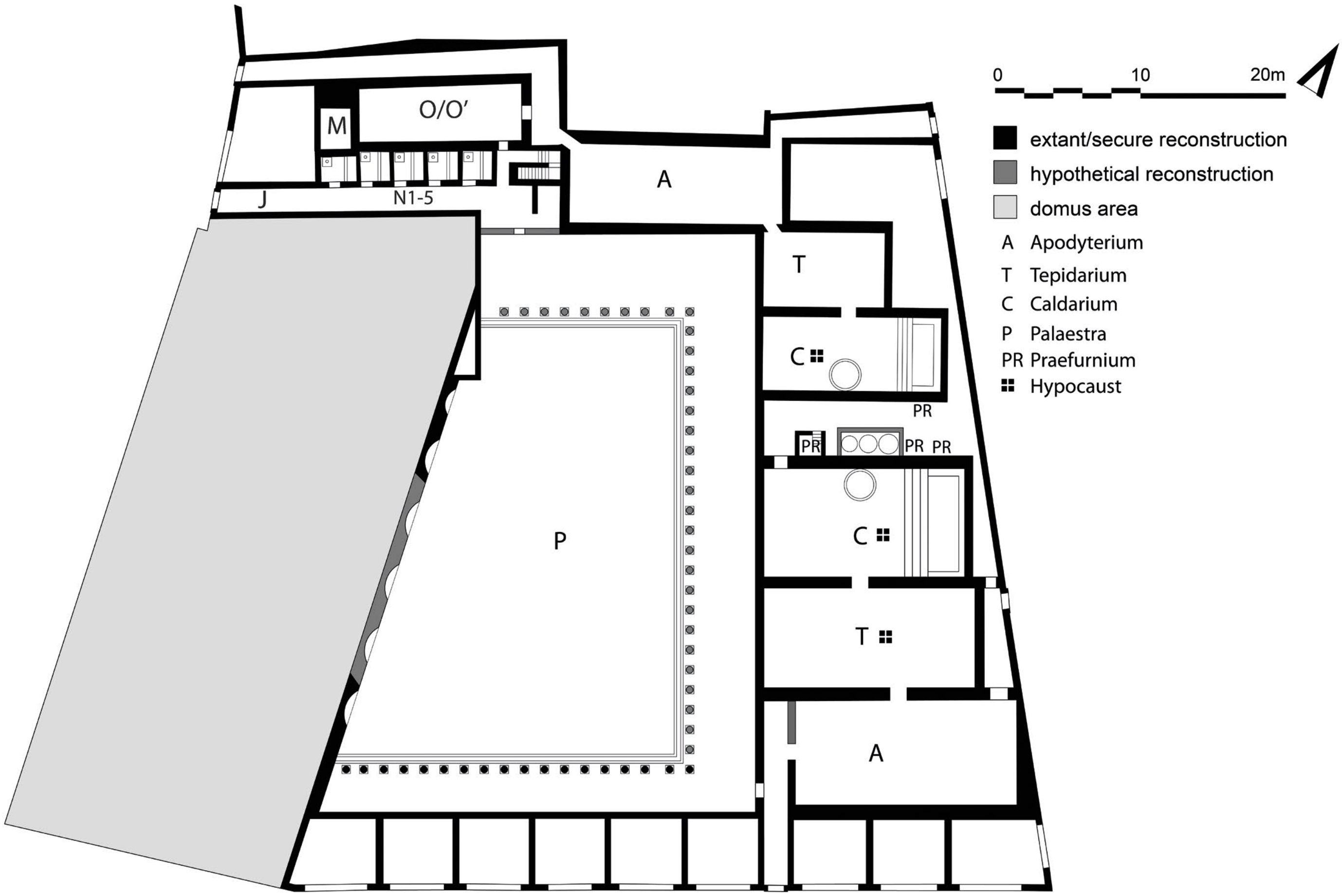

Fig. 3: Stabian Baths, reconstruction of the first phase.

rooms, the columns of the porticoes (fig. 2: B), and the pillars between the tabernae on Via dell'Abbonandza (fig. 2: 5–12).

Excavation and the analysis of standing remains imply a carefully planned, unified building program that also included the deep well and adjacent large water reservoir (figs. 2, 3: M; reservoir on top of O/O'), which constituted a major building effort and expense to ensure the required water supply of the baths.[10] The lot of the house in the southwest corner was obviously defined together with the lot of the baths, but the house was built together with the baths at the earliest or probably slightly later, and would not have blocked access to the site from the west during construction (fig. 3).

First Modernization

An inscription provides important information about the first modernizing remodeling process. It commemorates that "C. Ulius, son of Gaius, and P. Aninius, son of Gaius,

Fig. 4: Stabian Baths, trench in room L16a, earth foundation under the E wall of the women's tepidarium, from E.

duoviri for administering the law, by decree of the decurions, let contracts for the construction of a *laconicum* and a *destrictarium*, and for the restoration of the porticoes and the palaestra, from that money that, according to the law, they ought to have spent on games or in building. They saw to the work and also approved it."[11]

Some decades after construction of the baths, repairs were obviously necessary in two distinct parts, the porticoes and the palaestra. The original building had included porticoes to the east, south and possibly north of the men's courtyard. The term palaestra may refer here to the open courtyard, or the courtyard and porticoes together.[12] Excavation revealed several razed east-west oriented walls in the northern part of the courtyard, which clearly show that this area was remodeled several times (fig. 5). While the chronology of the walls has not yet been fully reconstructed, the northernmost (fig. 5: 1) has cautiously been assigned to the first phase (cf. fig. 3), serving as stylobate, and the central ones (fig. 5: 2, 3) to the remodeling after 80 BC, serving as stylobate and drain. Simultaneously, the eastern portico may have been relocated in this phase for about 3.00 m further west. The original stylobate slabs, columns and entablature of the north and west porticoes could have been reused in this remodeling, but the restoration of the porticoes and palaestra would still have required substantial works, rightly worthy of mention in a dedicatory inscription.

Fig. 5: Stabian Baths, trench in palaestra C, earlier east-west walls and drain, from W.

Eschebach convincingly identified room IV with the laconicum mentioned in the inscription, which was built at the expense of the men's tepidarium (fig. 2: III–IV).[13] The west wall of the tepidarium was demolished and re-erected about 1.00 m further east. The barrel vault was cut in the west, but did not have to be completely rebuilt. Accessibility to the new construction site via one of the two narrow entrances of the men's section (fig. 2: Ia, IIb) must have been difficult. The possibly substantial works carried out in the porticoes and palaestra, however, suggest that more convenient access was provided, for example by removing the back wall of one of the southern tabernae (fig. 2: 7, 8, 9). The required building material could have been stored in the open courtyard of the palaestra. While the well-preserved plaster on most of the inner and outer faces of the laconicum walls prevents full assessment, two features can be observed. First, the laconicum walls were at least partially made of opus reticulatum with cruma di lava, thus reflecting a change in available building techniques and a step towards standardization. The conical dome of the laconicum, a daring technical endeavor at the time, was made of opus caementicium. Second, the partition wall between the laconicum and the tepidarium was made of opus incertum with black lava and clearly reused material of the earlier tepidarium west wall including the blocks of grey tuff that framed the large upper niches of a frieze with double niches. In addition, the facing elements of the original incertum wall, as well as the rubble aggregate of its core, could have been recycled for the aggregate of the new wall.[14]

As the remodeling program of this phase was clearly confined to parts of the men's section, the women's section could easily have continued in use.

Fig. 6: Stabian Baths, E façade rebuilt after AD 62 with frames of fired bricks, from SE.

Connection to the Aqueduct

The connection of the baths to the public aqueduct enabled the development of bathing forms that required running water: a cold-water pool was created in room IV, transforming the laconicum into a frigidarium; two large labra with central fountains were set up on the western sides of the two caldaria (fig. 2: V, IX). While the women's original labrum was simply moved from the south wall to the west wall, the men's caldarium was extended with an apse for a new labrum by razing the original west wall. The daringly large apse was made of opus incertum with lava and sarno limestone and connected to the existing barrel vault. The connection between the original north and west walls and the apse was strengthened with fired bricks (opus latericium). The heating system in both caldaria was completely renewed, with partial use of standardized material: bessales for the pilae, bipedales for the floor above the pillars, and tegulae mammatae for the wall heating, while the floor of the hypocaust system consisted of roof tiles.[15] The socle of the men's labrum confirms the, admittedly sparse, use of fired bricks in this phase.

The building material required for these transformations could again have been stored in the courtyard, which was clearly affected by the remodeling process. A large drain, covered with an opus caementicium vault, was built in the center of the courtyard (fig. 5: 5). It ran under the back wall of taberna 7, which could have served as main access to the construction site. The southernmost of the east-west walls in the northern part of the courtyard may have been built at this time, running over the newly built large drain. This suggests yet another remodeling of the northern portico (fig. 5: 4).[16] This was correlated with major changes of the courtyard's west wall and of the adjacent house, which was significantly remodeled, if not built in this period.

The third phase saw more important remodeling than the second and certainly required a complete shutting-down of the entire baths.

Earthquake Damage and Luxurious Renovation

After the baths and adjacent house had been significantly damaged during the earthquake of AD 62, the baths were repaired (fig. 2: yellow) and received new features (fig. 2: brown). The eastern façade and the eastern walls of most bathing rooms were largely rebuilt, from foundation level upwards, in opus incertum with mixed local materials and with the use of fired bricks to strengthen door and window frames as well as corners (fig. 6). The western walls of some bathing rooms (fig. 3: X–XI) were only rebuilt in the upper part in order to install large windows, again framed by bricks. The endangered vaults of the men's apodyterium and caldarium (fig. 2: II, V) had to be supported with brick arches, but otherwise remained intact. The vault of the apodyterium was also shortened in the east for the installation of a new vestibule (fig. 2: IIa).

Newly built features significantly contributed to enlarging and improving the baths (fig. 7). New heating systems were installed in both tepidaria, including floor and wall heating now completely made of standardized material (fig. 2: III, X). A new cold-water pool was installed in the women's apodyterium (fig. 2: IX), and a new warm-water pool in the men's tepidarium (fig. 2: III). The increased bathing standard also required a new praefurnium and furnace with three cauldrons (fig. 2: VI). All of the mentioned features were made entirely of fired bricks.[17]

The most significant modification was the complete demolition of the house, whose walls were razed to make room for a luxurious new addition to the baths: a large natatio flanked by two grotto-nymphaea and tabernae in the south and west. While the natatio was dug down deep below the floors of the house, the other features were built right on top of the razed walls and pavements of the house.

In this phase, the courtyard must have served as a major construction site. Large quarry pits were dug everywhere in order to access volcanic ash, which was particularly useful for making concrete.[18] These pits were then filled with building debris, probably from the structures destroyed by the 62 AD earthquake. Other material was reused in the partially remodeled courtyard, such as a Doric column of grey tuff that was transformed into a drainage channel (fig. 8). The main entrance to the men's section was transferred to a large taberna (fig. 2: 8/A) and monumentalized in correlation with the northern portico of the palaestra, which was only now moved to its current position. The large

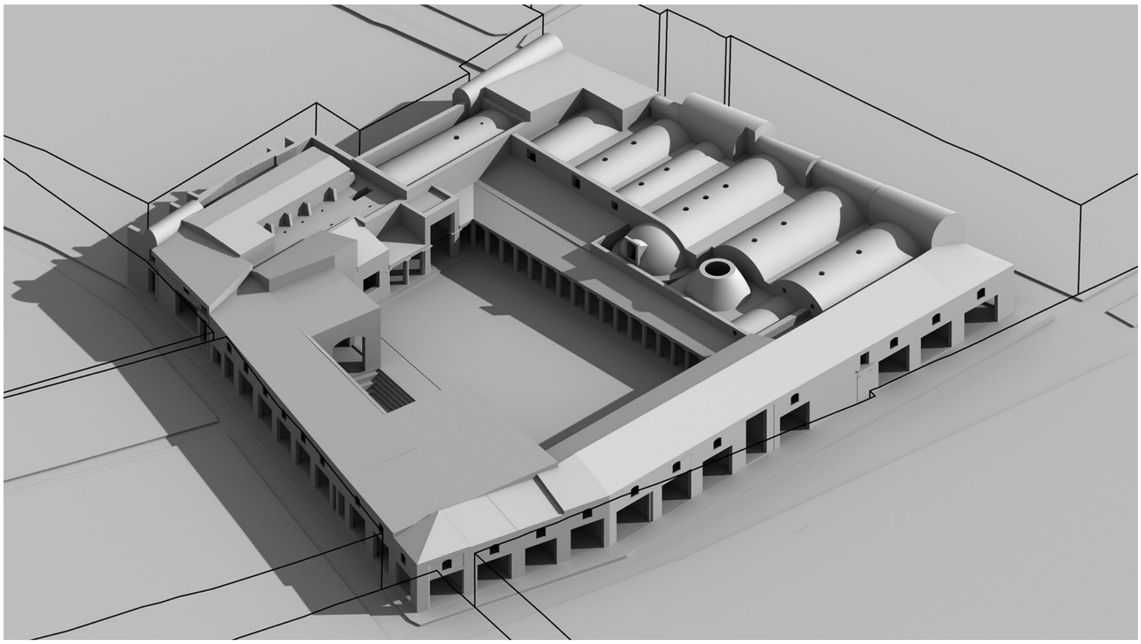

Fig. 7: Stabian Baths, 3D model of the baths after AD 62.

main drain in the courtyard had to be repaired in its northern part (fig. 5: 6), and it now needed to receive wastewater from a large newly built latrine (fig. 2: O).

The new natatio-nymphaea-tabernae complex included opus latericium and opus vittatum mixtum with fired bricks and small tuff blocks, but was still mainly made of opus incertum with local material, such as lava, sarno limestone and cruma di lava. The distribution of latericium and vittatum mixtum suggests that opus latericium was the more durable higher quality technique, used for the corners of the whole complex and features that had to resist water and heat. This phase also entailed a unified redecoration program with stucco decorations, wall paintings, opus tessellatum mosaics, and marble that was not locally available, but used quite abundantly for covering floors, pools, and walls.

Accessibility in this phase must have been easy because large parts of the eastern walls and the entire southwestern section were demolished. The baths must have remained closed during the major construction works, which may also have significantly hindered traffic in the adjacent streets.

Conclusion

If building efforts are evaluated in broad categories, the four building phases of the Stabian Baths can be classified as follows. Construction required the largest efforts, including the preparation of the terrain and the installation of all six bathing rooms with vaults

Fig. 8: Stabian Baths, E portico of the palaestra, Doric drum of grey tuff reused as drainage channel, from W.

(fig. 3). Key features of this original design, such as the position of the southern portico as well as the maximum extension of bathing rooms and vaults, were never changed in the following phases. Remodeling was motivated by decline and damage as well as newly available technologies and fashions. Improvements in the second phase were substantial and included the relocation of probably two porticoes (north, east) as well as the construction of two new vaulted rooms (laconicum, destricatrium). The remodeling of the third phase entailed even more changes, namely in vaulting, heating system, and water management. The fourth phase included a monumental building program that almost equaled the efforts of the original construction phase (fig. 7).

In all three remodeling phases, building measures were mostly, if not entirely concentrated on the men's section. The predominant building technique was opus incertum, used in all four phases with locally available materials. Prefabricated standardized materials were also employed in all four phases, but confined to architectural elements in the first phase and some opus reticulatum walls in the second phase. Fired bricks and standardized elements for the heating system became available in the third phase, and were much more abundantly used in the fourth phase. There is clear evidence that salvaged materials, including the marble slabs utilized for decoration, were reused in the second and fourth phases, similar reuse in the third phase seems probable. Accessibility was excellent for the major building processes in the first and fourth phase, but may have been unfavorably restricted in the second and third phase.

Public ownership of the baths will have facilitated control and regulation of access ways. All building processes were economically planned and carried out, with minimum efforts of rebuilding and reuse of material, which was well hidden by the decoration. Construction sites and related traffic as well as the closing of the

Stabian Baths during periods of renovation must have been noticeable in the urban landscape and life.

Notes

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[1] E.g. Dessales 2015; Mogetta 2016; Giannella 2017.

[2] Three of six campaigns, carried out between 2015 and 2018, investigated the Stabian Baths: <http://www.fastionline.org/excavation/micro_view.php?fst_cd=AIAC_4229&curcol=sea_cd-AIAC_10212> (22.06.2020).

[3] Eschebach 1979.

[4] Sundial with an Oscan dedicatory inscription, dated to 150–100 BC, Vetter 1953, no. 12; CIL 829, dated to after 80 BC; Trümper 2017a, 2017b. For the construction date of the baths, Trümper et al. 2019.

[5] E.g. Mogetta 2016; Anderson 2018, 530 f.

[6] For successful attempts, see DeLaine 1997; Volpe 2010; Bukowiecki et al. 2015; Maschek 2016; Bukowiecki –Wulf-Rheidt 2017.

[7] Barker 2010; Barker – Russell 2012; Russell 2013, 30–35. 228–232.

[8] The depth of these earth foundations could only be determined in one trench in room L16a, with 0.65 m. For the earth mortar, see in more detail Trümper et al. 2019, 143–145.

[9] For the provenance of stones used in Pompeii, Kastenmeier et al. 2010, 2014.

[10] This deep well is commonly identified as an older structure that was incorporated into the baths: Eschebach 1979, 6. 22. 27–31. 52 f. 56 f. 64; Schmölder-Veit 2009, 116 n. 22; 118 f.; discussion of the date in Trümper 2017b, 262.

[11] CIL X 829; translation Fagan 1999, 250 no. 61.

[12] For the use of the terms porticus and palaestra in connection with Roman baths, Taylor 2009.

[13] Eschebach 1973. Remains of the destrictarium, roofed with a barrel vault, were identified in fig. 2: IVa.

[14] Cf. Barker 2010, esp. 131.

[15] This floor is currently only visible in the men's caldarium. The phase plan fig. 2 cannot adequately show all changes carried out in phase 3.

[16] The possible reasons for the frequent relocation of the northern portico and reconstruction of the northern section in the various phases cannot be discussed in detail here.

[17] Further research will show whether these structures were made of locally or non-locally made bricks, and of new or reused bricks; cf. Dessales 2015.

[18] Robinson 2005.

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Fig. 1: M. Trümper after Eschebach 1979, pl. 33a. – Fig. 2: C. Brünenberg after Eschebach 1979, pl. 2; © FU Berlin. – Fig. 3: C. Brünenberg based on plan of the Grande Progetto di Pompei; © FU Berlin. – Figs. 4–5: C. Rummel; © FU Berlin. – Fig. 6 and 8: by the author; © FU Berlin. – Fig. 7: © BTU Lengyel Toulouse.

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The Construction of Pompeii's Sacred Buildings and their Role within the Local Building Industry

Cathalin Recko

The Temple of Isis is a small podium temple located in the theatre district of Pompeii.[1] It has rather narrow front stairs and two annexes on either side of the cella. The plaster is preserved in large parts of the walls' surface, but it is still visible that almost the whole temple is built from brick.[2] According to an inscription, the temple was rebuilt from the foundations up after the earthquake in 62 AD. This paper gives an insight into material estimations for this temple and illustrates with a few simple examples how a comparison with other sacred buildings can help us to understand their economic implications.[3]

Table 1 lists the main building materials used for the temple.[4] Focusing on the sheer volume, the largest amount is 153 m³ of caementicium from the foundations as well as the cores of the podium and the walls. It consists of a mixture of rubble stones and some ceramic fragments bound by mortar. Due to the aggregate's irregularity in shape and size, the aggregate to mortar ratio cannot be measured, but only estimated e.g. with a ratio of 60 to 40%. Further, the aggregate can consist of a variety of stone types and the actual composition can also only be an estimation.[5] A distinction has been made between the opus caementicium bodies of the foundations and the podium and the core of the cella's brick walls. The latter is of limited dimensions and thus, ceramic fragments are better suited to intertwine with the pointed bricks than the large rubble stones usually used as aggregates in Pompeii.

Although carved stone, respectively Nocera tuff in this case, was used selectively, as steps, stylobate and pedestal stones and for the pronaos columns, its total volume of nearly 11 m³ exceeds the overall volume of bricks. It seems that when (re-) building the temple, brick was the preferred building material over stone, as at least some of the stone parts were reused[6] and decorative parts were made of brick instead of tuff.

How do these observations relate to Pompeii's sacred architecture? In total, there are nine sacred buildings in the excavated area within the city-walls of Pompeii. With a ground area of around 80 m², the temple of Isis is a rather small Pompeiian temple and it is the only one having solely brick walls. The so-called temple of Vespasian – also of modest dimensions – has a brick cella, but large parts of the podium are of opus incertum. Further, in the Temple of Fortuna Augusta and the so-called Sacellum bricks are used as quoins for opus incertum walls as well as for niche and podium structures.

Therefore, different approaches to building materials and techniques might be visible here. On the one hand, the temple of Isis clearly favors brick materials over carved stone materials. Whereas other temples show a restricted use of bricks to locations, where their structural advantage can be exploited, i.e. corners and angles. Thus, bricks

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Location	Bulk materials	Volume
Foundations and temple podium	Opus caementicium: • Sarno limestone • Compact lava • Nocera tuff • Mortar Bricks Carved stone (Nocera tuff)	138 m³ 74 m³ (90% of the aggregate) 4 m³ (10% of the aggregate) 4 m³ (10% of the aggregate) 55 m³ (40% of overall volume) 1 m³ (1638 pieces) 7 m³ (104 pieces)
Cella walls	Opus caementicium: • Ceramic fragments • Sarno limestone • Compact lava • Mortar Bricks Carved stone (Nocera tuff)	14 m³ 6 m³ (70% of the aggregate) 2 m³ (20% of the aggregate) 1 m³ (10% of the aggregate) 5 m³ (40% of overall volume) 6 m³ (10.226 pieces) 4 m³ (38 pieces)

Table 1: List of building materials and their volumes from the Temple of Isis in Pompeii.

adopt the role small ashlar blocks formerly inhabited[7] and not the role as main material for constructing walls. One explanation for this might be the high level of flexibility that comes with rubble wall techniques. There are different types of stones common in Pompeii: gray and yellow tuff, volcanic scoria, so called Sarno-limestone, and compact lava.[8] They could be used for foundations, cores, and walls in different compositions, coming directly from the quarry or from reused stone blocks. Opposed to this, there are several processes involved in producing bricks. Further, the production depended on several products, like clay, wood, water, and the production cycles were bound to seasons. This might – in some cases – outweigh the standardized building and structural freedom that characterize opus testaceum.

Based on these observations, material and labour calculations have the potential to further support theories that try to explain the processes and characteristics of a local building industry.[9]

Notes

[1] Blanc et al. 2000.

[2] The surrounding structures show a range of different building techniques, but they are generally not considered in this paper.

[3] The considerations and figures are preliminary results of an ongoing PhD project.

[4] The foundations and all inner parts (caementicium core of the podium and the walls) as well as those parts of the walls concealed by plaster are reconstructed. The roof structure including the entablature has been omitted.
[5] In this case, the estimation is based on a small visible stretch of the foundations beneath the back wall of the podium and on observations made on other exposed wall cores in Pompeii.
[6] The capitals of the pilasters were definitely reused, as they were built in broken and then plastered over. Other stone parts might also very well be reused.
[7] Sacred buildings dating from the 2nd and 1st cent. BC (Temples of Jupiter, Apollo, and Asclepios) mostly have opus incertum walls enclosed by opus vittatum (mixtum).
[8] Kastenmeier et al. 2012.
[9] The method has first been applied to Roman buildings by DeLaine 1997.

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Economic Challenges of Building a *Geländemauer* in the Middle of the 4th century BC: Quantifying the City Wall of Messene

Jean-Claude Bessac – Silke Müth

The term *Geländemauer*, also called a great circuit, usually means a city wall that not only encircles a settlement itself, but also includes a considerable part of not built-up territory, at the same time making defensive use of the formations of the terrain. The popularity of these sizeable monuments in the Greek world from the Archaic to the Hellenistic period[1] forcibly raises questions about the economic challenges they implicated for the cities building them. In order to approach this question, an attempt of quantifying the city wall of Messene, one of the finest examples of the type[2], in terms of material, workforce, time and costs is made against the background of the city's historical situation.

The monument

Messene was founded in 369 BC as the new capital of Messenia by the Theban general Epameinondas after he had defeated the Spartans in the battle of Leuktra 371 BC and thereafter had liberated Messenia from the Spartan dominion, which had lasted about three and a half centuries. Messene was laid out on the south slope of Mt. Ithome, which bore a high symbolic and strategic value for the Messenians.[3] According to Pausanias (4, 27, 5–7), Messene was equipped with a city wall right at its foundation, which is confirmed by archaeological studies: typology, construction details as well as excavation material all point to its construction around the middle of the 4th c. BC.[4]

One of the best preserved Greek fortifications (fig. 1), the city wall of Messene includes a ring wall around the summit of Mt. Ithome, from where it climbs down to encompass the lower town (fig. 2). The northern, western and eastern parts of the fortifications run over the crests and ridges of hills, while the southern section is oriented along the northern side of a gorge. The total length of the circuit is 9,150 m, which include 1,450 m of natural defences where no wall was necessary, so the length of the built fortifications is 7,700 m. The trace of the wall was clearly chosen on strategic grounds: it constitutes the best defensible line around the city. The total area encircled is 360 ha, of which only around 100 ha (28%) were built-up.

The wall is built entirely of stone instead of having a mudbrick superstructure like most contemporary walls. The curtains consist of two stone faces with a filling of earth and rubble stones in between. In a few sections, this filling consists of large layered stone blocks and virtually represents solid masonry. The two faces are connected to the filling by their rough inner surfaces, by stretchers reaching into

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Fig. 1: Northern part of the western fortifications of Messene with tower 11 in the foreground.

it or by compartment walls connecting the two faces. In more endangered areas, the curtains are considerably wider and higher than in steeper and naturally better protected terrain. Large parts of the wall walk are plastered with limestone slabs. The battlements were crenellated all around the circuit, most sectors also including traverses to stabilize the merlons.

There are remains of 46 towers or other flanking structures preserved, but originally there must have been around 80. Distances between them vary flexibly between 26 and 160 m, according to factors of terrain or security. The towers are mostly square apart from two half-round ones and consist of a solid base with an artillery chamber on top. In crucial areas or close to gates, however, the towers are two-storied in order to increase their defensive potential. Only three two-storied towers are preserved, but we can estimate an original number of around 16 on the basis of topographic and strategic aspects. Their roofs were either gabled or shed.

As for the gates, the largest ones – the Arcadian Gate in the north (fig. 3), the West Gate and the South Gate – were designed as courtyard gates with two outer towers and lockable doors at their inner sides[5], the South-West Gate was originally flanked by two towers without a courtyard, the North-West Gate by only one tower, the South-East Gate perhaps by no tower at all, while the Laconian Gate in the east was designed as a tower-gate housing the entrance in its ground floor.[6]

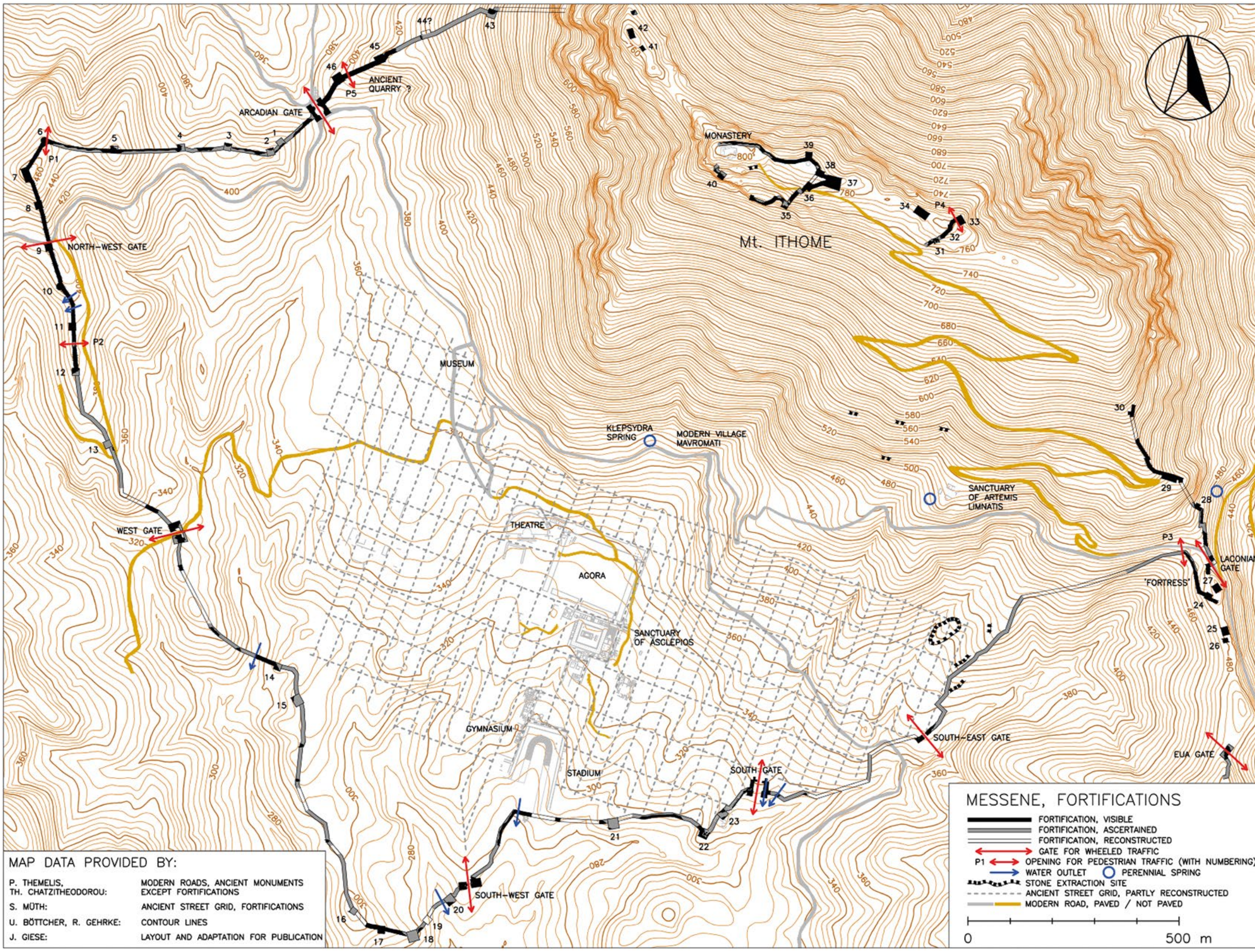

Fig. 2: Plan of the city wall of Messene.

Monumentality versus Efficiency

The circuit includes some heterogeneous elements like differences in construction techniques and typology of curtains, flanking structures, windows, gates and posterns, which indicate the employment of many teams with varying backgrounds and a certain degree of haste in the building process. Moreover, we have already observed aspects of economic planning in the flexible dimensions of curtains and number of tower floors. Also in the choice of material, a stringent economic plan may be observed: the high-quality hard limestone in the well-preserved parts was only used in the north and northwestern parts of the circuit (from the Ithome ring wall to south of T 11), where

Fig. 3: The Arcadian Gate of Messene and the adjacent stretch of wall to the east seen from southwest.

it forms the rocky ground. This hard limestone generates either ashlar or trapezoidal masonry according to the natural characteristics of its deposits (figs. 1, 3 and 8b). In the southeast (from the South-East Gate to T 30), the locally genuine hard limestone with virtually unworkable inclusions served as construction material (fig. 4a). This, however, did not allow for neat joints, so the wall there has largely collapsed. In the southwest and south (from south of T 11 to the South-East Gate) in contrast, a soft psammite (a variety of arenite) was used (fig. 4b). It was easily accessible in quarries south of Messene, could be quarried quickly and generated regular ashlar masonry. On the other hand, this material is prone to weathering and has vanished for most of its parts. Thus, it is obvious that the Messenians did not have time or money to quarry good-quality material for the whole circuit, but always took the easiest accessible variety.

All the same, the city wall of Messene was clearly designed as a strong defensive monument, which was also necessary against the continuous Spartan threat. Furthermore, the wall included various representative aspects like the particularly large double entrances of the main gates, which were chosen rather for reasons of monumentality than the amount of traffic[7], the fine masonry finishing of the Arcadian gate (fig. 3) or the decorative consoles used at its city side and under the lintels of the water outlets in the southern circuit. These features lead us to the conclusion that this

Figs. 4: a. Messene. West corner of T 24 built of hard limestone of mediocre quality with inclusions. b. Remains of the outer face of the psammite curtain south of the West Gate.

city wall was also meant as a monumental symbol, not only of the Theban victory over Sparta, but also of the freedom, independence and common identity of the Messenians.[8]

The defensibility and representativeness of this *Geländemauer* on the one hand and the economic aspects on the other hand indicate that its builders were in a kind of

Fig. 5: a. Extraction sites of hard limestone (marked with A) and course of the wall (pointed line) on Mt. Ithome. b. Extraction site close to the summit of Mt. Ithome with a row of wedge holes.

double bind between monumentality and efficiency and tried to limit the expenses in some way. This leads us to the question, how large an overall investment such a monument meant for its builders.

Quantifying

To estimate the investment of the Messenian wall, the character and amount of the stone material to be quarried, the transport of this material from the quarries to the construction site, the dressing of the blocks, their setting into place and the wood and tile work for second floors and roofs of towers and gates have to be taken into account. These steps have to be calculated in relation to workforce and time, i.e. how long each step took per worker and unit and how many people were employed, in order to estimate the total expenditure and time of construction of the wall.[9] Here, only the stonework as the most important part is considered in detail.[10]

Hard limestone is dominating in the parts of the circuit close to Mt. Ithome, where it outcrops and also serves as the foundation of the walls. It was often quarried on the spot and was normally not transported beyond a distance of 1 km. There are various points of extraction on the hill (fig. 5), sometimes erratic boulders were used and there must have been at least one large, systematic limestone quarry, probably east of the Arcadian gate. In the strata of hard limestone natural fractures facilitate the extraction with a lever. The technical quality of the hard limestone varies heavily: it is mediocre in the southeast of Mt. Ithome, quite good in the northwest and fair in general.

Fig. 6: Detail of the ancient quarry of psammite east of the village of Kalogerorachi (south of Messene).

The closest outcrops of the soft rock called psammite can be found southeast of Messene in a distance of roughly 5 km as the crow flies. We could discover only one ancient quarry close to the village of Kalgerorachi (fig. 6), which is mostly covered but presents a rocky mass without joint or fissure and fronts that prove that large-size masonry blocks have been extracted. The psammite blocks used in the vicinity of gates and in flanking structures often show a chamfer and a regular bevelling around a raw bossage, sometimes featuring a quarrier's mark (fig. 4b), while normal curtains mostly present more cursory faces. Different qualities of psammite can be found: the finest one is particularly used for the flanking structures, whereas the roughest quality used in the normal curtains as a minor variety is a sort of conglomerate composed of small hard pebbles, which are connected by a soft geologic cement. This indicates that different psammite quarries have been exploited at the same time.

The techniques of quarrying can be defined by studying traces on the quarry fronts and on the raw surfaces of the blocks, being mostly grooves caused by the quarrier's pick, while wedges served to break the blocks at their base.[11] In the 1990s,

Fig. 7: Transport routes of the psammite blocks from the quarry south of Messene to the construction sites.

several seasons of restoration and experimental archaeology were conducted in Doura Europos, Syria, using methods and tools similar to the original ones.[12] This allows us to estimate the production time of one psammite block of the average size used at Messene (116 cm × 50 cm × 42 cm) in the quarry at around 3 hours for one man.[13] The transport route for carts between the quarry and the circuit is between 6.5 and 8 km long (fig. 7) and can be estimated at roughly 6 hours, 30 min. including return.[14] If we add waiting times for loading and unloading and care for the oxen, one carter could transport six blocks of a total of 3 tons of weight per day, using six oxen dragging his cart. On the basis of a 10-hours working day[15], this makes 1 hour, 40 min. per block. Another 20 min. have to be added for one man loading and unloading the block.

Also the tools, techniques and time for dressing the blocks of soft rock on the construction site were tested in Doura Europos[16] and can be adapted to the psammite blocks of Messene so that one block would have needed 6 hours 40. For placing these blocks on the wall, two workers would have needed 1 hour and 40 min., which makes 3 man-hours and 20 min. Thus, a total of 15 man-hours was required for production, transport and placement of one psammite block.

As to hard limestone, apart from the naturally fractured strata quarried directly with the lever, quarrying is done by gouging holes and generating a fracture with the help of wedges before the blocks are detached with levers. One block could be produced by one quarrier in 3 hours 30 like this.[17] The general definition of the edges

Fig. 8: a. Experimental dressing of an erratic boulder of hard limestone at Messene by Jean-Claude Bessac. b. Tower 46 at Messene.

of the block is done with an embossing hammer, often in the quarry, but sometimes also on the construction site and did not take more than 10 min. on average for each block.

In order to evaluate the time for dressing hard limestone, practical experiments were conducted on an erratic boulder in Messene in 2006 (fig. 8a).[18] The first step was to remove the rough irregularities of the upper side in a depth of 4 cm in an area of 1 dm^2 with the help of a moil chisel. From this exercise we can calculate 7 hours 45 for a whole block of average size and quality. The other steps included the precise chasing with a flat chisel, which would take 2 hours for a whole block, and the finishing of the anathyrosis at the joints with a pointed chisel, which would take 5 hours 15. The total duration of the dressing of a typical hard limestone block (header or stretcher) may consequently be calculated at ca. 15 hours.

For the transport of limestone blocks, which was done by dragging the blocks on wooden slides, we can calculate an average distance of only 400 m, equivalent to 1 man-hour and 30 min.[19] Placing these blocks on the wall required the same time as for psammite blocks, i.e. 3 hours 20. Thus, the total time for production, transport and placement of one limestone block was 23 man-hours and 30 min.

On this ground, we can venture some total evaluations for the city wall of Messene. Calculating the team sizes according to ideal working procedures and including practical differences between the stone dressing and construction of curtains and towers as well as adequate extra time for the filling of curtains and tower bases with earth and rubble, a two-storied tower of hard limestone, which contained 704 blocks (fig. 8b)[20], would have taken 1,872 man-days or 117 days for 16 workers, and a one-storied tower 1,248 man-days or 78 days for the same workforce. A curtain of hard limestone of an average of 2.20 m width, 4.20 m height, 100 m length and a 2-m parapet would be equivalent to 5,550 man-days or 347 days for 16 workers. A two-storied tower of psammite would amount to 1,287 man-days or 117 days for 11 workers, a one-storied tower to 858 man-days or 78 days for 11 workers, and a curtain of psammite of 2.20 m width, 4.20 m height, an average length of 87 m and a 2-m parapet would have taken 12 workers 265 days, or 3,170 man-days. Looking at the relation between hard limestone and psammite, the use of psammite saves 26.8% of time (or workforce) for the curtains and 31.25% for the towers, which represents a considerable advantage, in spite of the inferiority of this rock in other respects.

For the whole circuit, we arrive at a total amount of 507,335 man-days for the stonework without foundations and special structures. This would mean a minimal time of 325 days or eleven months for a high workforce of 1,565 men, but an optimal organisation would result in 522 men working for 972 days, which is equivalent to two years and eight months.[21] Thus, the total construction time of the monument can be estimated between one and four years, and in consideration of the circumstances of the city's foundation is perhaps rather to be expected on the lower end of this range.

Financial Estimation

It is worth trying to estimate the financial investment, although we are leaving safe ground, as many variables are uncertain. Most importantly, we do not know if unpaid workforce, e.g. soldiers of the Theban and allied troops or parts of the new inhabitants, were available, but as Pausanias (4, 27, 5) explicitly mentions skilled workers having been summoned, we will calculate with paid workforce. The daily salary of a skilled worker on a construction site of the 4th c. BC was two Attic drachmas (dr.)[22], which means a minimum total cost of the stone work of ca. 1,015,000 dr. or 169.2 Attic talents. To this sum, we need to add costs for the carts for the transport of psammite blocks. In the 4th c. BC, a pair of oxen cost around 4 dr. a day[23], so six oxen cost 12 dr. For the total of 17,303 cart days, this would add another 207,640 dr. or 34.6 talents to the costs, which makes a total sum of 203.8 talents, where costs for building the carts are not yet included.

We need to add even more for the construction of transport ways, for special constructions like stairs, gates, posterns and water outlets, for the wall walk, decorative surface treatment of special features, metal clamps, tiles and woodwork for roofs, upper floors and shutters of towers, for lifting machines and leading and organizing personnel. Neither did we include the foundations the fortification had in its southern parts resting on soft ground, as we do not know their average depth. We are certainly not going wrong with assuming a minimum sum of 300 talents everything included.

For a comparison, the costs of the northern wall of the Epipolai of Syracuse with a length of only 5.7 km[24] are calculated by Henri Tréziny at a maximum of 500 talents, although this is based on the probably exaggerated numbers of workmen and carts given by Diodorus.[25] A wall of 7.7 km (like in Messene) would have cost around 675 talents under these conditions, which is more than the double of what we calculated as a minimum. For the rebuilding of the Long Walls of Athens and the walls of Piraeus by Konon in the early 4th c. BC, which were roughly 26 km of (mostly newly built) mud brick wall on a stone base, Tréziny calculates on the basis of inscriptions and written sources again around 500 talents, but without including the greater height of towers, roofs and special buildings.[26] In this case, the much greater length of this wall is partly balanced by the cheaper construction with mud bricks. On these grounds an estimate of 300-400 talents for the city wall of Messene might be quite realistic.[27]

Setting this into relation to religious buildings, a large temple would fall into the same financial category: the seven temples of Selinous can be calculated on average at around 300 talents each, the Alkmaionid and the 4th-c. temples in Delphi at 300–400 talents each and a masterpiece like the Parthenon at 500 talents.[28]

Thus, a *Geländemauer* like the one of Messene is comparable to a major temple in cost and must have meant an extraordinary expense, even more so for a population that just had gathered, that probably did not have many resources and had to build a whole new town on top of this. All the same, this fortification must have been urgently needed for its defence, and we must presume that the Thebans and their allies paid their share for its construction. This vast expense was worth spending, however, and paid off in the end, as Messene was able to persist and thrive over many centuries and Sparta could never lay hands on it again.

Notes

[1] Cf. Winter 1971, 111–114; Garlan 1974, 82; Beste – Mertens 2015, 284–285; Frederiksen 2011, 90.

[2] We had the pleasure of studying this monument with a team of colleagues in the course of a project of the Free University of Berlin from 2004–2008, thanks to the friendly cooperation of the director of excavations in Messene Petros Themelis and generous funding from the Gerda Henkel Foundation in Germany. The publication is in progress (Müth – Bessac, forthcoming).

[3] For more details cf. Müth 2007, 13–18.

[4] Cf. Müth 2010; Giese 2010; Schwertheim 2010; Müth 2014; Giese – Müth 2016.
[5] The West-Gate may be reconstructed like this with some certainty.
[6] For more detailed data on the walls of Messene cf. Giese – Müth 2016. The identification of the Laconian Gate as a tower gate, however, is a new observation by S. Müth.
[7] Schwertheim 2010.
[8] Cf. Müth 2014, 113–115; Müth et al. 2016.
[9] Cf. De Staebler 2016.
[10] The wood and tilework will be included in the final publication, cf. Müth – Bessac, forthcoming.
[11] Bessac 1980, 137–140; Bessac et al. 1997, 167–177.
[12] Cf. Bessac 1988, 297–313; Bessac – Leriche 1992, 72–78; Bessac 1997, passim.
[13] Bessac 1991, 303 with n. 1; Bessac 1996, 312.
[14] Based on calculations by Raepseat 1984, 118–119. 133–134; Vanhove 1987, 284–285.
[15] As the working hours per day have only in recent times been reduced to around 8, a 10-hours working day makes a realistic average for outside work in Mediterranean regions between winter and summer days.
[16] Bessac 1997, II, 244–250; Bessac 2004, 79–89.
[17] This duration has been calculated for the particular limestone varieties in Messene. For comparisons, cf. Bessac 1987, 34; Bessac 1996, 312–313.
[18] By J.-C. Bessac.
[19] Cf. Aladenise 1982, 104 fig. 55. The time calculation is based on own experience.
[20] For this number, the well-preserved tower T 46 served as a model.
[21] It is impossible to present all the details of this calculation in this frame. They will be supplied in Müth – Bessac, forthcoming.
[22] Loomis 1998, 108–115; Tréziny 2001, 373–374.
[23] IG II,2, 1673, 1, 64–89; cf. Martin 1965, 166–167; Loomis 1998, 108–115.
[24] Mertens 1999; Beste – Mertens 2015, 57–60. 255–259.
[25] Tréziny 2001, 373–374, while Typaldou-Fakiris 2004, 302–303 arrives at only 120 talents, which seems, however, to be based on an error (3000 instead of 6000 pairs of oxen) and too low wages.
[26] Tréziny 2001, 372.
[27] As a contrast, new calculations by Fachard et al., forthcoming for the fortress of Eleutherai with a wall length of ca. 600 m and 13 towers arrive at a cost of only 10–12 talents everything included, which would, translated to the 7,7 km of Messene, mean a sum of only 130-156 talents. This shows the high span for such calculations, depending on different variables.
[28] Cf. Tréziny 2001, 376–377; Hellmann 2002, 56; Hellmann 2010, 309–310 with further literature.

Image Credits

Fig. 1, 3, 4 a.b, and 6 by Silke Müth. – Fig. 2 by Silke Müth and Jürgen Giese on the basis of a plan by P. Themelis, Th. Chatzitheodorou, Ulf Böttcher and Ralf Gehrke. – Fig. 5 a.b, 7 and 8 b by Jean-Claude Bessac. – Fig. 8 a by Caroline Huguenot.

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The Energetics of Polygonal Masonry: Building Cosa's Walls

Seth Bernard

This paper presents the results of a field project to model the building techniques and labor costs of the walls of Cosa, the Latin colony founded in 272 BCE. Cosa's walls are the best-preserved example of Italian polygonal masonry outside Latium. Polygonal masonry is otherwise rare in Etruria, and the few other examples are either in a different technique (Roselle, Populonia), are much later (Saturnia), or otherwise may be related to Cosa's walls (Orbetello, Pyrgi). The connection between this Latin building technology and Cosa's status as a *colonia Latina* has been noted before, and the walls thus offer important evidence about the introduction and circulation of this building technique outside of Latium and around wider Hellenistic Italy.

Furthermore, the excellent preservation of the fortifications, as well as their sound date due to ceramic evidence dating to the 3rd century, has given the wall a prominent place in debates over the early colony's nature. Following his seminal excavations at Cosa in the mid-20th century, Brown[1] saw the solidity and massiveness of the fortifications as a signal of the permanent impact of Roman colonial power upon this region of Etruria. More recent work by Fentress[2], Bispham[3], and others revises this view of Cosa's earliest history, seeing the initial colonial effort as one brief and short-lived moment in the discontinuous history of Cosa over the *longe durée*. In this case, an assessment of the cost of Rome's initial investment in Cosa's fortifications takes on importance in our wider understanding of the mid-Republican colony and the expansion and stability of early Roman imperial power in coastal Etruria.

Modeling the labor costs of Cosa's polygonal masonry presents different challenges than serial techniques such as brickwork and ashlar; however, close technical study shows a systematic logic supportive of quantitative modeling and helps reconstruct the *chaine operatoire* of the walls' manufacture. The study employs data from the construction-estimating manual of the Milanese railroad engineer Giovanni Pegoretti[4] to reconstruct the time-costs of assembling the walls' polygonal masonry. Importantly, Pegoretti formed his calculations based on the 19th century walls of Verona, built in a dry-set polygonal masonry of limestone blocks only a decade or so prior to the publication of his work. This gives a solid basis to the resulting calculation.

In order to understand what sort of burden the walls' construction put on the early colonial population of Cosa, I model the overall flow of household labor in a colony of somewhere between 2,500–6,000 male settlers, which Cosa is likely to have contained. The Albegna Valley survey suggests that settlement before and after the implantation of the colony was largely discontinuous, suggesting this was by and large the size of the population responsible for building the walls. Accounting for other significant labor costs on colonists' households, particularly agricultural production, most population

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scenarios nonetheless see the walls having had minimal impact on the labor supply of the early colonial economy. That is, impressive as the monument may seem to us today, it did not represent a significant or burdensome cost to the early colonists. The walls cannot, therefore, be read as a sign of Rome's major investment in making Cosa into a permanent and durable site from its outset. This conclusion needs to be tested by further work incorporating the labor costs of other potential building projects of Cosa's earliest years, including the cisterns and possibly the colonial horreum, as well as the possible involvement of Cosa's settlers in the polygonal walls of Orbetello.

Notes

[1] Brown 1951; 1980.

[2] Fentress 2000.

[3] Bispham 2006.

[4] Pegoretti 1864.

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Ancient Working Processes and Efforts Considering Large-Scale Constructions Made of Timber in Rome

Steffen Oraschewski

One of the biggest problems that appears during the interpretation and reconstruction of the traces of ancient architecture, lies in the circumstance that only a part of the material survives. Even if we talk about monumental architecture as we find it in Imperial Rome, we must not be mistaken about the mass of different types of stones. Just like in buildings of a smaller scale, timber played an essential role in the construction of these monuments.

In this paper, I will be trying to put my attention on three points. Firstly, I will give a short summary of ancient sources concerned about trees and the use of timber to give an idea what kind of knowledge and approach to that material was common during Roman times. The second point is a model, which I would like to propose to work with, including calculations of the types of wood used for certain constructions. After that, I will give two examples from the city of Rome itself. The reconstruction of architectonic elements might give us an idea what amount of timber was used in buildings, which are famous for their dimensions, but especially known for their remnants, which consist almost entirely stone.

Ancient literature on timber

Theophrastus was the first who wrote an enquiry to plants in his "Περὶ φυτῶν ἱστορία" in which he undertook a classification of different trees, plants and shrubs. The most important Roman texts are the books 12–17 of Pliny's "*naturalis historiae*" especially on trees.[1]

In book 16 we learn as an example that fir was considered useful for creating beams of a considerable scale, what we might take as an advice to use it for equal construction plans: "*materia vero praecipua est trabibus et plurimis vitae operibus*."[2]

About the use of timber for building purposes we are being informed by Vitruvius in his work "*de architectura*", in which he describes devices like hoists and cranes.[3] Likewise Pliny, he praises the characteristics of the fir: "*Itaque rigore naturali contenta non cito flectitur ab onere, sed directa permanet in contignatione*."[4] His contemporary Strabo explains the distribution of plants in the Mediterranean area in his "Γεωγραφικά."[5]

Types of trees used for building purposes

Most of the ordinary purposes would require local woods, which should be expected to have been available in the surroundings of Rome. Especially the oak is supposed to have

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played an important role in the building industry, concerning structures of moderate dimensions.[6]

If we try to create a model to reconstruct the ancient building economy of Rome, including aspects like transport, we need to know where the city obtained the material. In that sense, the oak would be representative for all types of local trees that Rome needed for common purposes of a moderate scale. Another kind of timber would have probably been available by the use of beech. The transport would not be far, considering that these kinds of trees should be available in the region of Latium.[7]

However, some architectonic elements could not have been made out of the mentioned timbers. In these cases, Romans had to find other solutions to satisfy the needs for structures like the big tie beams, which spanned over the central nave of the basilicas. The distance to cover reached spans of some 24 m, but regularly more than 12 m. The tree Romans seemed to be using for these purposes was the fir. It grew in the higher areas of the Apennine and delivered the kind of timber needed for big and strong beams.[8] The distance to Rome would differ from at least some 50 km to several hundreds of km.

Another tree with similar characteristics, but more resistant to fire is the larch, which can be found in the Alpine region. There is no evidence, that Romans have used the timber of that particular tree for building purposes before the time of Augustus. And still afterwards fir seemed to be the preferred choice. One reason for that might be the distance, which made the transport to Rome quite difficult.[9] In his work about architecture, Vitruvius laments that very fact: "*Cuius materies si esset facultas adportationibus ad urbem, maximae haberentur in aedificiis utilitates,* […]."[10]

Even the nearest connections to the Alpine region would have required a transport of the material to Rome over the distance of at least 500 km, but in many cases more.

The last aspect leads us to adopt the idea that more exotic timbers like Lebanon's cedar would only be subject of transport to Rome in very special circumstances. In my following thoughts, this circumstance shall be rejected, even in the case of the large tie beams crossing the span of the central nave of Trajan's great basilica erected on his forum.

A calculation of the quantity of timbers used in the roof truss of the Basilica Ulpia

The following bit is an attempt to estimate the quantity of material that was used in the roof truss of the Basilica Ulpia, the biggest basilica ever built. Its central nave had a span of ca. 25 m (or 85 Roman feet).[11] A first step is to describe the single elements of the construction and establish the number needed for each of it.

The biggest problem concerning the reconstruction of an ancient roof truss is an obvious one. No example has survived to our day. Therefore, we need to look for structures that we can at least compare roughly to Trajan's construction. Searching for similar typologies, the early Christian basilicas in Rome seem to deliver the examples

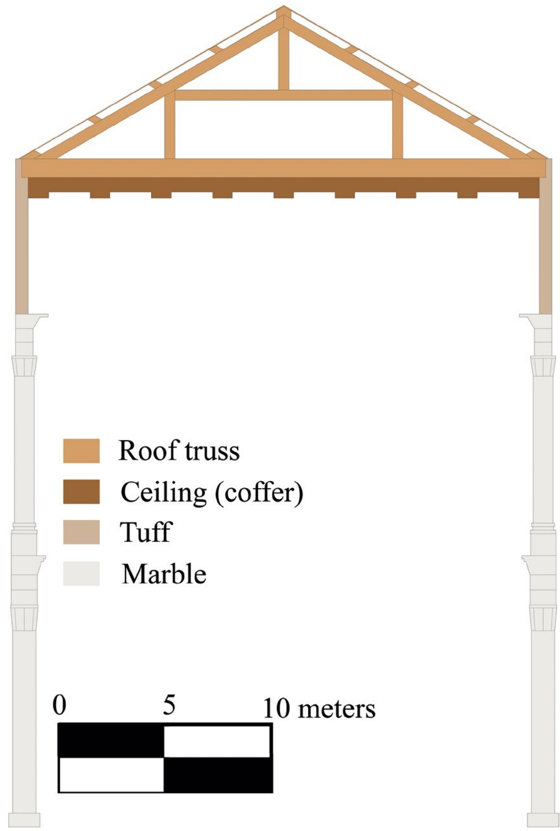

Fig. 1: Reconstructed section of the Basilica Ulpia.

most appropriate. Rodolfo Lanciani was still able to describe the measurements of a tie beam from the original roof truss of Saint Peter's. I shall be content to deal with the value given by him for its thickness, which is 91 cm.[12] We shall also follow the assumption that the beams of the roof truss, like in the Christian basilicas, would have been made out of a single piece.[13] The measurements for the remaining elements of the roof shall be taken from an example of Augustan architecture.

In the case of the forum of Augustus the big surrounding wall has survived in great parts until this day. What makes it a particularly fortunate circumstance, is the fact that many of the structures that were built into the wall itself have left traces of the elements where they connected. The missing blocks, which were refilled in later times in the area of the porticoes, are being interpreted as the imprint of the tie beams and rafters of the roof. Since this hole formed a square of four Roman feet (1.18 m; comprising the end of the tie-beams and rafters)[14], we shall be confident to apply similar measurements for the beams that provided the rafters and the remaining upper structure of the roof truss. Likewise, the imprints of the purlins have survived with a size of 60 cm in section.[15]

A roof truss as shown in the established reconstructions[16] of the Basilica Ulpia should be composed of the single elements as follows* (fig. 1):

Type of structure	Length in m	Width in m	Height in m	Volume in m³
Tie-beams	25.25	0.91	0.91	20.91
Rafters	13.88	0.60	0.60	5.00
Vertical beams (central)	2.83	0.50	0.50	0.71
Vertical beams (to each site of the centre)	3.32	0.50	0.50	0.83
Horizontal beams	10.47	0.50	0.50	2.62
Rows of Purlins	90.00	0.40	0.40	14.4
Roof covering for each half of the nave	90.00	14.75	0.05	132.8

Table 1: Construction elements of a roof truss (Basilica Ulpia).

- 18 Tie-beams with a volume of 20.9 m^3 each, altogether **376.3 m^3**
- 36 rafters with a volume of 5 m^3 each, altogether **179.9 m^3**
- 18 vertical beams in the center with a volume of 0.7 m^3 each, altogether **12.7 m^3**
- 36 vertical beams to each side of the center with a volume of 0.8 m^3 each, altogether **29.9 m^3**
- 18 horizontal beams with a volume of 2.6 m^3 each, altogether **47.1 m^3**
- 10 rows of purlins along the length of the nave with a volume of 14.4 each, altogether **144 m^3**
- Volume of the roof covering: **132.8 m^3**
- Adding all elements together the quantity of timber would add up to a number of **922.7 m^3**

*The assumption being that a tie beam lies above each of the columns around the central nave, the numbers will already have been rounded.

Proposal for a model to work with

If we want to determine the kind of timbers possibly used in a construction like the Basilica Ulpia's roof, there are three groups of the architectonic elements mentioned just before.

The simplest element is the roof covering consisting of wooden planks, which could have been obtained by the use of oak or other local trees.

A second group would comprise all other beams with the exception of the big tie beams spanning the nave. Although in comparable constructions, but on a smaller scale, these elements probably could have been made out of local woods, too, in the case of a large-scale building like the one in consideration, we should assume the need of stronger material.

Following our thoughts in the previous chapter about the types of timber in use for building, the fir seems to be the one to look for. In many cases, roof trusses of porticoes or basilicas of "moderate" scale should have also been made by fir, including the big tie-beams, but in our case, it is to assume that there was still another type of timber used.

The large tie beams, which had to span a distance of ca. 25 m (and therefore be even longer than that), could have been probably made out of larch. But in the case of an Imperial building in the very sense, we might be attracted to the idea that the famous cedars of today's Lebanon would have been imported to achieve the completion of the Basilica.[17] Nevertheless, the use of cedar as a construction material has been classified as unlikely.[18]

Following our model, the distribution of the different types of timber shows up as follows:

- oak (or other local trees) would add up to **132.8 m³**
- fir would take up the largest part of the total amount with **414.5 m³**
- cedar or larch would add up to **376.3 m³**

The numbers seem to suggest that the construction of the roof trusses of the ancient big porticos and basilicas could have been only in a small part operated by local materials.

An estimation for two hypothetical structures made of timber in the Colosseum

Although nothing of the upper parts inside the Colosseum, with the exception of the perimeter wall, survives, it has been generally agreed that the upper standings in the amphitheater would have been made out of wood.[19] Two parts shall be examined in this place (fig. 2).

Firstly, the stairs of the so-called "*maenianum summum in ligneis*" and secondly, its roof following the reconstruction shown by Rossella Rea in the 90's.[20]

The quantity of timber will be calculated for one of the building's sections and then be multiplied by 80. With a single section 6.55 m wide[21] and covering the span equivalent to the outer gallery of the ground floor (5 m)[22], assuming a thickness of ca. 30 cm (one Roman feet), the number can be established at 9.825 m³. For the quantity altogether, we have to consider all 80 sections arriving at some 786 m³ for the ceiling of the upper portico in the Colosseum.

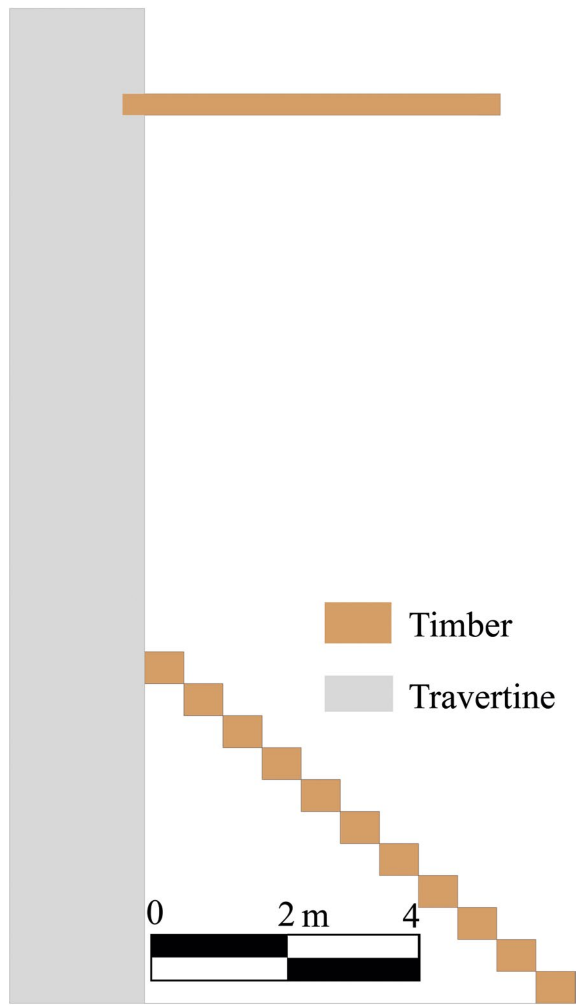

Fig. 2: Scheme of a reconstructed section through the highest ranks of the Colosseum

The second part to be estimated is the amount of timber for the steps of the grandstand. Its understructure will not be considered, as this part would be subject to more difficulties concerning its reconstruction. Van Gerkan proposed a height for each of the eleven steps of 55 cm.[23]

The width of the steps might be taken from a similar structure, which can be found in the steps of the cavea of Domitian's stadium in Rome. Scattered remains of its upper cavea have been found, allowing for a tread of 45 cm.[24] The manner to calculate the amount of timber is to establish the quantity for one step in one section of the building, then multiply it by eleven for all steps in one section. Finally, this number has to be multiplied further by 80 to get the amount for the whole building. Following these steps, we reach 1.62 m^3 for one step in a section, 17.83 m^3 for the eleven steps in one section and about 1,426.59 m^3 for the grandstand's steps all around the building.

Conclusion

In my paper, I have tried to make some considerations about the use of timber in grand-scale constructions in ancient Rome. Even though the exact numbers will always be an object of speculation, it became quite clear that in Rome's big buildings, the use of timber made an important part of the quantity of material that had to be supplied to the city's construction areas. The three examples shown are just a little aspect of all the timber that was used during constructions. Too often, we forget about that fact due to the bad conditions of preservation.

I also tried an approach to the question, what kind of trees would have been used by the Romans for a certain kind of architectonic structure. An intensification of matters like that in the future would be very welcome to our whole field of study. It certainly is helpful to make these considerations and develop them further using the ancient sources as a support, but without being totally dependent on them at the same time.

Notes

[1] Meiggs 1982, 17. 22.

[2] Plin. nat. 16. 18, 42. "But it supplies excellent timber for beams and a great many of the appliances of life".

[3] Meiggs 1982, 30.

[4] Vitr. 2. 9, 6. "It is held together by a natural stiffness, and is not quickly bent by a load, but remains straight in the flooring".

[5] Meiggs 1982, 30–32.

[6] Meiggs 1982, 221.

[7] Meiggs 1982, 219.

[8] Meiggs 1982, 226–227.

[9] Meiggs 1982, 248.

[10] Vitr. 2. 9, 16. "And if there were a provision for bringing this timber to Rome, there would be great advantages in building; [...]".

[11] Ulrich 2007, 149.

[12] Packer 1997, 239 note 48.

[13] Meiggs 1982, 241–242.

[14] Bauer 1985, 233.

[15] Ganzert – Kockel 1988, 186.

[16] Meneghini 2009, 140 fig. 176.

[17] Packer 1997, 241.

[18] Eissing 2011, 15.

[19] Colagrossi 1913, 69.

[20] Rea 1996, 71 fig. 60.

[21] Cozzo 1928, 210.
[22] Beste 2007, 86 fig. 4. 1.
[23] van Gerkan 1925, 39.
[24] Colini – Virgili 1943, 104.

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Considerations about the Cost of the Polychrome Decoration and the Constructive Materials of the Temple of *Divus Augustus* at *Colonia Patricia*

Ana Portillo-Gómez – Manuel D. Ruiz-Bueno

The purpose of our contribution is to share some of the main developments and considerations resulting from a critical research work carried out jointly. Our focus of study has been a monumental complex of *Colonia Patricia* (Cordoba, Spain) known as the *forum novum*. It is one of the most relevant places of Córdoba, the capital of the Roman province of *Baetica*. The *forum novum* is a monumental complex located next to the colonial *forum* of the city. It occupied four *insulae* of a former residential area, which were expropriated at the beginning of the Tiberian period.[1] The discovery of several structures in Calle Moreria 5 in 1998 was the starting point of the study and definition of the topography, architecture and function of this public space. The *forum novum* consists of a square[2] enclosed on three sides by a portico. In the centre, although it is slightly displaced towards the east, a marbled temple was raised. The religious building, located on the axis of the *decumanus maximus*, had 29.6 m (100 roman feet) in width, an approximate length of 45 m and almost 30 m in height (fig. 1).[3]

The discovery of several fragments of the dedicatory inscription of the temple, as well as the study of the architectural, sculptural and epigraphical program of the *forum novum*, has led us to consider that the temple was dedicated to *Divus Augustus*, while the *forum novum* probably served as the provincial centre of the imperial cult in *Baetica*. It is a colossal complex, which could be compared to other monumental complexes with similar size and functionality, such as the Provincial Forum of *Tarraco*, and the so-called "Provincial Forum" of *Augusta Emerita* (fig. 2). These places share close relations in their proportions and sense.

The amount of preserved architectural materials has led us to undertake a quite accurate restoration of the temple. All the pieces discovered have received a detailed study of their size and proportions that have made it possible to estimate the elevation of the temple. It was a temple with an octastyle front a pycnostyle rhythm, a Corinthian order, with columns that reached 16 m in height.[4]

The study of the architectural pieces discovered has revealed to us that different materials were used in the temple. On one hand, the extensive use of Carrara marble to build the outward of the building has been detected.[5] On the other hand, it can be highlighted the use of imported stoned materials from the Mediterranean area. Inside the *cella*, we have Teos marble, *cipollino, giallo antico* and *pavonazzeto* for the columns that decorated the niches, but also, for the *opus sectile* pavement.[6] Moreover, the use of regional stones from nearby quarries to the city such as Almadén de la Plata (Seville), Estremoz, Peñaflor (Seville) or Rodadero de los Lobos (Sierra of Cordoba) has been discovered .[7]

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Fig. 1: *Colonia Patricia* in the first half of the 2nd century AD (left) and the *forum novum* in the same period. 3D reconstructions made by the Sísifo Research Group (University of Cordoba).

Furthermore, it has been detected in several pieces a patina or a primer, but also a specific treatment known as "a gradina". As a consequence, we decided to carry out several analyses to determine the existence of remains from the original polychromity on the elements of the temple. Through the use of the *Visible Induced Luminescence digital imaging* technique, it is possible to detect remains of the pigment known as Egyptian Blue.[8] A synthetic pigment widely used in antiquity to paint sculptures and architectural elements.[9]

The pigment has the property of absorbing radiation and emitting infrared radiation. The technique visualises and detects particles of the pigment that remain invisible to the naked eye, which are captured using a modified camera[10] in an environment of absolute darkness. This technique made the detection of microscopic or submicroscopic traces of this pigment possible, which could appear at its finest (blue colour) or mixed to obtain other colours such as the green (blue + yellow) or purple (blue + red).[11] When this technique is applied, the remaining traces of the pigment react and emit several small luminous points. Regarding the use of gilding, the remains of this decorative technique are usually found under the concretions formed in the pieces as time goes by.

The results of the use of this technique were positive because we found some remains of Egyptian blue on the surface of several pieces of the elevation of the temple such as the column shafts, the frieze and the architrave. These remains reveal their mixture with another pigment. In reference to the use of gilding, it has been detected in a capital fragment, but also in an architrave piece. The capital had traces of a kind of reddish clay known as Armenian Bole or *bolus armena*. This kind

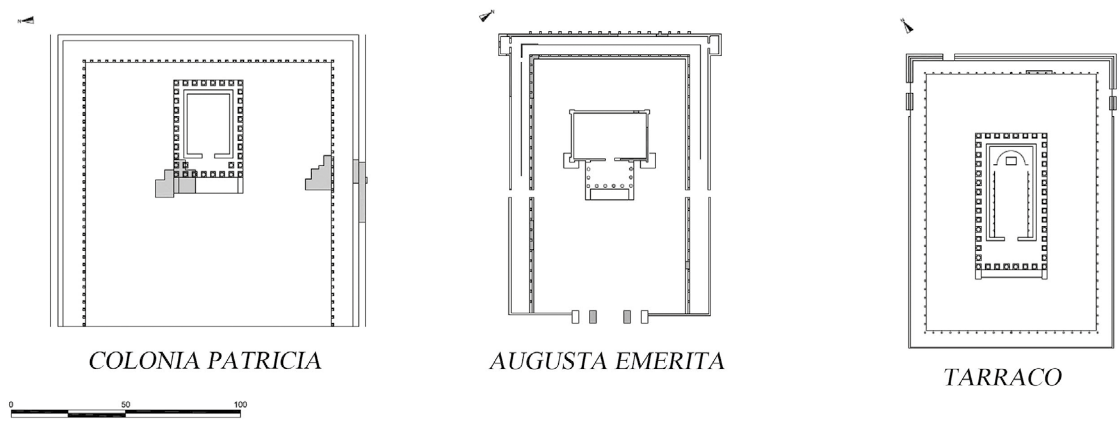

Fig. 2: Comparison of several imperial cult complexes found in *Hispania.*

of reddish clay was used as a preparation ground for gilding and as a technique to provide a warm looking effect to the pieces.[12]

After the hypothetical chromatic reconstruction of the temple, we suggest that the Egyptian Blue pigment was mixed with a type of red pigment, creating the purple colour. Purple is usually associated with wealth and the royalty.[13] This idea makes sense with the ideological meaning of this building. Moreover, this dark tonality creates a contrast in certain areas of the temple that were intended to be highlighted, such as the astragal, standing out as golden necklace, or the frieze, where the dark background makes easier to read the inscription in *litterae aureae* (fig. 3).[14]

As for the polychrome decoration of the temple, the main reliable parallel is the Palatine temple of Apollo in Rome, which has been studied by Stephan Zink and his team. They have carried out several analyses[15] to a set of architectural pieces from the temple such as several capitals, the architrave and the cornice.[16] The study of the capitals revealed traces of a light ochre and a pigment mix of cinnabar and a red bolus, which worked as a preparation ground for gilding. According to Stephan Zink, the temple's colour scheme shows a conspicuous display of both gold and white marble, although other colours were also detected, such as Egyptian blue or red on the cornice. As a result, the largest part of the temple was left untreated in white marble and the colour was used to support specific parts of the architectural design such as the capitals, the architrave, and the cornice.

Regarding the different dyes in antiquity, it goes without saying that the most valued was purple. It was not one colour but rather a wide range of colours obtained from the liquid that could be extracted with a somewhat complex process from two varieties of marine snails: purple (*Murex brandis*) and *buccinum* (*Thais haemastroma*), both native to the Mediterranean coast, and especially, the east coast.[17] The scarce quantity produced by each animal and the beauty of this pigment explains its high value. Moreover, its use was a symbol of a high social status and it was reserved for rulers and high officials.

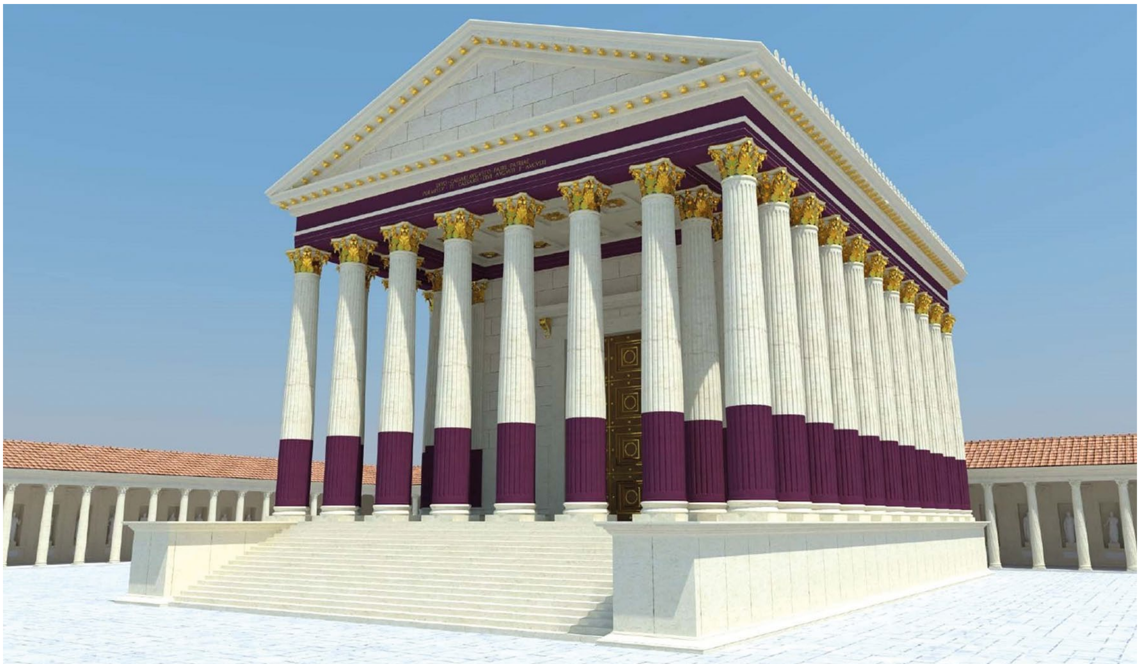

Fig. 3: Colour reconstruction of the temple of *Divus Augustus* at *Colonia Patricia.*

Purple was also a colour associated with the sacred sphere, as shown by numerous literary references from different cultures, which always linked it to temples (Exodus XXXVI, XXXVII, XXXIX).

Purple could also be identified with the figure of the emperor himself in his relation with the imperial power, acquiring the title of "*Divine purple*" and using the term *purpuratus* to designate the legitimate sovereign. The glow of purple and gold also alluded to the sun, linked to the imperial cult through the figure of Apollo and the *Sol Invictus*, a divinity closely linked to Augustus.[18]

The high value of purple led to the search for more affordable alternatives to reach this colour-scheme. One solution was the use of substitutive dyes, which have been registered in numerous literary sources (Stockholm papyrus[19], Pliny, Vitruvius, etc.). These substitutive dyes could be made with pigments of mineral, animal or synthetic origin such as Egyptian blue, mixed with some reddish pigment such as *kermes*, common madder, cinna, cinnabar / vermilion (mercury sulphide) or *minium* (lead oxide).[20]

In the Stockholm papyrus, also known as *Papyrus Graecus Holmiensis*, we can find several recipes to make some dyes, among which the imitation dyes stand out, as it goes with purple. Moreover, there are several recipes to make golden tinctures and yellow varnishes. Finally, both Pliny (Nat. Hist., XXXV, 26 and 45) and Dioscorides (*De Materia Medica*, V-67) mention a series of plants and natural substances from which substitutes of purple were obtained.[21]

Regarding the gilding and metallic colours, the Leyden Papyrus (3rd century AD) is mainly concerned with metallurgy and the production of imitations of gold and silver. In this regard, we have a wide range of archaeological and literary testimonies that show the use of gilding in the monumental architecture. According to Pliny (Nat. Hist., XXXIII, 57), capitals sheathed in bronze were used in the *Porticus Octavia* and the *Pantheon*, while gilt-bronze titles were used in the temples of Jupiter Capitolinus and Vesta. Another Roman historian, Suetonius (Ner. 31) mentions that several parts of the *domus aurea* were overlaid with gold, hence the name, Golden House. Finally, the archaeological discovery of gilded bronze plates belonging to the stylobate of the *Mars Ultor* temple in Rome[22] would confirm these written sources.

Conclusions

In conclusion, regarding the stone materials used in the construction of the Roman temple of *Divus Augustus* of Cordoba, we have noticed that there was a planned program. On the one hand, there are high-cost imported materials from various Mediterranean quarries, which are related to social prestige and the *domus augustea* sphere, as these were the most frequently materials used in the main construction projects of Rome.[23]

On the other hand, these stone, imported materials are combined with other materials of regional origin. Among them, we could highlight the use of several materials due to their quality, chromatic characteristics and aesthetic appeal. Such is the case of some stone slabs used in the floor of the *cella* that come from quarries located in the surroundings of Peñaflor (Seville). These stone slabs have also been detected in other monumental public buildings of *Baetica*[24], such as the Roman theatre of *Italica*. Moreover, other materials of regional origin could have been used due to the extraordinary similarity with certain Mediterranean *Marmora*.[25]

In Cordoba, there is another monumental building known as the cultural complex of Calle Claudio Marcelo, where we have detected the use of other stone materials of regional origin. Such is the case of a stone that comes from the quarries of Almadén de la Plata, whose resemblance to the *cipollino* of Karystos (Euboea, Greece) is truly amazing.[26] Moreover, the use of "nodulosa violácea", that is a limestone of local origin, for the paving of the square, plays a symbolic key role. In fact, the temenos would be demarcated by the purple tone given by this stone, thus distinguishing, through colour, the profane space of the sacred area.[27]

It is also possible that the remains of "supposed *cipollino*" found in the *Divus Augustus* temple of Cordoba, could be a stone material from Almadén de la Plata which is known as "*cipollino* from Almadén". If so, it would be the only possible imitation *marmora* used in the temple. Nevertheless, a detailed petrography analysis is needed to differentiate the regional stone from the *cipollino* of Karystos. The high price of the *cipollino* marble, as it is reflected in the Edict of Diocletian, but also other factors such as the proximity, accessibility and availability of the quarries of Almadén de la Plata, the extraordinary similarity of both materials, and finally, the complex transportation and process of the *cipollino*, could explain the use of an alternative stone material to reduce building costs.[28] However, this hypothesis should be corroborated by the study of the stone material in a laboratory in order to discover its nature and origin.

As for the polychrome decoration of the *Divus Augustus* temple, as it happens in the Palatine temple of Apollo, the chromatic scheme combines the use of painted areas with parts where the marble colour remained visible. In fact, in Cordoba, it is possible that the aim was to highlight only some parts of the temple. As regards the gilding technique, it was used in several surfaces such as stucco (i.e. architectural decoration elements inside the temple of Apollo Sosiano in Rome), bronze, and of course, marble.[29] The use of this technique involves the application of a preparation ground for gilding, as it has been detected by different researchers.[30] In the case of the *Divus Augustus* temple, we were able to identify this preparation ground for gilding in one of the capitals. Moreover, it was able to find remains of gilt under the concretions of part of the architrave. As a result, the use of gilding should have been one of the most expensive costs associated to the building of the temple.

Finally, regarding the use of pigments, we believe that the high price of the purple as a dye, and the large number of purple needed for the pictorial decoration of the temple, led to searching for alternative solutions.[31] In this way, we suggest that the Egyptian blue pigment was mixed with a red pigment, making a precious colour that, together with the gilt, gave the building all the symbolic and ideological connotations related to sacredness and power, and were suitable for a space where people could worship the emperor as a god.

Notes

[1] Portillo 2015a, 75.

[2] The square measures 126.822 m in width by 131.100 m in length.

[3] Portillo 2018, 46.

[4] Portillo 2018, 46–47.

[5] Ventura 2007, 224.

[6] Borghini 2004, 202. 214. 264; Pensabene 2013a, 423–425; Pensabene 2013b, 23–25.

[7] Beltrán – Rodríguez 2010, 565–568.

[8] Verri 2009, 1013.

[9] Liverani 2005, 196 f.; 2008, 66–80; Liverani – Santamaria 2014, 14–16.

[10] A digital camera with a RG 830 filter and without its internal IR cut filter.

[11] *Visible Induced Luminescence* image of reference: Egyptian blue at its finest and mixed with yellow (= green) and red (= purple) from a stucco of the Roman villa of Almedinilla, Córdoba (IPPH).

[12] Portillo 2015b, 181.

[13] Fernández 2010, 278–287.
[14] Stylow – Ventura 2013, 311; Portillo 2016, 33.
[15] The technique used in this building was UV-VIS Absorption Spectometry.
[16] Zink – Piening 2009, 112–114.
[17] Berke 2002, 2486; Bradley 2009, 148–150.
[18] Fernández 2010, 267 ff; López – Dalmau 2007, 110.
[19] Among the main sources of the time that provide information about pictorial materials, it can be highlighted the texts of Theophrastus (4th century BC) and Vitruvius, Pliny and Pedanius Dioscorides, all from 1st century AD. A special mention deserves the Papyrus of Leyden and Stockholm (end of the 3rd century – beginning of the 4th century AD), as both could be considered the first alchemical texts which artistic materials are intentionally mentioned. Both papyri contain numerous recipes; while the first papyrus focuses on metallurgy and describes methods for gilding, plating and colouring metal surfaces; the second contains recipes for dyeing, mordanting and manufacturing artificial gems. Moreover, all these texts have a key role in the history of alchemy.
[20] Porat – Shimon 1998, 81–83; Orna 2016, 43–45.
[21] Fernández 2010, 133–156.
[22] Ricci 1925–1926, 3–7.
[23] Barresi 2003, 151–153; Pensabene 2013b, 14–22.
[24] Portillo 2016, 28–35.
[25] Rodríguez 2009, 233–235.
[26] Gutiérrez 2016, 189–191.
[27] Luzzato – Pompas 2001, 36–38.
[28] Barresi 2003, 151–153; Rodà 2012, 87.
[29] López – Dalmau 2007, 126.
[30] Liverani 2009, 392.
[31] Porat – Shimon 1998, 83 f.; Orna 2016, 43–45.

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Fig. 1: Source: <http://www.arqueocordoba.com>. – Fig. 2: Portillo 2018, lam. 2. – Fig. 3: Portillo 2018, Imagen 3D nº 1.

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In recent years, the study of ancient construction has focused increasingly on putting the different aspects of the process of building into an economic framework. This entailed examining the various steps of construction and the organization of a building site in detail. It also meant that attempts were made to quantify the use of both the materials and the labour necessary for the building project, as these illustrate the scale of a building project and its impact on the overall economy.
The goal of this volume is to bring together different approaches of the study of the economy of building. With the help of methods of quantification and intensive architectural studies, the case studies of city walls, baths, temples and timber buildings in this volume not only shed light on the various constructional characteristics of these buildings, but also on a wide range of economic implications. The collection of papers ranges from Messene in the 4th century BC to Imperial Rome and are completed by practical insights from 19th century building manuals.

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