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Reconstructing the beginnings of Roman concrete

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The character of Roman concrete and its role in Roman construction technology have been topics of keen debate, speculation, and research since the time of Vitruvius, who, for practical or theoretical reasons, expressed some suspicions of concrete architecture (Vitr. *De arch*. 2.8.1, 2.8.8–9, 16–20).[1] Physical examination only began to make a real contribution to the discussion in the last 60 years or so, but advanced analytical techniques have now described the components of both the mortar and the aggregate that make up ancient Roman concrete.[2] Such analysis, however, does not in most cases by itself solve the questions of the chronology of the monuments from which samples have been taken, a particularly crucial problem for the earliest period of the technology in Republican Rome. Progress has been made in ^{14}C analysis of Roman mortars with hydraulic lime binders, but the accuracy may never be sufficient for the fine chronological distinctions needed by architectural historians.[3] This problem of chronology is the starting point of Mogetta's (M.) analysis of the early history of Roman concrete construction on land. He earlier published two substantial articles that form the basis for several chapters.[4] In this book, which originated as a University of Michigan dissertation (2013), he "aims to elucidate the pattern of implementation of that discovery across the constellation of higher-order settlements in the Italian peninsula" (3). This approach relies on careful analysis of the archaeological basis for dating early concrete structures in Rome and elsewhere on the Italian peninsula. M. concludes that concrete construction did not appear as the result of a centralized process in the city of Rome during the 3rd c. BCE, but rather it evolved at several centers in the Italian peninsula during the first half of the 2nd c. BCE. The topics are densely argued and deeply documented, both challenging and rewarding the careful

[1] For a discussion of Vitruvius's motivations, see Rihll 2013.

[2] Examples of relevant studies include Massaza 1998; Oleson and Jackson 2014, 4–5; Jackson et al. 2014; Jackson et al. 2017; Jackson et al. 2018; Marra et al. 2016; Tremsin et al. 2019; Asscher et al. 2020; Dasar et al. 2020; Rispoli et al. 2020; Arizzi and Cultrone 2021; Sağın et al. 2021; Chapkanski et al. 2021; MacFarlane et al. 2021; Seymour et al. 2021; Dilaria et al. 2022; Djerad et al. 2022; Montesano et al. 2022; Secco et al. 2022; and others cited in the book.

[3] Asscher et al. 2020.

[4] Mogetta 2015; Mogetta 2016.

reader. M. may not convince everyone of the simultaneous, independent adoption of concrete at numerous urban centers in Italy, but in this reviewer's opinion his proposals concerning the date for the introduction of this material and the role of elite civilian builders are correct.[5]

In the introductory Chapter 1, "Aims and Methods," M. begins with the dismissal of a standard theory that the technology of concrete resulted from the "incremental accumulation of experience from trial-and-error" as early as the mid-4th c. BCE (2) and that early, unsuccessful experiments simply did not survive for modern examination. There is indeed a paucity of evidence for both domestic and civic architecture (other than temples and fortifications) prior to the 2nd c. BCE, when Rome adapted to her new position as the capital of an empire through intense civic construction and renewed colonization. This historical context fostered the "early experiments with concrete construction" (3). M. confidently asserts that his book "attempts a first synthesis of the new data" (3). He finds that this technology did not result from a centralized process but emerged simultaneously at various places for various local reasons. Not surprisingly, he emphasizes the role of "patrons and builders who had agency" (4). This theory is tied up with the important role of contracts (*locatio conductio operis*) for both private and public construction projects. Since failure to complete a public project could ruin the career of an office holder (usually from an elite family), patrons depended on trusted specialists with significant construction experience. This was the intense environment in which concrete construction technology evolved, as this reviewer pointed out in 2014 regarding the appearance of marine concrete in 2nd-c. BCE Italy. Many of the early concrete monuments were commissioned by the noble *piscinarii* ("fish-pool fanciers"), who built *piscinae* in the sea in association with their elaborate *villae maritimae* along the coastline of western central Italy in the 2nd and early 1st c. BCE. These were members of the political class that fostered, as well, the development of commercial and military harbors executed in pozzolanic marine concrete in the 1st c. BCE.[6]

In this first chapter M. defines concrete as "a mixture consisting of stone fragments (aggregate)…hand-laid in a lime-based binder (mortar) with high-quality hydraulic qualities, and packed into place" (8). The hydraulic properties of the mortar (essentially the ability to set in the absence of contact with atmospheric CO_2, such as in a very thick wall or underwater) were fostered by the addition of a pozzolan such as volcanic ash, vegetable ash, or crushed potsherds, or occasionally by using lime burned from siliceous limestone. Modern scholars often refer to this construction material as *opus caementicium*, after the *caementa* (aggregate) it contains, but the term only occurs once in ancient literary sources. For this reason, M. uses the term "mortared rubble" to refer to rubble with aggregate and clay or nonhydraulic mortar, and "cemented rubble" for rubble set in lime mortar (14–15). In practice, this terminology may be misleading if the character of the mortar/binder has not been determined by laboratory analysis, which is seldom the case with the structures M. considers. In addition, the term "cement" adds the confusing concept of powdered cement, developed in the 1800s, which Romans did not use. He accepts the commonly used terms *opus incertum* for concrete walls faced with irregular blocks of an

[5] As also proposed by Oleson in Hohlfelder and Oleson 2014, 227–35.

[6] Hohlfelder and Oleson 2014, 227–35. M. mentions *piscinarii* and their fish-pools (44) but does not link them with his argument concerning elite involvement with terrestrial concrete.

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approximately uniform size and *opus reticulatum* for walls faced with blocks of a standard size and shape set in a diagonal grid pattern. The latter technique in particular was probably adopted to increase the speed of construction and facilitate the use of unskilled labor. Toward the end of the 1st c. BCE, bricks came into use as a facing material on concrete walls (*opus testaceum*), resulting in even further economies. Scholars such as G. Lugli developed building typologies based on the assumption that *opus incertum* evolved into *opus reticulatum*, which was in turn replaced by *opus testaceum*. This typology was largely followed by Coarelli, and it has remained the standard interpretation, either explicit or implicit, in discussions of Roman architecture.[7]

M., however, undertakes "to deconstruct the arguments underlying the currently accepted sequencing … by acknowledging that different wall-facing styles and building techniques could be in use simultaneously" (23). His redating of numerous public and private monuments from Rome, Pompeii, Cosa, and several sites in Campania and throughout the Italian peninsula (see map fig. 1.1) is usefully tabulated in Tables 1–5. The redating is based on the use of stratigraphic dates harvested through a close reading of numerous excavation reports, use of the contextual method, and rejection of dating based simply on the typology of the wall facing. M. also seeks to uncouple the development of concrete architecture from the city of Rome and to alter the role of concrete as a defining symbol of *Romanitas*, as presumed in some of the earlier scholarship about architecture of the later Republic.

In Chapter 2, "Deconstructing Roman Concrete," M. first reviews how scholarship since the 18th c. CE has tended to see concrete architecture as an expression of specifically Roman attitudes and a symbol of imperial domination. Mommsen, for example, presented concrete as the embodiment of the Roman spirit.[8] M.'s review touches on the contributions of Delbrück, Van Deman, Frank, Lugli, Brown, Coarelli, Rakob, Carandini and Papi, Giuliani, and others.[9] One theme that has continually emerged in the scholarly and popular literature is a "fascination with the exceptional strength of Roman concrete" (29). Although M. does not elaborate, this is a mirage. Research by ROMACONS and other projects has shown that Roman concrete is in fact much weaker in compressive strength than modern cement-based concrete, although it is very durable and has a highly resilient response to processes of weathering, fracture, and chemical action.[10] Most modern concrete architecture simply could not be executed with the Roman material, and many of the surviving Roman monuments – particularly marine structures – were significantly over-engineered, bulked up to avoid potential structural problems that the architects understood empirically but did not have the means to calculate accurately. At the end of the chapter, M. proposes that Cato and Vitruvius imply aristocratic builders have a responsibility to avoid excessive spending on their homes and villas, and that they should foster experienced contractors and technological advances. This sets the scene for M.'s examination of the archaeological record in Chapters 3 to 6, the core of the book. These chapters examine, in turn, the dating and patronage of monuments in Republican Rome,

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7 Lugli 1957; Coarelli 1977; Blake 1947; Blake 1959.

8 Mommsen 1854–56, vol. 1, 23–24.

9 Delbrück 1912; van Deman 1912a; van Deman 1912b; Frank 1924; Lugli 1957; Brown 1951; Coarelli 1977; Rakob 1976; Carandini and Papi 1999; Giuliani 2006.

10 Oleson and Jackson 2014, 10; Jackson 2014, 141–42; 174–85; Jackson et al. 2014; Seymour et al. 2021.

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villas in the suburbs of Republican Rome, Samnite Pompeii, and building in selected Roman colonies in Italy during the Republic.

Chapter 3 focuses on redating the earliest use of concrete in Rome and an analysis of the role of the elite in introducing it and directing this development. After a brief discussion of the sources of building materials in and around Rome, M. turns to chronology, beginning with the problem of the "Testaccio Building." This large structure, near the left bank of the Tiber downstream from the Aventine, constructed of concrete with *opus incertum* facing, was first excavated between 1886 and 1931. The distinctive plan, involving 50 long, vaulted rooms facing the river, resembled a building plan on the Forma Urbis labelled […..]*lia*. Gatti connected this structure with a historically attested rebuilding of the *Porticus Aemilia* in this area in 174 BCE, providing what was subsequently assumed to be an early fixed point for the dating of concrete structures in the city. The substantial and sophisticated design suggested an even earlier starting point for the technology. Recent research, however, has shown that the structure on the Forma Urbis is more likely a ship-shed complex (*navalia*) of uncertain but much later date, in which case this important fixed dating point disappears.

M. then reassesses other structures that were part of the dating canon followed by Coarelli, who depended in large part on an assumed progression of concrete wall facing styles.[11] The analysis of archaeological and literary evidence – too lengthy and detailed to summarize here – runs from the Temple of Magna Mater (Coarelli 204–191 BCE; M. post-111 BCE) to the Porticus Metelli (Coarelli 146 BCE; M. later 130s BCE). M. had the opportunity to incorporate evidence from recent excavations. In the end, he concludes that the earliest evidence for the use of concrete in public architecture in Rome dates to the third quarter of the 2nd c. BCE (69). Appendix 1 contains a handy summary of the dating and building materials of the key structures. M. also highlights the promise of archaeometric analysis of these early mortars. He proposes that by the early 1st c. BCE, the Roman engineers engaged in terrestrial architecture were seeking out deposits of more highly reactive pozzolanic deposits within the city area. Although M. does not mention it, engineers designing marine structures such as fish-tanks and breakwaters in the 2nd c. BCE routinely made use of distinctive volcanic pozzolanas from the region around Naples.[12] One reason for the early selection of this crucial ingredient for marine construction projects is that it could easily be loaded onto ships from quarries near the shore and transported from the Bay of Naples to anywhere along the coast of Italy. As early as 20 BCE, pozzolanic materials were even shipped from this region in enormous quantities for construction of the harbor of Sebastos at Caesarea in Palestine, the first large-scale imperial harbor project.[13] Another 70 years passed before a harbor project on a similar scale was built, at Portus near the mouth of the Tiber.

M. points out that while archaeological evidence for domestic architecture in the later Republic is scarce, recent excavations on the northeast slopes of the Palatine exposed a house with *opus incertum* walls of the mid-2nd c. BCE. Literary sources also suggest that during the mid-2nd c. BCE the elite in Rome decided to renovate their centuries-old ancestral homes in the latest styles and materials. This experience fueled the renovation of public

[11] Coarelli 1977.

[12] Jackson 2014; Appendices 1–4 in Brandon et al. 2014, 238–305.

[13] Oleson and Jackson 2014, 6–8; Hohlfelder and Brandon 2014, 73–81.

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architecture, too, since magistrates "could assign contracts to builders whose skills would have already been tested in private projects, thus minimizing the social and political risks associated with innovating in public architecture" (87). M. makes the interesting point that cocciopesto, a mixture of mortar and ground-up potsherds that had hydraulic properties, was well known to Roman builders but seldom used for large-scale structural application because the potsherd additive was too labor intensive and consequently expensive (89). Volcanic ash was an apparently cheaper and somewhat better alternative.

In the following three, very substantial chapters, M. examines the chronology and properties of concrete construction in the suburbs of Rome (Ch. 4), Samnite Pompeii (Ch. 5), and the Roman colonies in Italy (Ch. 6). There were numerous villas in the suburbium of Rome, many built during a period of increasingly intensive agricultural activity in the 3rd c. BCE. There was a concomitant growth in lime production, which served both agricultural production and building construction. Nevertheless, M. finds that cemented rubble or concrete became the material of choice for rural luxury villas only by the mid-1st c. BCE (123). This change was apparently motivated in part by the desire to execute more elaborate vaulted designs.

Chapter 5 focuses on the development of concrete construction in Late Samnite Pompeii. There is an enormous amount of evidence, of course, at the site, but interpreting the chronology has been difficult. Lugli and others assumed a period of Samnite experimentation with mortars based on local pozzolanic volcanic ash in the later 3rd c. BCE, which the Roman colonists arriving in the region at the beginning of the 2nd c. leveraged into large-scale construction involving vaulted designs. This chronology was based mainly on the "combined analysis of historical dates, construction techniques, and associated building materials" (128). M. uses the archaeological evidence to show the inadequacy of this traditional approach and to down-date the beginnings of concrete architecture at Pompeii to the middle of the 2nd c. BCE, with elite domestic architecture preceding public architecture. The Casa del Fauno and Casa del Centauri are both assigned to 175–150 BCE or later, while the Stabian Baths are attributed to 125 BCE and the Basilica to post-112 BCE. A summary of the redating and materials can be found in Appendices 2 and 3.

M. proposes that concrete architecture appears in the Bay of Naples area about 150 BCE not simply as a response to local volcanic deposits, which did indeed include an abundance of pozzolanic ash, but also due to cultural developments. The new architecture had little connection with earlier vernacular architecture. It was rooted instead in the new cultural and social milieu fostered by Roman imperialism and its expanded horizon (179). M. attributes the appearance of lavish domestic architecture to investment in "self-aggrandizement and self-presentation" by the local elite in the context of intense competition (164). As with Rome, M. emphasizes the importance of private builders hired as contractors to be "the link between public building and private entrepreneurship, and … the mechanism for the technological transmission from domestic architecture to the public building industry" (165).

Chapter 6, "Colonial Networks," has a wider focus and, as a result, features a more diffuse analysis. M. attempts to "characterize the distribution of building techniques at colonial sites that were either founded or resettled during the period in which cemented-rubble architecture made its first appearance at Rome and Pompeii" (183). Twenty-three colonies with Latin rights were founded in Italy between 334 and the late 3rd c. BCE. Little remains of the public and domestic architecture in these colonies other than fortifications and

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temples. At Norba (founded ca. 350 BCE), *opus incertum* architecture appears only at the end of the 2nd c., but in both public and domestic architecture. The pattern is the same for Fregellae (328–313 BCE), although the abandonment of the town in 125 BCE resulted in less evidence for structural concrete. At Cosa (273 BCE), it now seems that the area within the fortifications was thinly occupied until the arrival of a new contingent of 1,000 colonists in 197 BCE, with consequent construction activity. M. sees Cosa as an "ideal testing ground for exploring the relationship between technological innovation and stylistic behavior in the architecture of Roman Republican colonization" (196). He interprets construction of the Comitium (200–175 BCE) and "Capitolium" (175–150 BCE) as projects meant to give "both the designers and the colonists an opportunity to materially shape the collective identity of the colony" (203). Since the introduction of concrete construction might have lowered both overall costs and the ratio of skilled to unskilled labor, M. sees it as a means to integrate the heterogeneous colonist population, in that "structural mortar served as a social glue" (230). This is an appealing metaphor but stretches the evidence.

Around 26 other Latin and Roman colonies were founded in the first half of the 2nd c. BCE, but problems of access and lack of excavations make it difficult to evaluate the spread of concrete architecture in these settlements. M. nevertheless finds some bits of evidence at Luna, Puteoli, and Aquileia. It is interesting that at both Cosa and Luna, local materials were used for the building medium, including the addition of ground terracotta to increase hydraulic properties and strength.

The final chapter of the book provides a brief review and summary of M.'s arguments and conclusions. He emphasizes once again the role of the elite and their dependence on work teams experienced in the use of cemented rubble (concrete), which allowed relatively rapid and reliable construction with local materials, often including recycled rubble aggregate. Pozzolanic mortars allowed the construction of thick supporting walls and vaults that could be relied upon to cure relatively quickly with little shrinkage. The earlier use of cocciopesto in pavements and cistern linings may have led to experimentation with volcanic ash, which was cheaper and easier to prepare than crushed ceramics and, to the Roman mind, similar in origin: an earthy substance transformed by heat. According to M., these developments did not spread out from Rome, and the "Pompeian evidence confirms that concrete construction could surface in different areas as a response to similar needs of elite self-presentation and competition" (235). The new material appears first in domestic architecture, in the mid-2nd c. BCE, and in public architecture possibly only from 130–120 BCE. M. expresses the hope that the book will "provide a useful reference tool for future studies that will apply geochemical methods for the characterization of the composition and physical properties of Roman-era mortars" (242). He also suggests the need for research into the energy needs for lime production as a supplement to calculations of the labor requirements of concrete construction. The book ends with a catalogue of sites in five appendices, a useful glossary of terms, a bibliography, and a well-constructed index.

While this book is a very useful contribution to our knowledge of the development of Roman concrete, it has several serious drawbacks. While M. seems to document well his redating of the earliest concrete structures in Rome and nearby areas, his proposal that the technology itself was invented independently in various locations outside Rome is not clearly developed and seems unproven. The circumstances of the early use of concrete

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by elite individuals using experienced engineers and, to a certain degree, locally available materials seem correct, but both elite administrators and trained engineers could certainly move and carry their knowledge with them.

A larger, more structural issue is the complete omission of marine concrete and the failure to take account of the research of the ROMACONS Project (Roman Marine Concrete Study), whose final report was published in 2014, before M.'s first article on Roman concrete.[14] This project involved the collection of 36 cores of Roman marine concrete at 11 Roman harbors and one *piscina* dating from the 1st c. BCE to the 2nd c. CE. This reviewer was one of the co-directors of the project. The cored material was subjected to careful macro- and micro-scale examination and extensive chemical and structural analysis of the various materials that made up the mortars and aggregates. The analytical work is just the sort of research M. hopes his book will foster "for future studies" (242). M. cites the analytical studies of architectural concretes by scientists such as Marra, Jackson, Miriello, and Rispoli, and yet analytical investigations of marine concrete have flourished over the last decade.[15] While M. shows an understandable desire to focus on terrestrial architecture and the chronological problems, complete neglect of well-documented parallel developments in marine concrete, to which Vitruvius dedicated many of his observations, seems perverse.[16]

The final ROMACONS report also provides careful cataloguing and analysis of all published Roman concrete structures built in the sea around the entire Mediterranean coastline, along with detailed consideration of the methods of construction, including wooden formwork. Greek and Latin literary and epigraphic sources concerning early concrete construction, particularly that in the sea, are collected and presented with translations. In the concluding chapter there is an extensive treatment of the pozzolana trade and the mechanisms for the spread of concrete technology, concluding with an explanation of the role of the *piscinarii* – elite landowners with seaside villas fronted by fish-tanks built of marine concrete – in perfecting this type of construction and bringing it into play in the design and construction of the early Roman harbors.[17] Since M. first published his idea about the role of elite landowners in the spread of concrete technology on land in his 2015 article, it seems likely that both he and this reviewer came independently to the same conclusions at about the same time. It is a puzzle that this role of maritime villas and marine concrete is not acknowledged in his book, since it would strengthen his own arguments concerning the role of the elite in terrestrial architecture.

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[14] Brandon et al. 2014. M. lists this book in his bibliography (265) but omits Oleson from the list of principal authors.

[15] For a small sample of more recent research, including some that compares samples of marine concrete with samples of terrestrial concrete, see the following publications with references: Jackson et al. 2014; Jackson et al. 2017; Jackson et al. 2018; Marra et al. 2016; Tremsin et al. 2019; Asscher et al. 2020; Dasar et al. 2020; Rispoli et al. 2020; Arizzi and Cultrone 2021; Sağın et al. 2021; Chapkanski et al. 2021; MacFarlane et al. 2021; Dilaria et al. 2022; Montesano et al. 2022; Secco et al. 2022.

[16] Oleson 2014, 14–23; Jackson 2017.

[17] Hohlfelder and Oleson 2014, 230–35. See Gianfrotta 2011 for an evaluation of the utility of the information generated by the ROMACONS project for the historical interpretation of Roman concrete technology.

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