ONE

INTRODUCTION

AIMS AND METHODS

Concrete construction represents Rome's major contribution to the history of ancient architecture and engineering. Scholars have touted the modern character of this man-made material, which gave planners the ability to cast structures wherever they were needed, emphasizing the inextricable link between building medium and building forms.[1] Observation of the durability and longevity of concrete features, and particularly their survival in hostile environments such as seawater, has stimulated the scientific study of the material in order to identify the constituent elements and to describe the mechanical, chemical, and physical characteristics for possible reproduction.[2] As a result, the systematic testing of ancient samples has greatly improved our understanding of how Roman builders of the Late Republican and Imperial periods exploited raw materials.[3] Moreover, the approach has shifted to concentrate on the step-by-step examination of the construction process, and standardized procedures have been developed to quantify the costs of construction, thus allowing for a contextualization of the building industry within the broader Roman economy.[4] As current scholarship shows, by teasing out the actual choices made by patrons and builders from the

[1] On the concept of Rome's architectural revolution: Lechtman and Hobbs 1987. On the relationship between Roman concrete and vaulted architecture see Ward-Perkins 1981 (first published in 1970) and MacDonald 1982: 3–19; Yegül and Favro 2019: 134–37.
[2] Lamprecht 1987: 41–69.
[3] Brandon *et al.* 2014; Jackson 2014.
[4] DeLaine 1995; 1997; 2001.

range of technological options available to them at any one time and place, it has been possible to recognize that innovative techniques emerged independently in the provinces, in response to local environmental circumstances and sociopolitical conditions.[5] Thanks to these seminal methodological advances, the issue of originality in the architectural manifestations of the Roman imperial period has been fundamentally reoriented, moving the debate away from the old perspective that privileged the center over the periphery. Such an investigation, however, has not been undertaken yet for the formative phases of Roman architecture.

The advent of concrete construction has attracted far less attention than its large-scale adoption in imperially sponsored programs. The general consensus is that the building technology was first developed in central Italy during the Mid-Republican period. Partly because of the scattered nature of the dataset, previous studies have discussed the initial dissemination of the building medium only in anecdotal fashion.[6] A common idea has been that it was the outcome of slow and incremental accumulation of experience from trial-and-error starting as early as the middle of the 4th century BCE.[7] Based on this assumption, architectural historians have avoided assigning hard dates to the origins and significant advances in concrete technology, claiming among other things that early experiments would not have survived due to their presumed inferior quality.[8] Excavations and architectural surveys of relevant sites, however, have continued to yield new information, radically changing the nature of the archaeological evidence available from Rome, the core regions of Latium and Campania, and beyond. Traces of ephemeral Archaic hut architecture have been uncovered in the deeper levels of the monumental center of Rome and elsewhere in the *suburbium*,[9] thus undermining that theory. Despite the recent wave of fieldwork, however, the record for the Mid-Republican period has generally remained elusive throughout central Italy. Beyond fortifications and temples, many urban entities – Cosa and Pompeii being the most thoroughly explored and published besides Rome – have very little civic architecture that

[5] For this perspective, see Lancaster 2015: 5–7, following Greene 1992 and 2008. On the diversity of construction techniques in the Roman provinces, see also Yegül and Favro 2019: 145.

[6] E.g., Adam 1994: 79–80; Billig 1944; Boëthius 1978: 128–29; Coarelli 1977; Lugli 1956; Rakob 1983. Peterse 1999 represents a notable exception, though narrowly focused on the Pompeian phenomenon (*infra*, ch. 5).

[7] Giuliani 1998: 50.

[8] E.g., Ward-Perkins 1981: 98, "Such slow, empirical advances are in the nature of things hard to document. It is the successes that survives, the failures that are swept away." See also Adam 1994: 73, "In reality, the only buildings with concrete masonry [. . .] that have survived above ground in a good condition are those that were constructed with great care, using a high-quality lime [. . .] It is not possible to discuss the innumerable inferior buildings since those remaining in the open air have disappeared due to their vulnerability."

[9] Cifani 2008. Evans *et al.* 2019 presents an example of hut architecture from Gabii.

predates the 2nd century BCE.[10] Similarly, the sample size of domestic architecture is surprisingly smaller when compared to that of previous or later periods.[11] This book attempts a first synthesis of the new data.

By investigating how the innovation of concrete came about and spread within Roman society, I explore the relevance of the material to answer questions about the cultural implications of Rome's expansion. Pushing the date for the emergence of the technology forward by a few generations, the chronological scope of my project spans from the aftermath of the Second Punic War to the age of Sulla (200–80 BCE), a period that encompasses a fundamental moment of change for Roman urbanism and its physical topography. By the early 2nd century BCE Rome had already morphed from prominent regional polity to capital of a Mediterranean empire.[12] Throughout the middle and second half of the 2nd century BCE, a disproportionate amount of public funds were earmarked for the maintenance of urban infrastructure and for construction projects – in 179 BCE the entire *vectigal* (i.e., the revenue derived from public land and state property) was spent on public building according to Livy (40.46.16) – culminating in the introduction of new building types such as the *basilica* and *porticus*.[13] This phase was also characterized by a revival of Rome's colonization program, which resulted in a number of ex novo foundations and the redevelopment of colonial sites. Moreover, elites from allied city-states in central Italy became increasingly engaged in Rome's imperialistic agenda, earning economic and social capital that could be reinvested in urban beautification programs at an unprecedented scale, in both the private and communal spheres.[14] As is argued here, this complex historical context sparked those social and cultural dynamics out of which early experiments with concrete construction eventually materialized.

The possibility of identifying precisely by whom, when, and where it was originally discovered how concrete could be used for structural purposes is probably beyond our reach. Rather, this work aims to elucidate the pattern of implementation of that discovery across the constellation of higher-order settlements in the Italian peninsula.[15] Technological change is often brought

[10] On Mid-Republican Rome, see Bernard 2018a. For Roman Italy, see Lackner 2008; Sewell 2010. For Pompeii: Ball and Dobbins 2013.

[11] Bentz and Reusser 2010; Jolivet 2011 (atrium houses); Sewell 2010: 169–71 discusses the scarcity of house construction at other colonial sites for most of the 3rd century BCE (Fregellae, Alba Fucens, Paestum). Cf. Pesando 1999.

[12] For the internal periodization of the phase, see Flower 2011.

[13] Cf. Nünnerich-Asmus 1994; Davies 2014. For a comprehensive overview of public building, see Davies 2017: 78–182.

[14] Cébeillac-Gervasoni 1983. Monumental building has played a central role in accounts of the diffusion of Hellenistic art and architecture in Italy: Zanker 1976; Wallace-Hadrill 2008: 103–43. On economic growth after the period of the Second Punic War, see Kay 2014. On the agency of the Italians in the process, see Roselaar 2019: 61–120.

[15] On the structural characters of Mid-Republican urbanism in Italy, see Sewell 2016.

about as a result of everyday use and experience of something that already existed rather than abstract thought. Thus, innovation happens with relation to an existing tradition, to which it contributes something "new." It is precisely the focus on contrasts and differences observed at the local level that reveals the variety of technological solutions accessible to sponsors, planners, and masons, thereby making the study of the "new" possible. Expanding on this idea, I pursue a set of research problems to define the context of innovation and disentangle the web of social, cultural, and environmental factors that influenced the sudden shift from previous practice.[16] By drawing from studies that present individual techniques at particularly representative urban centers, my intention is to show that key steps in the switch from ashlar to concrete construction were achieved simultaneously yet differently at different places for different (mostly local) reasons. As we see, the lack of any discernible common thread from the broader scale of analysis suggests that concrete construction did not emerge as part of a centralized process. The results, therefore, will provide an opportunity to test ideas about the relationship between Roman hegemony and the mechanisms of technological transfer, and to reassess the contribution of both Roman and non-Roman patrons and builders.

GROUND RULES: THE BUILDING INDUSTRY OF REPUBLICAN ROME AND ITALY

At the core of my argument is the idea that the built environment of Roman Italy was not shaped by impersonal forces or processes, but by patrons and builders who had agency, especially in periods of sociopolitical crisis or change. In order to write a history of early concrete construction it is, therefore, necessary to take into account relevant aspects of the organization and administration of public building, identifying which stresses on the system may have triggered technological innovation.[17] Unfortunately, the loss of Livy's text for the period after 167 BCE means that we lack a crucial source of data to reconstruct the full scope and extent of the phenomenon throughout the critical phase analyzed in this book. The surviving literary evidence is sparse, but it does provide some valuable information on the functioning of Rome's building industry. In addition, building inscriptions from urban sites across the study area outline the procedures involved in funding and executing monumentalization programs and other civic benefactions.[18] Collectively, the

[16] For a survey of building techniques used in earlier periods in Rome, see Jackson and Marra 2006; Cifani 2008.
[17] E.g., Bernard 2018a: 193–227 links advances in Mid-Republican Rome's stone masonry with urban labor migration and high demand for builders and contractors.
[18] For Latium and Campania, see Cébeillac-Gervasoni 1998: 66–79; Panciera 1997.

available details shed enough light on the overarching economic and legal conditions under which the early development of concrete technology was actually negotiated, revealing significant overlaps between the public and private spheres.

By the 2nd century BCE, architectural projects were undertaken on the basis of legally binding contracts formed between a landowner who commissioned the construction of a building on their property and a builder who possessed or could provide the required expertise, labor, and materials. The most common framework regulating such transactions, generally referred to as *locatio conductio operis* (after the term for contracts involving hire and lease), originated in the building period dominated by ashlar construction.[19] In its basic form, the *locatio conductio operis* holds the contractor who has agreed to organize the job on a fixed price (*conductor*) accountable for the correct execution of the work until final inspection and approval (*probatio*), normally by the same individual who let out the contract (*locator*). The system applied to both the private and public domains, though in public building only elected magistrates duly authorized by local councils could discharge those duties (in public contracts the *conductor* is replaced by the *redemptor*, but in legal terms they represent the same party). Given the time constraints imposed on public officials tasked with the oversight of building projects by municipal constitutions based on yearly appointments,[20] it is not uncommon to find cases in which construction work lasted longer than a single term of office. This is demonstrated by building inscriptions such as the one associated with the Temple of Castor and Pollux at Cora, one of the *priscae coloniae latinae* in Latium. The document (*CIL* 1^2.1506; early 1st century BCE) records one pair of magistrates supervising the letting of the contract and most of the construction, and another pair giving final approval and dedicating the building in the following year; different members of the local *gens Caluia*, however, were involved through the various stages.[21] Thus, there were ways to maintain control over the project, and the prestige that derived from it, within the same extended family.

The explicit nature of the obligations and liabilities under the *locatio conductio operis* served primarily to protect the patrons, explaining why the system came to be preferred over older contract forms such as the *stipulatio*, which were

[19] On the origins of the system, see Biscardi 1960. The earliest document mentioning a *probatio* in the context of public building in Rome refers to the construction of a mosaic floor in the Temple of Apollo Medicus (*CIL* 1^2.2675; first half of the 2nd century BCE. Davies 2017: 88 and 91, fig. 3.11). On the nature of pre-2nd century BCE contracts, see Anderson 1997: 79–82, and the discussion in Bernard 2018a: 153–57.

[20] For Rome see Davies 2017: 1–5. Steinby 2012a emphasizes the prerogatives of the Senate in allocating tasks and controlling expenditures.

[21] *[- – -] Caluius P(ubli) f(ilius) P(ubli) n(epos) C(aius) Geminius C(ai) f(ilius) Mateiclus aed[em] | Castoris Pollucis de s(enatus) s(ententia) faciendam pequn(ia) sac(ra) coeraver[e] | [M(arcus] Caluius M(arci) f(ilius) P(ubli) n(epos) C(aius) Crassicius P(ubli) f(ilius) C(ai) n(epos) Verris d(e) s(enatus) s(ententia) prob[auer(unt) d]edicar(unt)q(ue).*

based on verbal agreements.[22] Cato's prescriptions on how to establish and equip a rural residence from scratch (*Agr.* 14.1–5) seem to relate to this generalized pattern, although the literary nature of the work means that the evidence can only be used with caution: His list specifies almost obsessively all the activities and items that were supposed to be the sole responsibility of the builder – among which a round table, three benches, and five chairs! Cicero's letters suggest that for certain small-scale private projects the *conductor* could serve also as architect and supervising mason (e.g., *Att.* 12.18.1 on the *fanum* in memory of his daughter Tullia), but in most cases the primary roles were divided more specifically, with the property owner performing the *probatio*.

The *Lex Puteolana parieti faciendo* (*CIL* 1^2.698 = 10.1781; 105 BCE), a building inscription from the Roman colony of Puteoli, is the best surviving example to show the degree of detail that could be incorporated in public building contracts.[23] The text spells out the terms for the *locatio* of minor structural modifications in the public area in front of the Temple of Serapis, which were part of a larger project begun earlier (l. 4: *operum lex* II). From it we learn that, besides providing sureties, the *redemptor* C. Blossius was required to follow sets of design instructions for each aspect of the construction (walling, carpentry, and roofing), supplying building materials that met certain specifications. The payment was to be rendered in two installments, one half paid as an advance at the time of signing and the remainder disbursed after work had successfully passed the *probatio* (ll. 54–57). In all likelihood the technical requirements were issued by the panel of ex-magistrates (ll. 48–50: *duouirales qui in consilio esse solent Puteolis*) who assisted the sitting *duouiri* in judging the conformity of the works throughout the building process. Vitruvius' description of his own project at Fanum (*De arch.* 5.1.6–10) seems to imply that architects in charge of the design and planning of public buildings could be expected to serve as general organizer of the entire building process, and therefore to play their part in arranging for the contracts to be let.[24] Thus, the provisions set out in the *Lex Puteolana* may also reflect the advice and input of the architect at the time of the initial decision about what sorts of materials were to be used (cf. Vitr., *De arch.* 6.8.1). There are, however, other cases in which the task of selecting the appropriate building materials was left entirely to the *redemptor*, as was generically stated in the contract for the restoration of the Temple of Castor and Pollux in the Forum Romanum in 73 BCE (Cic., *Verr.* 2.1.146: *hoc opus bonum suo cuique facito*). Interestingly, the terms explicitly

[22] As noted by Martin 1989. See also Anderson 1997: 68–75 (defining the terms of *locatio conductio* contracts as a "sword of Damocles" over the neck of the contractor who had to undergo the *probatio*).

[23] Dessales 2016.

[24] Anderson 1997: 13–14 suggests that training in the legal requirements of contracting was part of the ideal theoretical education of Roman architects.

allowed for the use of recycled components (Cic., *Verr.* 2.1.147: *rediuiua sibi habeto*).

Given the visibility that public construction projects brought to their sponsors, linking the terms of payment with the *probatio* provided an effective mechanism to safeguard against the risks associated with the mismanagement of public finances. In fact, monumental building inscriptions make abundantly clear that the correct expenditure of public funds was advertised as a civic virtue.[25] Since initiating, financing, and coordinating the completion of public monuments was such an important component for the career of Roman aristocrats, technological innovation in the field of public architecture implied greater social and political dangers.[26] This is likely the reason why individual patrons of public architecture in Republican Rome tended to form lengthy connections with trusted specialists, often taking advantage of preexisting political ties among elite families. The best documented and intriguing case is by far that of L. Cornelius, *praefectus fabrum* and *architectus* of a Q. Catulus, probably to be identified with the younger Q. Lutatius Catulus, a close associate of L. Cornelius Sulla, who was responsible for the building of the Tabularium (as consul in 78 BCE) and for the reconstruction of the Temple of Jupiter Optimus Maximus (as censor in 62 BCE).[27]

Similar factors must have been at play in the logistics of urban construction projects across Roman Italy, regardless of the juridical status of the towns.[28] A passage in Polybius (6.17.2–5) is often used to demonstrate that there was an increasingly intensive use of *publicani* who accepted government contracts for public building works on behalf of Roman magistrates throughout the peninsula.[29] Polybius, however, says he is describing the industry as it existed at the start of the Second Punic War, a period for which there is no evidence of censorial contracting outside of Rome.[30] Another fragmentary testimony in Livy (41.27–28) suggests that one of the Roman censors of 174 BCE, Q. Fulvius Flaccus, used allotted funds to carry out replanning projects at the Roman colonies of Sinuessa, Pisaurum, and Potentia, but it also indicates that the move was strongly opposed by his colleague. Thus, it is hard to extrapolate from this notice how widespread the direct intervention of Roman officials was in the early period. More reliable is an inscription referring to the refoundation of Aquileia in 169 BCE (*AE* 1996.685), which demonstrates how the commissioners (*tresuiri*) sent from Rome were also responsible for configuring the

[25] Pobjoy 2000.
[26] On the perception of the dangers associated with large-scale construction projects in Republican Rome, see Bernard 2018b.
[27] *AE* 1971.61. For the identification and career, see Anderson 1997: 26–32.
[28] For a synthesis on the organization of public building outside of Rome, see Horster 2014.
[29] See the discussion in Sewell 2010: 110–11.
[30] The exaggeration is rightly noted by Anderson 1997: 99–100.

physical topography and urban fabric of colonies of Latin right.[31] Once colonies had been established, however, local magistrates and town councils remained in charge of the administration of public projects. This was the case for the Latin colony of Luceria (originally founded in 315/314 BCE), whose fortifications were rebuilt in the late 3rd or early 2nd centuries BCE by local *praefecti*.[32] The *Lex Puteolana* demonstrates that the same degree of autonomy applied to Roman colonies, despite the fact that these were located on *ager Romanus*. The corpus of Oscan building inscriptions from Pre-Roman Pompeii and other Samnite centers in the region reveals that the organization of public construction in allied cities followed the same principles as the Roman *locatio conductio operis*. As we will see, the technical language normally employed in those texts corresponds precisely with the Latin terminology.

BASIC TERMS AND DEFINITIONS: WHAT IS ROMAN CONCRETE?

The book is organized so as to systematically document the earliest examples of concrete construction in relation to sources of building materials through excavation reports and, where possible, on-site examination. For each site and region included in this study (Figure 1.1), the main goal is to establish a reliable developmental chronology for specific building techniques and types, and to then chart their geographical spread against the local geology. To that end, a preliminary discussion of general terms and distinctions that I apply to the dataset is in order, starting with the building medium.

In the specialist literature, the term Roman concrete indicates a mixture consisting of stone fragments (aggregate) normally ranging from fist- to head-size (0.10 to 0.30 m), hand-laid in a lime-based binder (mortar) with high-quality hydraulic properties, and packed into place.[33] Archaeologists and architectural historians normally distinguish the material from other forms of mortared rubble in which the binder did not feature volcanic ash as an additive, consisting of a simple lime-and-sand compound.[34] There is scientific evidence for the development of volcanic ash mortars going back to the Late Minoan period in the Eastern Mediterranean, but in the absence of a continued tradition its significance for the Roman phenomenon is negligible.[35] Builders outside of central Italy, however, had other ways to create hydraulic mortars than simply by adding volcanic ash, so the conventional distinction appears problematic if applied more widely across the Roman Mediterranean.

[31] Gargola 1995.
[32] Gregori and Nonnis 2013: 495, no. 30 (= *CIL* 9.800 = 1^2.1710 cf. p. 1028).
[33] For a comprehensive overview of the differences between modern and ancient concrete construction, see Wright 2005, 1: 182–85; Lancaster 2008.
[34] E.g., Ward-Perkins 1981: 98.
[35] Maravelaki-Kalaitzaki *et al.* 2003 (Late Minoan structure at Chania in Crete); Koui and Ftikos 1998 (6th century BCE cistern from Cameiros on Rhodes).

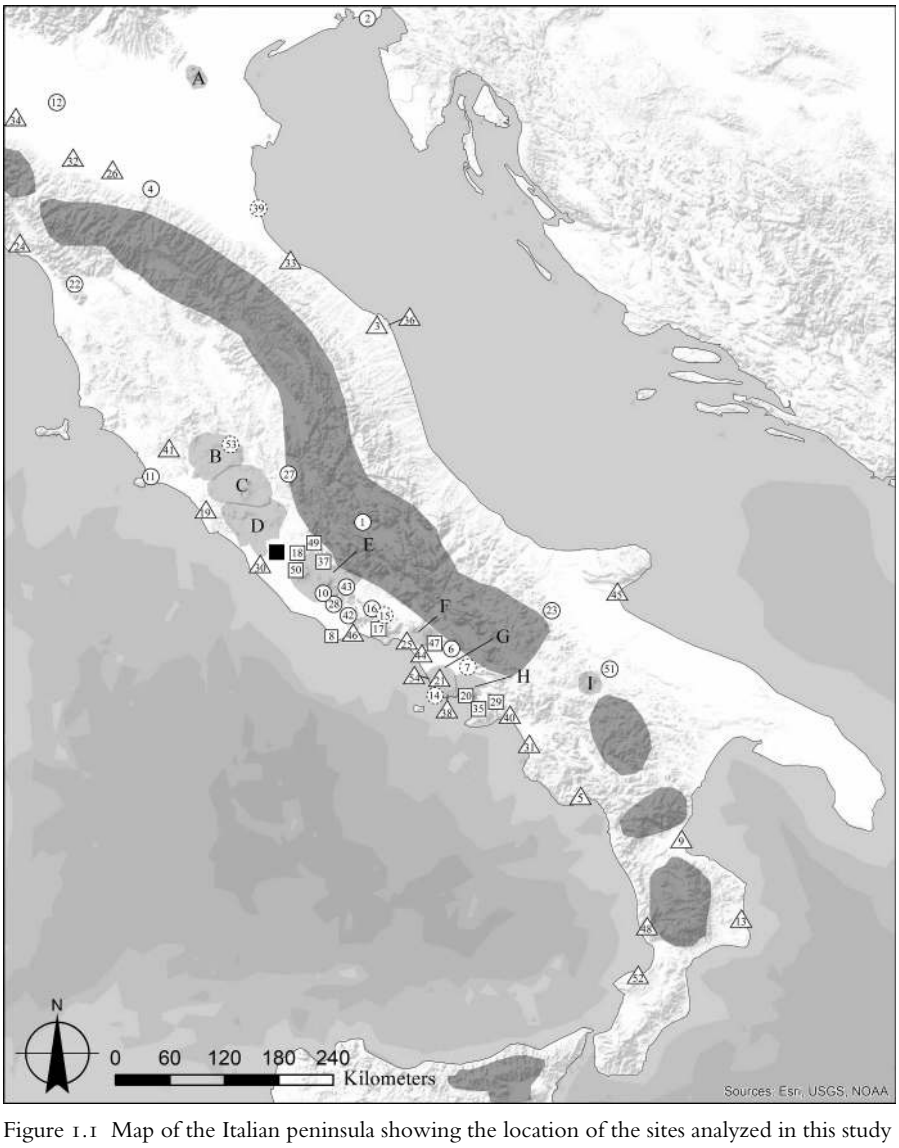

Figure 1.1 Map of the Italian peninsula showing the location of the sites analyzed in this study with relation to volcanic geology and sources of timber (dark grey). Drawing: M. Harder. Key: solid square = Rome; empty squares = allied cities; triangles = Roman colonies; circles = Latin colonies; dashed circles = other (e.g., *praefectura*) or uncertain status. Sites: 1=Alba Fucens; 2=Aquileia; 3=Auximum; 4=Bononia; 5=Buxentum; 6=Cales; 7=Capua; 8= Circeii; 9=Copia; 10=Cora; 11=Cosa; 12=Cremona; 13=Croton; 14=Cumae; 15=Fabrateria Nova; 16=Fregellae; 17=Fundi; 18=Gabii; 19=Graviscae; 20=Herculaneum; 21=Liternum; 22=Luca; 23=Luceria; 24=Luna; 25=Minturnae; 26=Mutina; 27=Narnia; 28=Norba; 29=Nuceria; 30=Ostia; 31=Paestum; 32=Parma; 33=Pisaurum; 34=Placentia; 35=Pompeii; 36=Potentia; 37=Praeneste; 38=Puteoli; 39=Ravenna; 40=Salernum; 41=Saturnia; 42=Setia; 43=Signia; 44=Sinuessa; 45=Sipontum; 46=Tarracina; 47=Teanum; 48=Tempsa; 49=Tibur; 50=Tusculum; 51=Venusia; 52=Vibo Valentia; 53=Volsinii Novi; 54=Volturnum. Volcanic districts: A=Colli Euganei; B=Monti Vulsini; C=Monti Cimini; D=Monti Sabatini; E=Colli Albani; F=Roccamonfina; G=Campi Flegrei; H=Vesuvius; I=Vulture.

Deposits of unconsolidated volcanic materials (i.e., ash and lapilli of pumice and scoria) were readily available in the environs of Rome. These pyroclasts occur in different varieties, which are sometimes improperly identified with the catchall term "pozzolana." This term was originally associated with the volcanic ash found around Pozzuoli (ancient Puteoli), but was later applied to any volcanic material with similar properties. Geologists working in Rome use the term as a proper name to refer to specific strata of the Colli Albani volcanic district. The correct scientific word to describe materials with pozzolanic properties is "pozzolan" (a category which includes fired clay and certain organic ashes in addition to volcanic ash).[36] Volcanic ash contains enough soluble silica to react with lime when water is added to the mix (hence the term "hydraulic mortar"). As a result of the chemical reaction, cementitious gels characterized by a crystalline matrix are produced (calcium aluminum silicate hydrate, or C-A-S-H, intermingled with Al-tobermorite in lime clasts). Thus, a denser mortar is developed with stronger bonds within it, and which hardens faster than mortars made of lime and nonsoluble silica such as quartz sands of nonvolcanic origins. The reaction does not require evaporation to occur, making volcanic ash mortars well-suited for use as a binder in airtight environments (e.g., foundations and wall-cores), as well as vaulting. By contrast, simple lime mortar mixtures never achieve the same degree of strength, especially when used in thick applications, since they revert back into a type of artificial limestone by absorbing carbon dioxide from the atmosphere (hence the term "aerial mortars"), in an exchange that can occur only on the outer surface.[37]

The ancient terminology that scholars associate with Roman concrete was originally coined to denote structures built with either hydraulic or non-hydraulic mortars. *Opus caementicium* (or *caementitium*), a term derived from the Latin word for rubble (*caementa*), is often employed interchangeably with Roman concrete.[38] Architectural historians generally use the title to describe any sort of rubble mixed with hydraulic mortar featuring volcanic additives. With relation to masonry styles, the term applies to layered concrete fabric with differentiated facing of any pattern, but the usage is often vague and inconsistent from author to author. In ancient primary sources it occurs only once, as *opus cement*(*icium*?), in a rather late inscription from the sanctuary of Silvanus at Philippi (*CIL* 3.633; 2nd century CE).[39] Considering the location, however,

[36] See discussion in Lancaster 2015: 21–23.

[37] On the chemistry of pozzolans, see Lancaster 2015: 24–25, with further bibliography. For simple lime mortars, see the discussion in Lancaster 2015: 20. The distinction between "aerial" and "hydraulic" mortars is in Rapp 2009: 265–66.

[38] Ginouvès and Martin 1985: 51–52.

[39] See Kloppenborg and Ascough 2011: 315–18, no. 68a. Oleson 2014: 11 assigns incorrectly the inscriptions to the later 1st century BCE. This is repeated in Lancaster 2015: 21. The reference is to a wall built in front of the main temple, but the actual structure has not been identified.