Building Trajan's Markets 2: The Construction Process

LYNNE LANCASTER

Abstract

The well-preserved state of many parts of Trajan's Markets provides the opportunity for a detailed study of the building techniques used there, which in turn sheds light on the construction process. Topics included in this paper are the planning of the drainage, design of multistory buildings with noncongruent plans, and organization and protection of the building site. They are discussed in relation to specific archaeological evidence from various parts of the Markets, such as the use of relieving arches, brick vaulting ribs, metal dowels and clamps, and travertine corbels and lintel arches. The results show that some structural and constructional elements within the building appear to have been intended to aid the construction process rather than to provide any long term functional or structural benefit. In the summary of each section, the archaeological findings presented in that section are examined in relation to broader questions dealing with the building industry, such as the use of scale drawings, the relationship between the architect and the builder, and the legal responsibility for the protection of the site during construction. Finally, two case studies involving a wider range of complexities are presented: the Aula at Trajan's Markets and the Trajanic latrine at the Forum of Caesar.*

Trajan's Markets represent a uniquely well-preserved monument (in spite of the extensive restorations undertaken earlier this century), and as such they provide evidence for building techniques and construction processes used in Rome during the early second century A.D. This is the third of three articles examining the organization of construction at Trajan's Markets and Trajan's Column.[1] The focus of this article is on the logistics of construction and on the ways the builders resolved particular problems, both structural and organizational. During the course of construction, builders had to confront a number of issues even before the actual construction began. Many of these are easily forgotten or dismissed by modern scholars when examining an ancient building, but often the builders left clues that reveal how the process was managed. These, in turn, give some indication of the issues facing the ancient builders.

Trajan's Markets were built on a hillside site using primarily brick-faced concrete. In planning such a project, the builders had to take into account a number of factors. The provision for drainage would have been one of the foremost considerations. The layout of the drains had to be planned at the earliest stages of design since the ground level drainage channels would have been built along with the foundations of the building and then connected to the existing urban drainage system. Since concrete required time to cure and gain strength, the scheduling of the work would have been crucial. In the case of a large or complex vaulted structure, the stability of the constituent parts was sometimes precarious until they were all in place, and measures had to be taken to ensure equilibrium during the process and to protect the elements from damage during assembly. If a multilevel structure had floor plans that did not align from one level to the next, certain precautions had to be taken to channel the weight of the upper walls to those below. Building concrete vaulted structures also required great amounts of wooden scaffolding for the bricklayers and wooden centering and formwork for the vaults, all of which had to be removed once the concrete was set. Providing the means and route for the removal of so much material would have been an important aspect of the organization. Access to the site had to be planned carefully so as not

* This article has been long in the making and has greatly benefited from the input of many people during the past decade. I very much appreciate the support I have received from Lucrezia Ungaro and Roberto Meneghini of the X Ripartizione AA.BB.AA of the Comune di Roma, who have granted me unlimited access to the monument and the archives there as well as providing advice and information. I am particularly indebted to Jim Coulton, Janet DeLaine, and Mark Wilson Jones for their comments on Roman construction in general and for reading some of the earliest drafts of this paper. I thank Susan Martin for sharing her insights on the legal aspects of the organization of Roman construction as well as Jim Packer and an anonymous *AJA* reader for their comments on the submitted version of this paper. Finally, I am grateful to Tom Carpenter for the hours he spent proofreading and for his invaluable advice on how to make this rather technical study of Roman construction more user-friendly for readers. The M. Aylwin Cotton Foundation generously helped fund my time in Rome during 1996–1997, when I made many of the final preparations for the text and drawings. All drawings and photographs are my own, and many of the drawings were created with AutoCad.

[1] Lancaster 1998a, 1999.

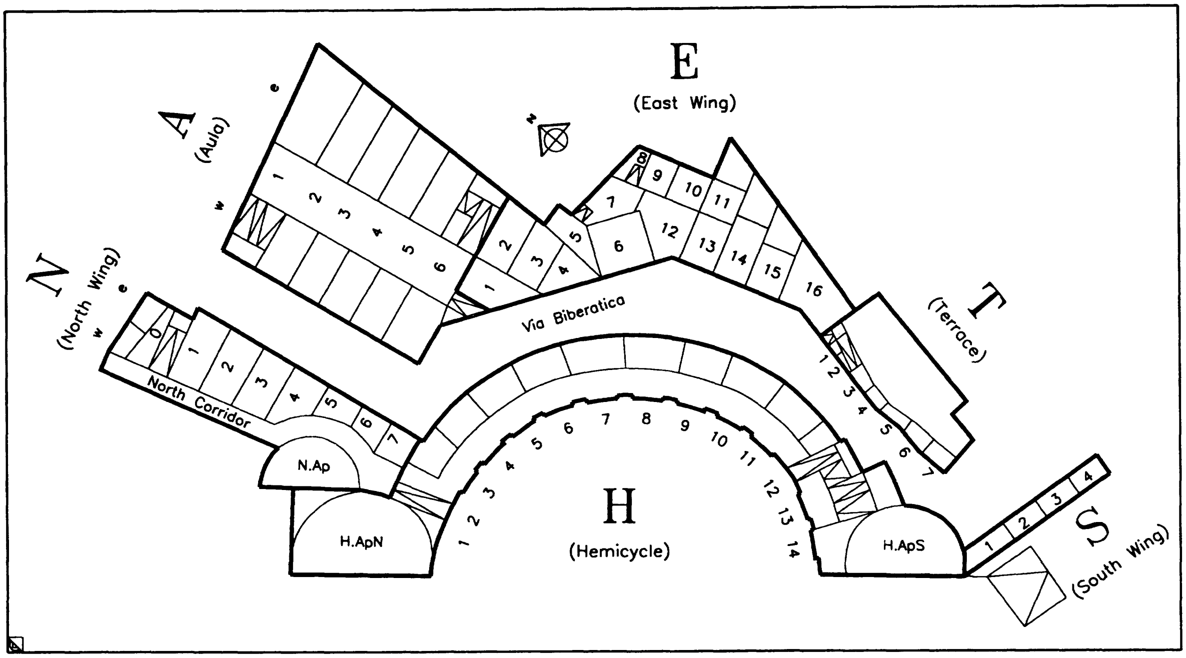

Fig. 1. Key to room numbers at Trajan's Markets. Both the lower and upper complexes are divided into three sectors: the lower complex includes the North Wing, the Hemicycle, and the South Wing, which are located on levels I–III, and the upper complex includes the Aula, the East Wing, and Terrace, which are located on levels III–VI. Each space has been given a code denoting its sector, level, and position. The first designation in the code is a capital letter referring to one of the six sectors. The second is a Roman numeral referring to the level. The last designation is usually a number locating the position of a space within the sector. For example, a typical room is labeled "H.II.14," which signifies that it is located in the Hemicycle sector on level II in position 14. The three major apsidal halls are simply referred to by their sector designation and "Ap," as in "N.Ap," "H.ApN," and "H.ApS." Stairs are referred to by their sector designation followed by the numerals of the levels they connect and, where necessary, by a position number, as in "stair H.I/II.2."

to block off one area while another was being built, thereby causing delays. These are all fundamental issues encountered by architects and builders, both ancient and modern.

In this study, I first examine clues left at the Markets for how these types of problems were resolved, and in the summary to each section I explore some of the broader implications regarding the construction process. Finally, I discuss in detail the complexities of construction in two case studies: the Aula at Trajan's Markets and the Trajanic latrine at the Forum of Caesar. Since Trajan's Markets are spread over six levels and comprise two different building complexes, a key to the various parts and an explanation of the numbering system is given in figure 1.

PLANNING THE DRAINAGE

At Trajan's Markets, parts of the original drainage system have been either destroyed or covered in subsequent periods, but enough evidence exists on the north side of the monument to allow at least a partial reconstruction of the system in this area. I start in the rooms on level II of the North Wing just behind the apsidal hall, N.Ap (fig. 1), and trace the evidence by working down through the monument following the course the rainwater would have taken. The builders did not have the advantage of starting at the top and working down; they had to envision the entire course of the drainage before laying the foundations, and in some cases they may have encountered unanticipated problems. The drains themselves, being for the most part under the floors of the rooms, are usually not visible today without further excavation. The builders, however, often employed relieving arches in the walls above drains to protect the channels from the weight of the walls. By comparing the location of the relieving arches with known drains, one can trace the course of the channels through the building.

Drainage in Level II of the North Wing

A number of relieving arches exist in the walls on levels II and III of the North Wing. In the past, the purpose of these arches has been speculatively attributed to the strengthening of walls over weaknesses in the foundations (fig. 2),[2] but a careful examination shows that these relieving arches were used

[2] Blake (1973, 23, 24 n. 122) is the only scholar to address the function of the relieving arches in the North Wing of the Markets.

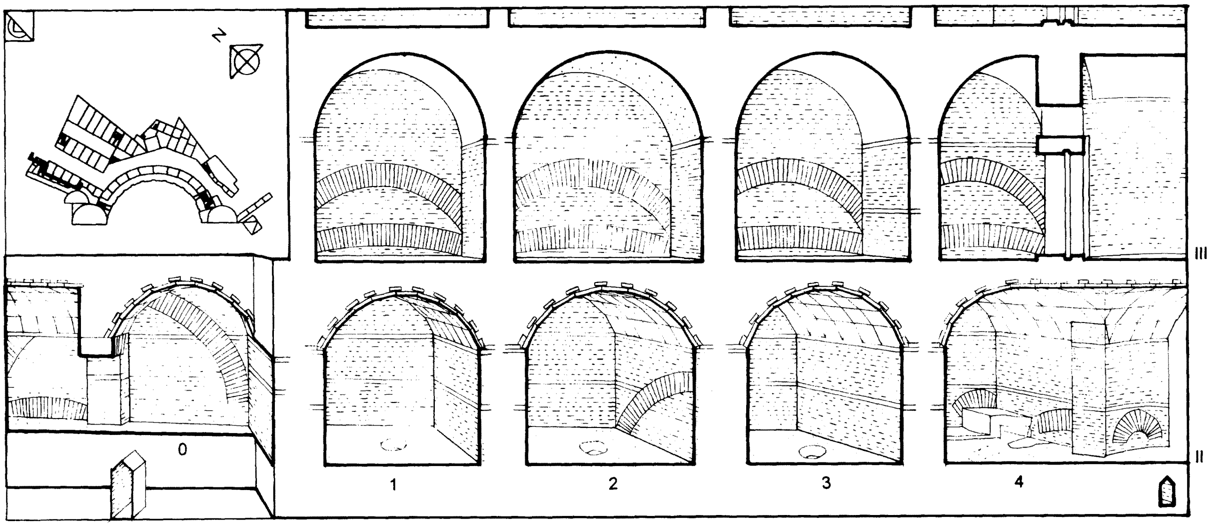

Fig. 2. Perspective drawing of North Wing showing locations of relieving arches and drains

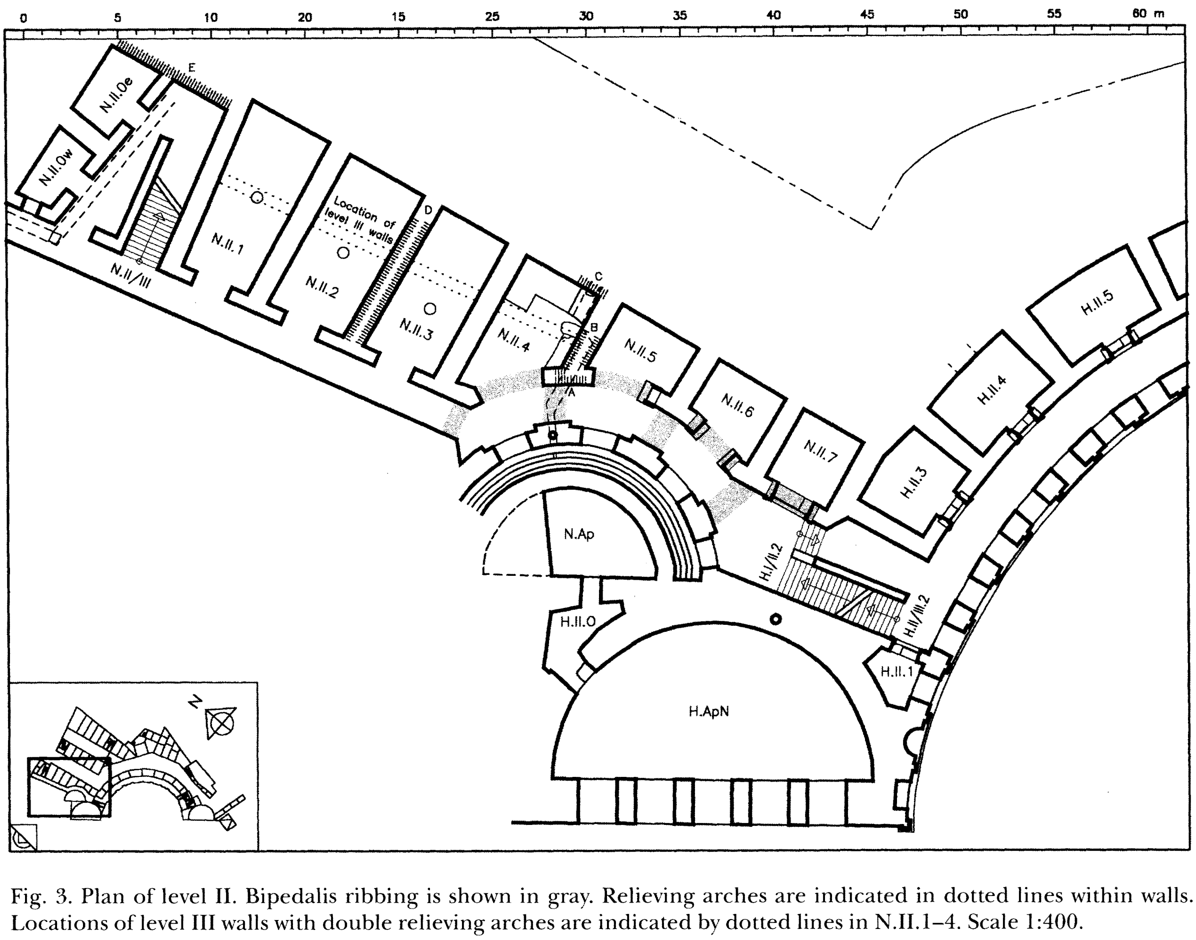

Fig. 3. Plan of level II. Bipedalis ribbing is shown in gray. Relieving arches are indicated in dotted lines within walls. Locations of level III walls with double relieving arches are indicated by dotted lines in N.II.1–4. Scale 1:400.

for various purposes and that some but not all of them relate to the drainage system. The elaborate system of drainage in this area highlights the complicated nature of the planning required to build on such a hillside site and demonstrates the way in which the architects and builders dealt with the drainage of the complex juxtapositions of vaulting found in this area.

In room N.II.4, an unusual concrete structure, which has been ignored in previous publications, provides the first clue (figs. 2–4). The structure is broken away next to a damaged section of the floor. During a particularly wet period in December 1990, the room flooded, loosening the dirt in the damaged area and revealing a channel that slopes down underneath the south wall and then turns to run directly beneath it. In the walls surrounding this structure are three relieving arches, each of which is built over a section of the channel (fig. 4A–C). The small arch (C) in the back wall of the room is built over the channel where it enters the concrete structure. The second arch (B) is located over the section of the channel running underneath the south wall. The third arch (A) occurs in the front wall where the channel crosses under the corridor. Directly across the corridor from arch A is a projecting pier containing a down drain collecting the runoff from the semidome of N.Ap (figs. 5–6). The channel, therefore, must continue under the floor to connect to this down drain. This relationship implies that the structure in N.II.4 was also some sort of drainage channel. The reason for building it into the concrete structure rather than under the floor is unclear. One possibility is that it could simply have been the result of a mistake in laying out the drainage system. Another is that either the geological makeup of the hill behind the wall or earlier structures in this area may have impeded the layout of the drainage at this point.[3]

Drainage for the Semidome of N.Ap

As mentioned above, the runoff from the vault of N.Ap is collected in a down drain built into one of the projecting piers of the level II North Wing corridor. The existence of this drain is attested by a small triangular opening visible in the channel running around the base of the semidome (fig. 5, drain indicated by arrow at bottom left). The bottom of the

Fig. 4. View of room N.II.4 showing concrete drainage channel surrounded by relieving arches (approximately same view as shown to the right of fig. 2). Arch B is built over the section of the channel that runs directly underneath the wall.

[3]Other relieving arches in this area may also relate to drainage. A large relieving arch in the back wall of N.II.0 (fig. 3E) aligns with a large drain (ca. 2 m deep) running under the corridor next to the stairway. Another small flat arch is built into the base of the same wall of H.II.0e. In addition, a large relieving arch that stretches almost the entire length of the wall occurs in the dividing wall between N.II.2 and N.II.3 (figs. 2 and 3D). Lugli (1929–1930, 538), in his publication of the Markets during their excavation, mentions a complex system of drainage under the floor of these rooms, but the basis of this comment is not clear. Without further excavation, the nature of any drainage or earlier structures underlying the level II North Wing rooms remains unknown.

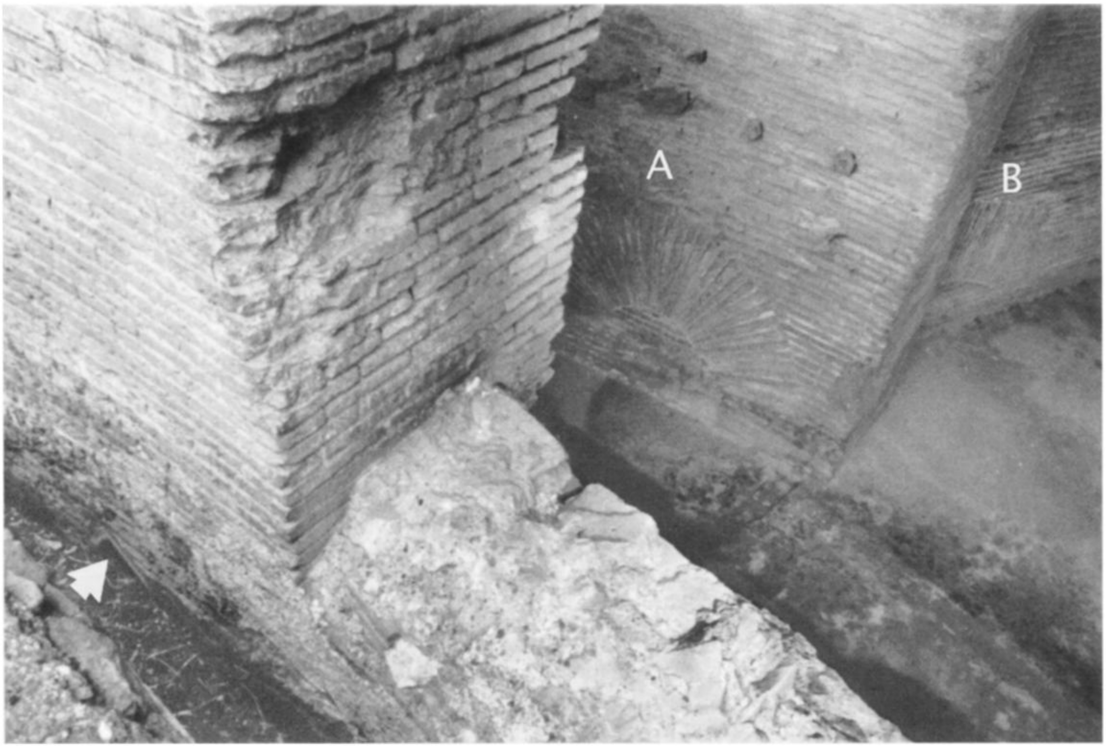

Fig. 5. Extrados of the semidome of N.Ap. The triangular drainage opening (indicated with arrow) at the base of the channel collects the rainwater. The relieving arches in room N.II.4 are shown in the background.

channel slopes down so that the lowest point occurs at the triangular hole. This room is nestled into the North Wing and was built amid other structures on all sides, much like the dome of the famous octagonal hall of Nero's Domus Aurea. In both monuments, the clerestory windows along the haunch of the vault lit spaces radiating out from the central room, a very rare configuration in Roman architecture. The octagonal room at the Domus Aurea was visible for less than 50 years and was not particularly influential in later Roman architecture. In fact, the Trajanic builders who buried it when they built the terrace supporting Trajan's Baths were the last ones to see it. The lighting configuration around N.Ap remains one of the only legacies of this innovative design. One reason for the rarity of the clerestory window over the haunch of a vault may have been the drainage problems it created.[4] The situation was not easily resolved, and a great deal of forethought was required to plan for the drainage connections before construction began.

Drainage under Apsidal Hall H.ApN

The drainage at ground level can be traced through the locations of three relieving arches at the base of the curving wall of the apsidal hall, H.ApN (fig. 7F–H).[5] The southernmost arch (H) roughly coincides with another relieving arch on the exterior face of the wall, which occurs directly above a triangular drain opening at street level.[6] The middle relieving arch (G) aligns with an upper drain that services the level III terrace surrounding the semidome of this room. The third arch (F) roughly aligns with the down drain from N.Ap, which must connect with a ground level channel running beneath the floor of N.Ap, under the relieving arch, and then out into the area of the Forum of Trajan. The exact course of the various drains that run under H.ApN is difficult to determine without damaging the floor, but the large drain located in the Forum of Trajan directly in front of H.ApN suggests that a significant amount of runoff from the north side of the complex was

[4] The way in which this situation was resolved at the octagonal hall of the Domus Aurea is unclear. The water from the dome would have run right down through the windows unless there was a channel at the base of each window that is no longer visible.

[5] The arches occur just above the remains of a brick-faced bench (55 cm high × 55 cm wide) that ran along the base of the curved wall.

[6] Lancaster 1998a, figs. 2 and 4.

channeled underneath this room and into the Forum drainage system.[7]

Summary

The drainage on the north side of the monument was particularly complicated because of the unusual juxtapositions of semidomes in this area, and a great deal of forethought would have been necessary to lay out the drains at ground level. For example, when the vertical down drains that align with the relieving arches in H.ApN were positioned and built, the builders had to know precisely where in the plan at level II those down drains would occur. They also had to know how and where the semidome of N.Ap was to be drained. All of these connections had to be planned before the ground level drains were laid, and even more importantly, they had to be communicated to those who laid out the plan on the site.

Use of Scaled Drawings. The use of scaled drawings to communicate ideas is attested both from written and graphic sources by the Roman Imperial period. Vitruvius notes that *ichnographiae,* made with compass and rule, were used to lay out the plans on the site.[8] Examples of such drawings that were actually used on-site do not survive, but dimensioned architectural plans from Rome have been found incised on marble and set in mosaic, and these provide some idea of what the ichnographiae must have looked like, though not necessarily of their size and material.[9] A number of fragments of stone plans of the city of Rome have also been found, the Severan Marble Plan (early third century A.D.) being the best-preserved and most well-known of these. The Severan Marble Plan has no measurements indicated, but a comparison of the monuments represented with their surviving remains shows that it was drawn to a scale of 1:240.[10] A fragment from a first-

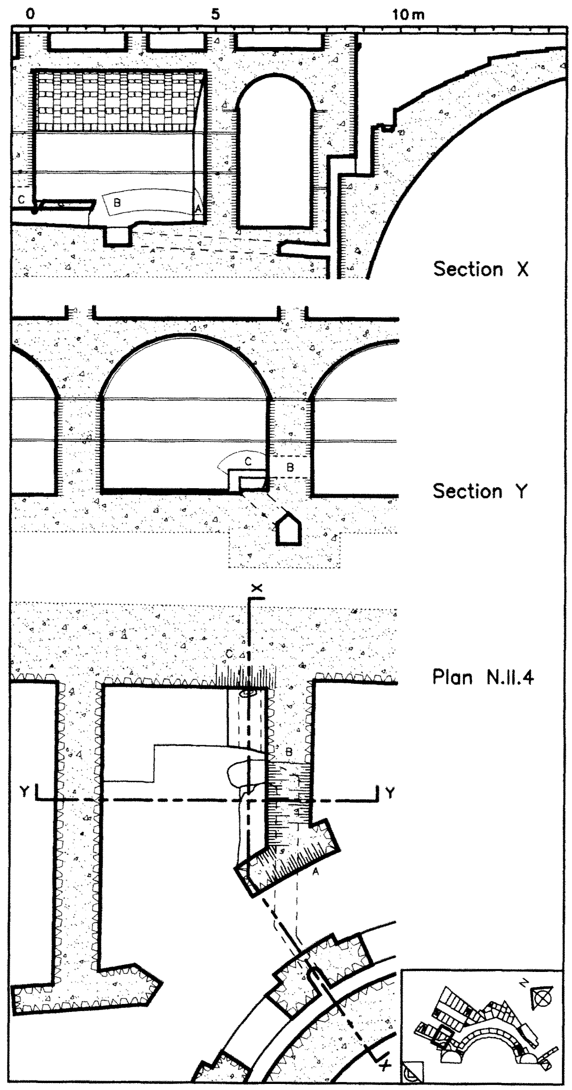

Fig. 6. Plan and sections of N.II.4. Scale 1:200.

century A.D. plan (found near Via Anicia) was also drawn to a scale of 1:240.[11] Fragments of other plans at a similar scale have been found in

[7] I have not examined the construction of the large drain in front of H.ApN to determine how much is original, but the modern functioning drain probably incorporates at least parts of the ancient drainage system. All of the runoff from the areas to the south of the Basilica Ulpia drained towards the south (i.e., in the direction of the Forum of Augustus and the Cloaca Maxima), whereas the areas to the north of the basilica drained towards the north. I thank R. Meneghini for this information.

[8] Vitr. *De arch.* 1.1.4, 1.2.2. See also Frézouls 1985, 216.

[9] Two marble examples, one now in Perugia and the other in Urbino, depict funerary monuments while a mosaic, found in a bath building in Rome, depicts the floor plan of a bath building: *CIL* 6.29847a (Perugia); *CIL* 6.29847 (Urbino); *CIL* 6.29845 (mosaic). By comparing the measurements noted on the plans, Carettoni et al. (1960, 206–10, nos. 3, 4, and 7) propose that three different scales are used on the Perugia plan: ca. 1:84, ca. 1:140, and ca. 1:230. The mosaic plan is drawn at a scale of 1:16. The scale of the Urbino plan cannot be determined. None of these three plans was intended to be used to lay out the buildings represented on them but rather to record them for posterity, so scaled accuracy was not necessarily a major consideration.

[10] Carettoni et al. 1960, 206. Since some of the more important buildings seem to have been slightly enlarged in relation to others, the precise scale of the map has been controversial, but 1:240 is commonly accepted.

[11] Conticello de' Spagnolis (1984, 30) points out that the Via Anicia fragment has inscribed measurements that probably denote private property boundaries corresponding to structures indicated on the map and argues that it was part of a catastral map.

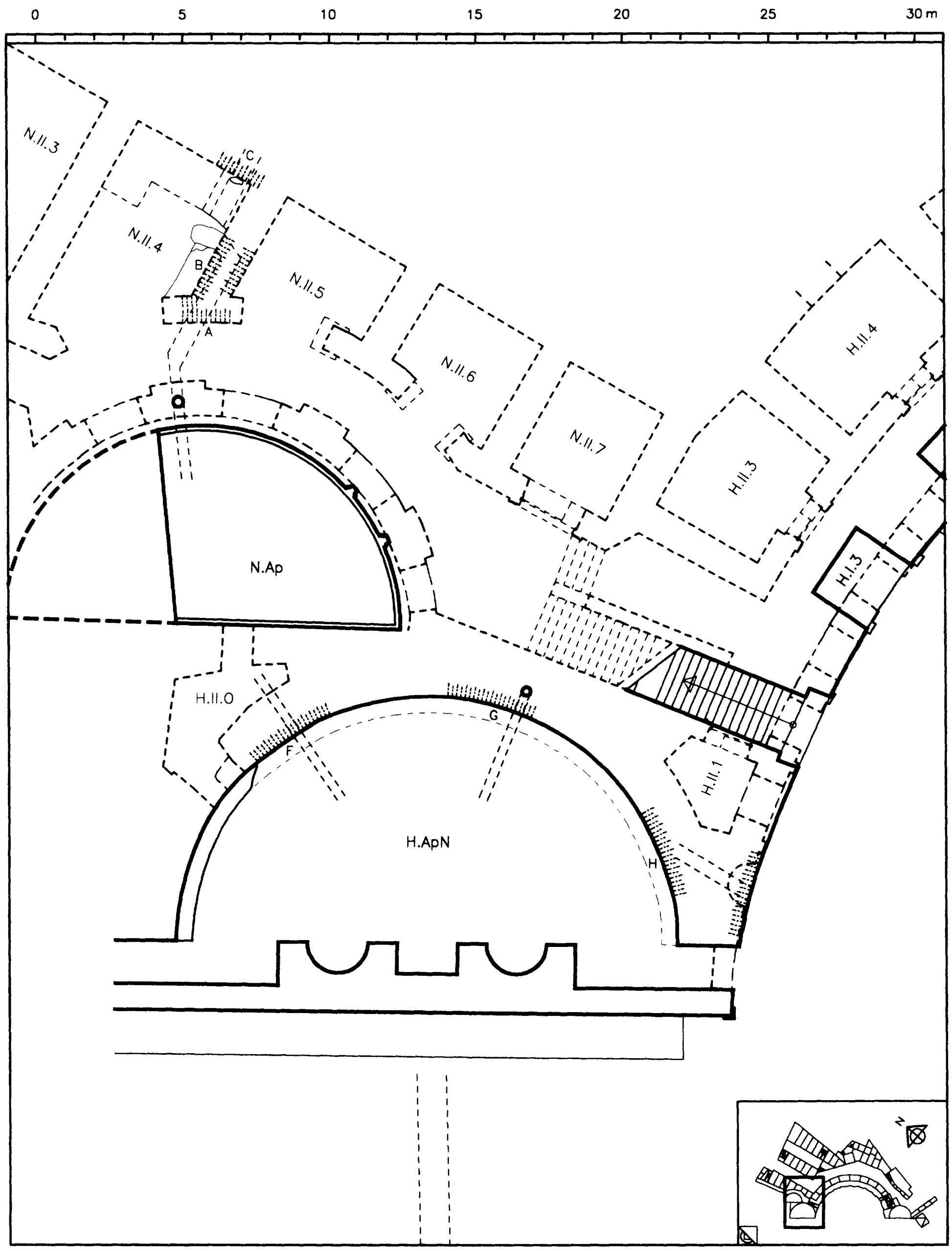

Fig. 7. Plan of level I with plan of level II (dashed) superposed. Relieving arches are indicated with letters. Scale 1:250.

Rome and Ostia.[12] These city plans represent the level of competency attained by Roman surveyors, and they must have been compiled from a series of portable plans, which were probably kept in an archive in Rome.[13]

In contrast to the drawings on stone, the ichnographiae used by surveyors and architects would have most likely been made on papyrus or less likely parchment and would have been limited in size. The scale chosen for the drawings would have been

[12] Carettoni et al. 1960, 206–10. In addition, two fragments of first-century A.D. marble plans have recently been found in the excavations at the Forum Transitorium and the Forum Pacis. The latter example, which shows part of the Forum of Augustus, was drawn at a scale of around 1:260/270 but was apparently left unfinished (Rizzo 1999).

[13] For a discussion of the use of these large scale marble plans and the existence of archives, see Carettoni et al. 1960, 214–6.

determined both by the ease of translation and by the size of the available papyrus, which tended to range from 24 to 44 cm wide.[14] The choice of scale for a drawing would have been based primarily on the unit divisions of the foot so that the standard ruler (*regula*) could have been easily converted into a scale measure. Since Roman feet (*pedes*) were divided into either 12 inches (*unciae*) or 16 digits (*digiti*),[15] one would expect the scales chosen for Roman floor plans to be multiples or fractions of 12 or 16.[16] A majority of the extant examples of marble plans of the city of Rome appear to be drawn at a scale of 1:240, which is divisible by both 12 and 16 and results conveniently in one inch representing 20 feet or one digit representing 15 feet. Since the plans of the city were typically drawn at this scale, we may assume that whatever plans used to create them were at a similar scale and that this scale would have been the most likely starting point for an architect planning a large urban project. In the case of Trajan's Markets, a plan of the whole complex at a scale of 1:240 would fit onto a papyrus roll 35 cm wide.[17] This would have been large enough to denote measurements for each room and to indicate details such as drains. For a rough comparison of size, see figure 7, which is drawn at the slightly smaller scale of 1:250.

DESIGNING AND BUILDING NONCONGRUENT FLOOR PLANS

Trajan's Markets is composed of a variety of different shaped rooms, and in some situations, the plan of one floor does not mirror the one below, resulting in some walls being left unsupported. To design such complex structures, the architects and builders had to have confidence that the weight of any unsupported walls at an upper level could be transferred down to lower level walls. Roman builders typically used two different methods to accomplish this. Either they reinforced the vault supporting an upper wall with brick ribbing, or they built relieving arches into the upper wall to divert its weight to places where walls were located below. Since both relieving arches and brick vaulting ribs were also used for other reasons, examining each situation separately is critical in determining the purpose of a particular use of a technique.

Relieving Arches Used to Protect Vaults

In the North Wing of the Markets, the plan of the walls of the rooms at level III (N.III.1–N.III.4) does not coincide with that of those at level II because the upper level rooms are divided by cross walls that do not exist in the lower rooms (fig. 3). To divert the weight of the level III cross walls away from the level II vaults, the builders employed double relieving arches in the level III cross walls (fig. 2).[18] The double relieving arches, in which a semicircular arch was combined with a shallow arch, were intended to reduce the load on the vault to a minimum by eliminating the amount of wall bearing directly on the vault below. The use of double relieving arches is relatively common over windows and doors, as can be seen in the Flavian work at the Domus Augustana on the Palatine. Single or double relieving arches employed to protect vaults are less common, though earlier examples of single arches exist at

[14] Pliny the Elder (*HN* 13.78–80) cites papyrus rolls in standard widths, the largest of which was 13 digits (24 cm), but he also cites larger widths of a foot (29 cm) and a cubit (44 cm). The maximum width found is 47–48 cm for two Egyptian papyri dating to the second millennium B.C. (New Kingdom) (Cerný 1952, 16). Pliny does not mention the length of the sheet, but once the sheets were glued together into rolls they would reach lengths of 6–8 m, so the length would not have been a great limitation (Cerný 1952, 8–9). For a discussion of sizes, see also Lewis 1974, 56.

[15] The typical regula consisted of a foot-long rod of bronze with a hinge in the center to allow it to fold (Ciarallo and De Carolis 1999, cat. 300, 310, 380; Donati 1998, cat. 99). The digits and/or inches were simply marked off with dots (De Pasquale and Marchis 1996).

[16] The mosaic plan (scale 1:16) mentioned above (supra n. 9) conforms to this principle. The same principle of scale related to the units of measure is found in Egyptian and Greek drawings. A mid third-century B.C. drawing from Didyma is drawn at a scale of 1:16 using a system of 1 foot = 16 dactyls, so that one dactyl represents one foot (Haselberger 1983, 93). A sketch on a papyrus from third-century B.C. Egypt shows an irrigation system drawn at a scale of 1:420 using a system of 1 cubit = 7 palms (or 28 digits), so that one digit represents 15 cubits (Pestman 1980, 253–65). The plan of the tomb of Ramses IV from 12th-century B.C. Egypt was drawn at a scale of 1:28, also a multiple of seven (Badawy 1948, 238–9, 274).

[17] Having worked as an architect on a large urban project in San Francisco in 1988, I discovered that the drawings of the site plan, which measured ca. 3 × 6 ft., could easily be cut into 8½ in. wide strips, faxed to other parts of the world, and then reassembled in long strips (provided they did not get tangled in the fax machine). Similarly, for a project as large as Trajan's Forum, one might imagine that the project was drawn on a number of papyrus rolls.

[18] These walls have been extensively restored, but the remains of part of one of the original arches can also be seen on the west side of the cross wall in N.III.4, suggesting that the restoration of the other walls is justified. Also, the missing back wall of N.III.1 was never rebuilt, and the bipedales of the original springing of both the upper and lower arches can be seen in the side walls. A rectangular brick stamp (*CIL* 15.1000f) is still visible in one of the remaining bipedales (Lancaster 1995, cat. 42).

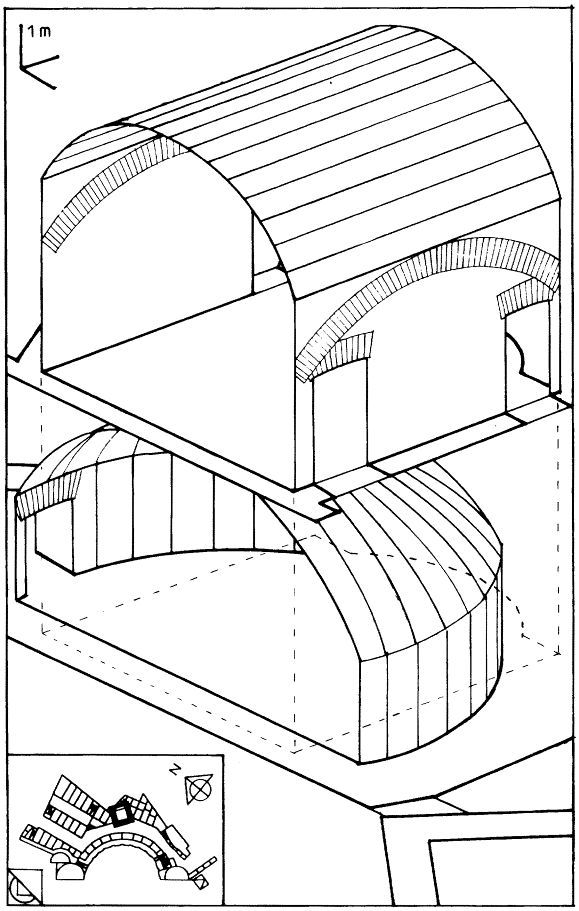

Fig. 8. Isonometric drawing of apsidal rooms E.IV.6 and E.V.6 with relieving arches in side walls

the Theater of Marcellus (ca. 17 B.C.) and the Colosseum (ca. A.D. 80).[19]

In the East Wing of the Markets, another slightly different use of the same technique occurs in room E.V.6. Here, a large relieving arch stretches the entire length of each of the side walls just below the imposts of the barrel vault. This rectangular room is located directly above the apsidal hall E.IV.6 (fig. 8). Since the apsidal hall is wider than the rectangular room above, the side walls of the upper room are located above the semidome of the lower rooms and are only supported by walls at either end. The large relieving arches help direct the weight of the vault to the ends of the wall where there is more support underneath. The necessity of including door openings in the side walls of E.V.6 precluded locating the relieving arches lower in the wall as in the level III North Wing rooms. The parts of the semidome supporting these walls are thick and apparently were not perceived as being as vulnerable as the crown, where the thickness is much less.

Brick Vaulting Ribs

The second method of resolving noncongruent floor plans is the use of brick ribs of *bipedales* to reinforce vaults. This technique had also been used earlier at the Colosseum.[20] At the Markets, the brick ribbing sometimes occurs in places where there is no obvious need for reinforcing, and as with the relieving arches, each individual case must be carefully examined to try to determine why the builder chose to use them.

In two places in the Hemicycle, brick ribbing was clearly meant to reinforce vaults in places where walls pass above them. In the south stairwell of the Hemicycle, stair H.I/II.12, a wide brick rib occurs in the rear portion of the vault (fig. 9). In this case, the back wall of the stair projects farther into the

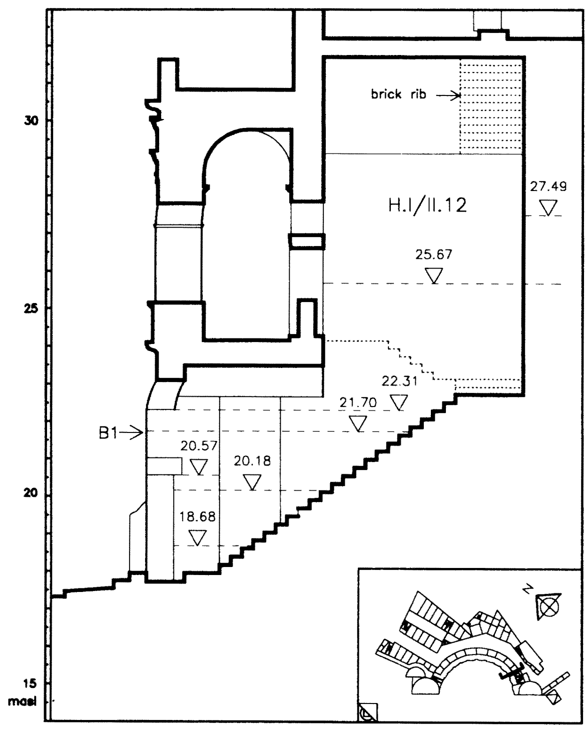

Fig. 9. Section through stair H.I/II.12 showing location of rib in vault. Scale 1:200.

[19] Theater of Marcellus: Calza Bini 1953, figs. 10 and 15; Colosseum: Lancaster 1998b, 167–9, fig. 31.

[20] Lancaster 1998b, 153–7, 167, figs. 25, 27–28. Some of the vaulting ribs at the Colosseum were also built of travertine voussoirs.

hillside than that of the adjacent room (H.II.11) so that the requisite number of treads and risers could be accommodated. The rib was apparently built into the extended portion of the vault to reinforce it where the level III wall passed above.

The second example of brick ribbing occurs at the north end of the Hemicycle in H.II.3. The rib, which is partially concealed behind the face of the wall, is particularly revealing because it is located above a bend in the back (north) wall of the room where two wings of the monument come together and possibly where the work of two crews of builders met (fig. 3).[21] A similar joint occurs directly above at level III, but it is not as neat and results in a jog in the north wall of H.III.3 so that the plans of the two rooms do not coincide.[22] The rib may have been built as a precautionary measure to reinforce the vault when it became clear that the walls at levels II and III did not align precisely (fig. 3). It would also have provided the constructional benefit of containing the concrete of the vault of H.II.3 until the adjacent work in the North Wing was complete.

Summary

The complexities involved in building a multilevel structure with noncongruent plans required a great deal of interaction between the architect, who designs such a structure, and the contractor, who actually integrates the ribs and relieving arches into the fabric of the building. The two different techniques of relieving arches and vaulting ribs were used interchangeably at the Markets to divert the load of an unsupported upper wall to the walls at the level below. In most cases, using the vaulting ribs would have been the easier and more economical of the two techniques, since the bipedales in a rib could have been laid less precisely than those in relieving arches, which would have been on the exposed face of a wall. In a situation such as the North Wing rooms, one might expect the vaults of the level II rooms to have been reinforced rather than to have had the double relieving arches built into the level III walls, since this required both more bricks and more labor. The explanation may be that the double relieving arches represent either a fix to a situation where the ribs were omitted when the vault was built or a change in the design that was made after the level II vaults had already been built.

Relationship between Architect and Builder. One wonders who decided when and where to use these techniques, the architect or the builder? Did the architect also act as site supervisor, or were the structural decisions left largely to the builder as the construction progressed? Vitruvius notes that he both designed and supervised the construction of a basilica at Fanum.[23] On the other hand, he speaks elsewhere of a separation between the supervision of the works and the duty of the architect, implying that the two were often distinct. He goes on to say that the architect should be willing to take advice from the workmen, which suggests that there was typically a hierarchy of site supervision with the architect perhaps making periodic site visits.[24] In most buildings, structural issues were no doubt resolved using long-established conventions passed down through the generations, but in a highly innovative structure, it is unclear who was ultimately responsible for the stability of the building—the architect who designed it or the contractor who built it.

Legal evidence from the *Digest of Justinian* sheds some light on the legal responsibilities of the architect and builder. One of the most common types of contracts used for Roman building projects was *locatio conductio*, a contract of lease and hire between two parties, the client and the builder.[25] In these types of contracts, the jurists are particularly concerned with the legal obligations of both the client and the builder in situations of building failure, but since the architect is not a party in the contract, his obligations are not discussed. The final legal responsibility for the stability of the building would lie either with the contractor (*redemptor*) who built it or with the client who hired the architect but not with the architect himself.[26] A builder working on a contract of *locatio*

[21] The significance of this building joint is discussed further in Lancaster 1998a, 293–7.

[22] The top of the rib was visible as the top part of a relieving arch in the facing of the projecting section of wall, though a recent (1999) raising of the floor level in H.III.3 has hidden it. The rib is apparently only one bipedalis wide, since it does not appear on the back side of the north wall of H.III.3.

[23] Vitr. *De arch.* 5.1.6.

[24] Vitr. *De arch.* 6.8.10.

[25] The imperial administration often hired private contractors for public works (Kolb 1993, 116–7; Martin 1989, 58–62; Brunt 1980; Lancaster 1998a, 305, nn. 52 and 53; Daguet-Gagey 1997, 223–30).

[26] Some hint of the architect's role can be gleaned from Ulpian's discussion of making faulty estimates where he equates architects with surveyors (*Dig.* 11.6.7.3), and then in the same section, he also notes that surveyors were not held responsible for faulty estimates since they provide their services as a favor based on an *honorarium* (*Dig.* 11.6.1). Martin (1989, 49) has suggested that in some cases architects may have also been hired on the basis of an honorarium rather than for a daily wage since both surveyors and architects offered technical rather than manual skills. In such cases, the architects would not seem to have been legally accountable for their mistakes.

conductio operis (in which he takes on a set amount of work for a fixed price) was responsible for the building only until the final inspection (*probatio*) by a designated approver,[27] who could have been, but did not have to be, an architect.[28] The role of the approver for the probatio, therefore, would have been critical, and in the case of Trajan's Markets, this could well have been an architect employed by the imperial administration. Even if he was not legally responsible for his own incompetence, he would surely have been held accountable by his superiors. With regard to the relieving arches and vaulting ribs at Trajan's Markets, we cannot know who made the decisions about where and when they were used, but there certainly would have been incentives, however different, for both the architect and the contractor to get it right.

ORGANIZING AND PROTECTING THE BUILDING SITE

For large projects such as Trajan's Markets, the design of the building site and the scheduling of the works were critical aspects of the planning process. The site had to be kept clear so that workers and materials could have access at all times. This was particularly important on a hillside site where stairs were the main passages. Another consideration was the protection of the site; travertine elements could chip or break, and concrete needed time to cure before acquiring its full strength. A number of unusual constructional features at the Markets may be best explained as precautions or conveniences related to the building process rather than to the final structure.

Layout of Hemicycle Facade

One of the first acts in building the Markets would have been to excavate and level the site and then to lay out the ground plan. In general, the Roman architects used geometrically defined forms and units of whole numbers as the starting points in the design. This practice is clear in the design of the Forum of Trajan itself.[29] For this reason, the layout of the Hemicycle curve at Trajan's Markets is anomalous: the curve was surely conceived as an arc, but as built it is not geometrically defined. The plan in figure 10 shows that the Hemicycle wall deviates from the arc that it most nearly approximates by as much as 87 cm. This would be an odd mistake, since laying out an arc was simply a matter of stretching a cord or chain from a central point. The other semicircular forms of the apsidal halls at the Markets are all accurate, geometrically defined arcs. One wonders why such a distorted form was used for the Hemicycle. One possibility is that a geological formation or earlier structure impeded the use of a true arc. Another possibility could be related to the organization of the building site. If the Hemicycle facade was laid out after the east exedra of the Forum had already been built up a few courses or more, stretching a cord from a central point located within the exedra would have been impossible, and the builders would have had to lay out the Hemicycle using offsets from the outer face of the exedra wall, which could have easily resulted in miscalculations.[30]

Brick Vaulting Ribs and Roof Tiles in Level II of the North Wing

Some of the vaults of the level II rooms of the North Wing contain *bipedalis* ribbing, the purpose of which is not as obvious as in previously discussed examples. The ribs occur in the annular barrel vault of the corridor around N.Ap and span from the projecting piers on the outer wall to the dividing walls of the opposite rooms (figs. 3 and 11).[31] They also are found where the barrel vault of each room joins the annular barrel vault of the corridor. Those at the entrances of rooms N.II.4–N.II.6 occur directly underneath the curved wall at level III and may be intended as reinforcing, as were those discussed above; however, the one at the entrance to N.II.7e does not support another wall above, nor do those spanning the annular corridor. Why then were they used? One explanation is that the builders added the ribbing as reinforcing because of some difficulty caused by the awkward working conditions in this area. The brick ribbing would have acquired strength much sooner than the surrounding concrete of the vaults because of the thin layers of mor-

[27] For a discussion of the legal obligations of the client and builder, see Martin 1989, 89–113, esp. 97–8; Kolb 1993, 129–30.

[28] In a third-century B.C. contract from Delos the architect is named along with the contracting agents as responsible for the final inspection (Burford 1969, 98).

[29] E.g., the width of the Forum itself is 400 ft. (without the porticos, 300 ft.), the length of the Basilica Ulpia (including apses) 600 ft., and the length of its nave half as long at 300 ft. (Packer 1997, pl. 24).

[30] I thank an anonymous *AJA* reader for pointing out this potential problem.

[31] Each rib is constructed of two rows of whole bipedales crudely placed in the mortar and staggered slightly to make a bond.

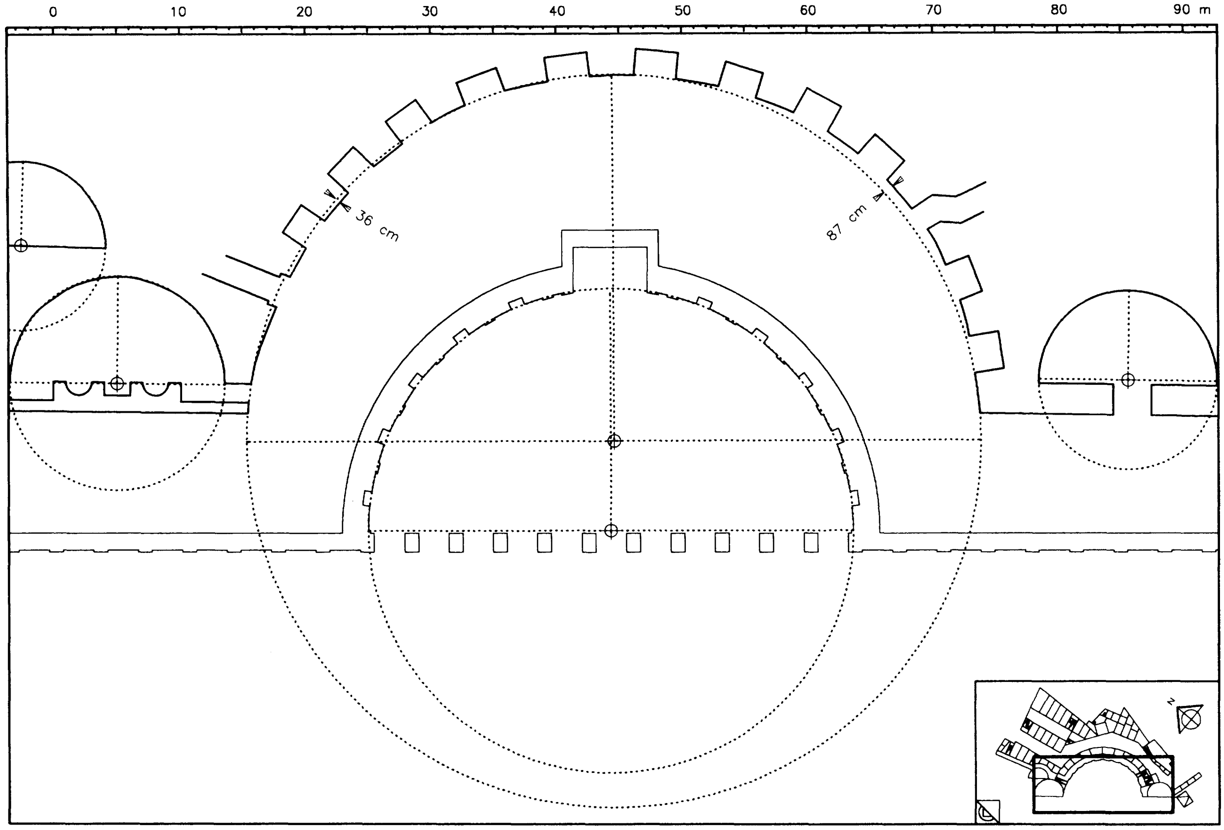

Fig. 10. Plan of level I of Trajan's Markets showing the governing geometry of curves. The degree of incongruity between the form of the Hemicycle facade and the nearest approximation of an arc is indicated at either side. Scale 1:600.

tar used between the bricks and the fact that the bricks acted like the voussoirs in a stone arch.[32] Since the access to these rooms during construction would have been restricted by the excavated hillside to the east and by the semidome of N.Ap to the west, the vault may have had to withstand heavier than normal loading at an earlier stage in the process. Other examples of brick ribbing used to reinforce vaults that underwent excessive loads during the building process suggest that this was an issue that often concerned Roman builders.[33]

Another unusual technique in the same area lends support to this explanation. The extrados of the semidome of N.Ap was covered with a double layer of roof tiles (fig. 12).[34] Since the adjacent semidome of H.ApN had no rooftiles, they do not seem to have been necessary for waterproofing. As mentioned above, construction in this area must have been very awkward because of its confined location, and like the vaulting ribs, the tiles could have been employed as added protection against damage from the activities in the adjacent areas. They would have also had the advantage of providing a firm base on which to set up scaffolding.

Buttressing Wall and Stairs on the Extrados of H.ApN

H.ApN is the largest of the four apsidal halls at the Markets (17.15 m dia.), and its vault displays two features of particular interest: a brick-faced buttressing wall surrounding the base of the semidome and three sets of stairs built into the extrados (fig. 13). These elements provide some evidence for the builders' concern both for the structural integrity of the building and for the building process.

---

[32] DeLaine 1997, 164.

[33] For examples of vaulting ribs used to protect the building site, see Lancaster 1999, 423–4; DeLaine 1997, 164–5, 168.

[34] On the bottom row, *tegulae* were placed side by side with the flanged joints covered by mortar and then by curved tiles (*imbrices*). Usually two pieces of broken brick separated by layers of mortar were placed on top of the tegulae between the imbrices to create a level surface, and another layer of tegulae, most of which is missing, was added on top. At least one of the whole tegulae has a Trajanic brick stamp (*CIL* 15.97b; Lancaster 1995, fig. 6, cat. 7).

The brick-faced wall once surrounded the entire base of the vault,[35] but at some point in the post-antique period, a large portion of the north side of the semidome and the wall surrounding it was cut away revealing a vertical section through the vault. A 15 cm thick layer of *opus signinum* (mortar with crushed terra-cotta added) covers the curving profile of the vault and extends under the concrete core of the wall all the way to the level of the terrace (fig. 14). This detail has not been noted in the past, but it is significant to the interpretation of the purpose of the wall. W.E. MacDonald has suggested that rings of masonry, such as the wall around H.ApN, were sometimes built simultaneously with the vault to avoid having to construct the lower sloping parts of the extrados.[36] The wall around the base of H.ApN, however, was clearly built after the semidome was completed and given a covering of opus signinum. In this case, the wall was probably intended primarily as a buttressing device to add weight to the lower part of the vault to counteract any lateral thrusts that developed.

Fig. 11. Brick vaulting ribs in North Wing corridor outside of room N.II.6

The second feature comprises the three sets of steps built into the extrados of H.ApN. K. de Fine Licht has commented on the oddity of building three sets of steps on such a small dome,[37] and this feature deserves some comment. The steps extended below the top of the surrounding wall to the level of the terrace,[38] as can be seen where the north part of the surrounding wall has been cut away (fig. 14). Other domes, such as the "Temple of Minerva Medica" at Rome (24.50 m int. dia.), the "Temple of Mercury" (21.5 m int. dia.) at Baiae, and most notably the Pantheon (43.3 m int. dia.), have steps built into the extrados. These, however, are larger, full round domes, and the necessity of having steps to access the top for construction and maintenance is understandable. So many stairs located close together on the extrados of the semidome of H.ApN is more difficult to explain. The fact that the stairs on H.ApN were covered by the buttressing wall after they were built suggests that they were used during construction rather than for maintenance afterwards. One possibility is that they aided in the construction of the vault by dividing it into zones and providing access to the top so that the workers did not have to step on the previous day's work. The bipedalis treads could also have acted as bases for supports for benches on which supplies of *caementa* and mortar could rest while the masons were laying the upper parts of the vaults. The function of the stairs probably related to the construction process in some way, and like the tiles on the extrados of N.Ap, the stairs may well have been intended to protect the vault from workers and materials while the mortar was setting and curing.

Construction Opening in H.II.4

Occasionally one finds in Roman buildings

[35] The height of the remains of the surrounding wall varies; at the highest point, a brick cornice lies ca. 1.30 m above the level of the terrace. On top of the wall, a mixture of mortar and broken bricks slopes up from the edge of the facing towards the extrados of the semidome. This area was restored in the 1930s, and some of the mortar mixture may belong to these restorations, but Trajanic brick stamps found in the facing of the wall itself show that it was an original feature of the design (*CIL* 15.67a and 610; Lancaster 1995, fig. 6, cat. 4, 9, and 10).

[36] MacDonald 1982, 110 n. 42.

[37] de Fine Licht 1968, 275 n. 20.

[38] The treads are flush with the outer surface (fig. 13) and are covered by two bipedales placed side by side. The risers are faced with three or four courses of brick underneath the bipedales. In most cases, the treads are at least partially covered by the opus signinum that covers the rest of the extrados.

Fig. 12. Extrados of N.Ap showing remaining roof tiles on semidome

walled up openings that were clearly never intended to act as windows or doors during the life of the building, and in many cases, these were probably built to aid in the construction process.[39] One such example occurs in the back wall of H.II.4, where a relieving arch and the outlines of a bricked up opening are visible (fig. 15). The opening could never have functioned as a window or door because its threshold, which was formed by a course of bipedales, occurs ca. 1.7 m above the present floor level, and it would have opened directly onto the hillside against which these rooms are built. The opening must have been closed soon after construction, since the brickwork of the closed area resembles that of the walls to either side.[40] The most probable explanation is that it was used during the construction process and then closed when it was no longer necessary. During construction, the opening would have allowed access to the other side of the wall. Concrete walls were typically built with a pair of masons, each working on opposite sides of the wall. Before the vaults of the Hemicycle rooms were added, the back side of this wall would have been easily accessible from the top. Once the centering for the vaults was built, however, the workers would have had to go all the way to one end of the Hemicycle to get around to the other side. Construction of this opening into the back wall of one of the rooms allowed easy passage from one side of the wall to the other. Once it was no longer of use, the opening would have been closed.

Construction Sequence of the Rooms along the Hemicycle Facade

The planning of the construction sequence is easy to take for granted once everything is in place, but during the building process it could have presented substantial challenges to the builders. Stone elements were particularly susceptible to damage, and precautions had to be taken to protect them. In cases where the stone pieces were cantilevered, maintaining a structural equilibrium was essential. In addition, the wooden centering necessary for the concrete vaults had to be lowered and removed without damaging other parts of the structure. A clear example of the complexity involved in planning and building an apparently simple structure can be seen in the ground level rooms along the Hemicycle facade.

The curving facade of the Hemicycle is today one of the most recognizable features of Trajan's Markets. At ground level, it comprises a series of small,

[39] E.g., DeLaine 1992, 172; de Fine Licht 1974, 15.

[40] Patches of the brickwork in both the surrounding wall and the infill have been restored, though much of the original is preserved. The module (= height of five courses and joints) of the surrounding wall varies from 25.5 cm to 27.5 cm. The courses of the infill at the upper left corner aligns precisely with those of the surrounding walls, but those at the lower right corner do not align and have a module of 30 cm.

barrel-vaulted rooms opening onto a road running behind the east exedra of Trajan's Forum. A wide, projecting travertine doorway, which supported a brick-faced facade wall,[41] provided access to each room. The unusual tripartite construction of the lintel of the travertine doorframe indicates the challenges faced by the builders during the construction of these rooms.[42] The central piece of each lintel was formed as one long voussoir supported by the two corner blocks, which were doweled to the top of the travertine jamb blocks and embedded into the side walls of the rooms for a distance of ca. 80 cm (fig. 16). The jamb blocks themselves were not bonded to the Hemicycle wall. The corner blocks cantilevered out from the jamb about 20 to 30 cm and, therefore, had to be embedded into the wall to stabilize them before the central voussoir block was added. By choosing to add the central block of the lintel as a separate piece, the builders created a difficult situation requiring careful balancing between the parts. Why then did they not simply make the lintel block span from jamb to jamb in a single monolith?

Fig. 13. Overview of extrados of H.ApN showing stairs and cut away portion of vault to right

One reason could have been structural: adding the central piece as a shorter segment supported on the cantilevered corner blocks would have resulted in less bending stress on all three blocks than would have occurred in one long lintel block.[43] Special precautions were taken to protect the voussoir block, which was the most vulnerable part of the doorframe construction since too much pressure at the center could cause it to break. A relieving arch in the facade wall served to divert the load of the wall away from the central portion (fig. 17).[44] The facade wall of H.I.6 has been reconstructed with a window above the lintel, and if this is an accurate reconstruction, as seems probable, the window would also have served to eliminate the pressure from the critical part of the voussoir block. The only other original travertine doorframes at the Markets were found in the doorways of the level III North Wing rooms along Via Biberatica. All three have monolithic rather than tripartite lintel blocks. The openings of these doorways are ca. 2.5 m wide and are covered by lintels 35 cm high, whereas the openings of the Hemicycle rooms are ca. 3 m wide and are covered by lintels 45 cm high. Even though the Hemicycle openings are somewhat wider, this increased span does not seem sufficient to justify the tripartite construction for purely structural reasons given the larger lintel size of the Hemicycle rooms.

A second reason for building the lintel in three pieces would have been constructional: an obvious advantage of this method is that it allowed a clear opening for erecting and then removing the centering of the vault (fig. 16). If the lintel had been fixed in place earlier in the process, it would have created a horizontal barrier partially blocking the opening and impeding access to the room. Since the lintel projects out from the facade, it could also

[41] Most of the upper parts of these brick-faced facade walls have been destroyed, though traces still survive in some places. One of these, H.I.6, was reconstructed during the work of the 1920s and 1930s and gives an idea the original appearance.

[42] The following analysis was inspired by a discussion of the use of the lintel arch in these rooms by J. DeLaine (1990, 414, figs. 5–6). I am grateful to her for bringing this detail to my attention during the early days of my work at the Markets.

[43] A similar tripartite construction is used in the lintels over the doorways leading into the octagonal room of the Domus Aurea; however, the central part there is built of bricks rather than a monolithic stone. DeLaine (1990, 411) discusses the advantages of the lintel arch over the monolithic lintel.

[44] The original parts of these arches are visible at H.I.4, H.I.8, and H.I.11.

Fig. 14. Detail of cutaway portion of vault showing the line of opus signinum (indicated by arrows) and the steps continuing below the concrete of the surrounding wall

have been easily damaged during the construction of the vault and during the decentering process, when the wooden structure was lowered and taken apart. Building these apparently simple rooms in such a complex manner had the advantages of reducing the possibility of long-term damage and of providing short-term protection during the construction process.

The connection between the central block and the corner blocks differs from one room to another, which suggests that the details may not have been specified and were left up to the builders. The surviving oblique surfaces of some of the corner blocks have dowel holes cut into them, indicating that in some cases the central block was doweled to the corner blocks. The oblique surfaces of both corner blocks survive and are visible in only two of the rooms: H.I.4 and H.I.13. The two surviving surfaces of the former have no traces of the dowel holes, whereas those of the latter each have the dowel holes. The northern face of H.I.13 also has a vertical pour channel (missing on the southern one) showing that at least one of the dowels was fixed with lead. The detail of the pour channel is also visible on the oblique face of the southern corner block of H.I.8 (fig. 18). In cases where dowels were used, they would have first been attached to the central piece and then lowered into position, probably by tilting one end down to slip the dowel into its hole and then lowering the other end. The indentation of the vertical pour channel would have also provided some extra space for the second projecting dowel to slip into its hole. The block would have then been anchored by pouring lead into the

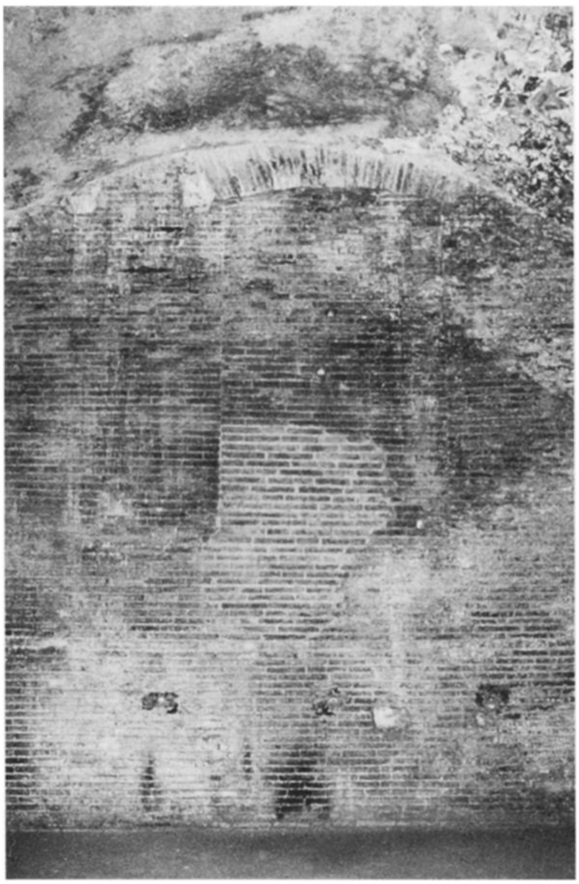

Fig. 15. Blocked opening in room H.II.4

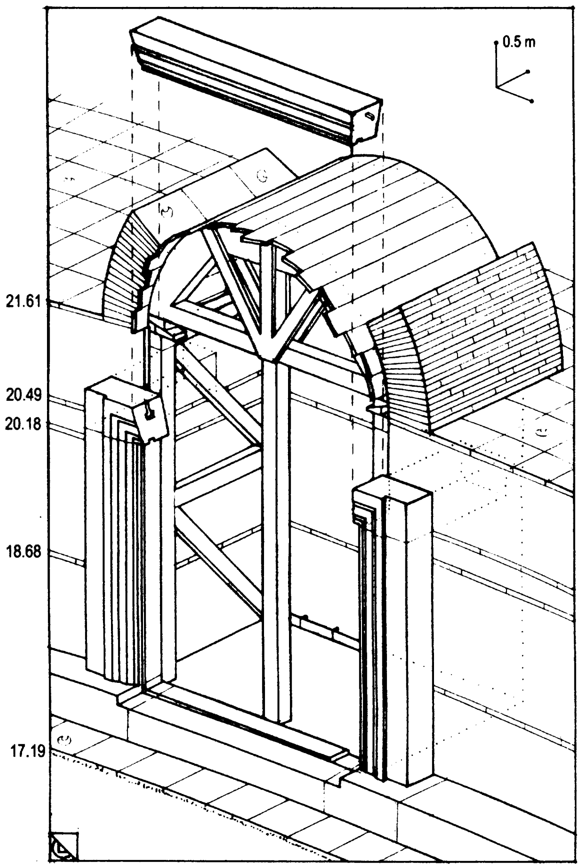

Fig. 16. Reconstruction of centering and formwork used to construct level I Hemicycle rooms. Travertine lintel piece is shown above. Numbers indicate height (masl) of bipedalis courses.

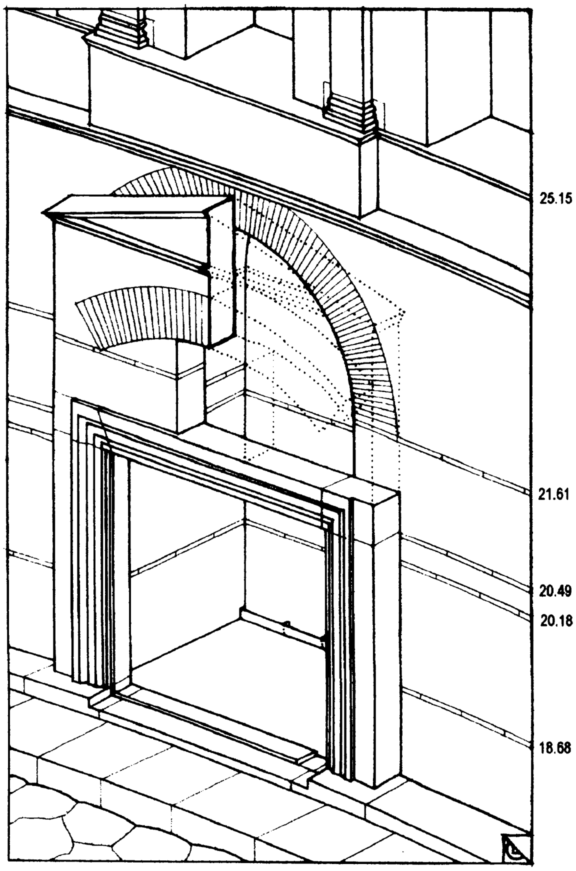

Fig. 17. Reconstruction of finished level I Hemicycle room partially cut away to reveal face of vault. Numbers indicate height (masl) of bipedalis courses.

channel from above. The surviving evidence suggests that only the dowel at one end was secured with lead and that in some cases the central piece was not doweled at all. The differences between the construction of one doorway and another could be the result either of various builders using different techniques or of a process of experimentation, during which they found that using the dowels was simply too cumbersome. In any case, it would appear that the method of connecting the blocks was not a specified detail and was left up to the discretion of the builders.

All of these rooms were built with vaults consisting entirely of brick ribbing (figs. 16 and 18), a very unusual detail that again suggests that the builders took special measures to protect this area during construction. The bipedalis ribbing may have been employed as reinforcement, since the vaults of the rooms support the 1.17-m thick facade wall at level II. It would have protected the vaults against excessive loads during the construction process. In addition, since the bipedalis ribbing would have acquired strength faster than normal concrete vaulting, it would have facilitated the early removal of the centering so that the construction of the facade walls could begin immediately. These rooms along the Hemicycle appear to be quite simple constructions, but the care with which they were built is indicative of the level of forethought and planning required of the builders to ensure that both damage and delay were avoided.

Summary

Designing the work site and scheduling the sequence of building phases was an important aspect of planning such a large and complex project so that access to critical areas was kept clear at all times. The deviation of the curve of the Hemicycle facade from a geometric norm could have been a result of having to lay out the curve once construction had proceeded to the point where it was no longer possible to stretch a cord from the appropriate center point. Even if this was not the case, it exemplifies the type of problem that the builders had to anticipate. Similarly, the opening built into the back wall of H.II.4 was clearly intended to be used only dur-

Fig. 18. Detail of corner block of travertine lintel of room at H.I.8 with dowel hole and pour channel (indicated by arrow). Note the bipedalis ribbing of the vault.

ing construction to solve some difficulty in accessing certain parts of the site. The sequence of construction was also important in maintaining stability and equilibrium during the process of putting the pieces together, such as in the rooms along the Hemicycle facade. An even more complex example, the Aula, is discussed below.

Protection of the Building Site. Other techniques seem to have been used to protect the site from damage during construction. In private construction, the builder accepting a project on locatio conductio operis also took on the responsibility of protecting the building and its site during the construction process,[45] and, as discussed above, he was freed from responsibility once the building was inspected. Projects such as Trajan's Markets were undertaken by the imperial administration as opposed to private individuals, and little evidence exists for the way in which these projects were managed,[46] but evidence shows that private contractors were often used.[47] Whether they took on the same degree of responsibility when agreeing to work on a highly innovative, imperially sponsored structure is unclear. At Trajan's Markets, the examples of the anomalous brick vaulting ribs in the level II North Wing rooms, the brick ribbing of the ground level Hemicycle rooms, or the use of roof tiles on the extrados of N.Ap may imply that the builders were responsible for damage to the site and took added precautions to prevent such occurrences.

CASE STUDY 1: THE AULA AT TRAJAN'S MARKETS

The Aula at Trajan's Markets provides an instructive example of the many issues confronting the ancient builders. Toward the end of the 16th century, the Aula was incorporated into the convent of St. Catherine of Assisi, and parts of the original structure were altered. Much of what is visible today, such as the floor covering and the travertine doorframes, is the result of the reconstructions of the 1920s and 1930s, but the underlying brick and concrete structure is original, albeit refaced and patched in places. The Aula consists of a central hall at level IV covered by six cross vaults and flanked by two levels of rooms on the west side and three on the east side (figs. 19–20). The six cross vaults covering the central hall are supported on 14 travertine piers that once formed the corbels supporting the cantilevered portion of the vault. The projecting corbels and vaults were cut away when a floor dividing the central hall into two stories was added after the structure was converted into a convent.[48]

[45] Martin 1989, 89–102.

[46] The generally accepted view is that the organization and management of the construction of new buildings was not the responsibility of the *cura operum publicorum* and that the emperor entrusted these duties to other experts (Bruun 1991, 200–6; Eck 1992, 242–3), but Kolb (1993, 53–7) suggests that, in spite of the dearth of direct evidence for the involvement of the cura operum publicorum, this agency may well have supervised the construction of new buildings.

[47] Supra n. 25.

[48] It has been suggested that the Aula cross vaults were originally divided by projecting brick ribs (Incisa della Rochetta 1961, 203; Bianchini 1991, 109–10, figs. 11 and 12). The evidence consists of Renaissance depictions of the Aula. A painting by Giulio Romano, *The Stoning of Saint Stephen* (Genoa 1523), shows projecting ribs, but they are obviously a result of artistic fantasy, as is clear from some of the other unusual constructional features evident, such as pots embedded in the vaults. A sketch by Sallustio Peruzzi (Bartoli 1919, pl. 395 fig. 703) shows the arch on the north facade of the Aula, but a close examination of the drawing shows that the interior vaults are, in fact, not shown with ribs at all. The surviving archaeological evidence shows no scars remaining on the vaults to indicate that ribs ever existed.

Layout of the Aula

The layout of the rooms to either side of the Aula is at first glance regular, but a comparison of the widths of these rooms illustrates some of the problems encountered in translating a drawn design to the built structure. At level IV, the six rooms to either side of the central hall of the Aula vary in width by a maximum of 43 cm (west) to 65 cm (east) (fig. 19);[49] the average width of these rooms is just over 15 ft., although no single room is built to that precise width.[50] The dividing walls do not align from one side to the other, nor are the variations in width consistent on each side.[51] A situation similar to the Aula rooms occurs in the level II North Wing rooms, where the widths also average about 15 ft., though they, too, vary and are rarely exact. Elsewhere, the four East Wing rooms along Via Biberatica, E.III.13–16, were all laid out and built with widths of precisely 15 ft. (4.41 m). A 15 ft. module also seems to have been used in laying out critical heights along the Hemicycle facade elevation,[52] so it was not restricted to the design of the plan. As mentioned

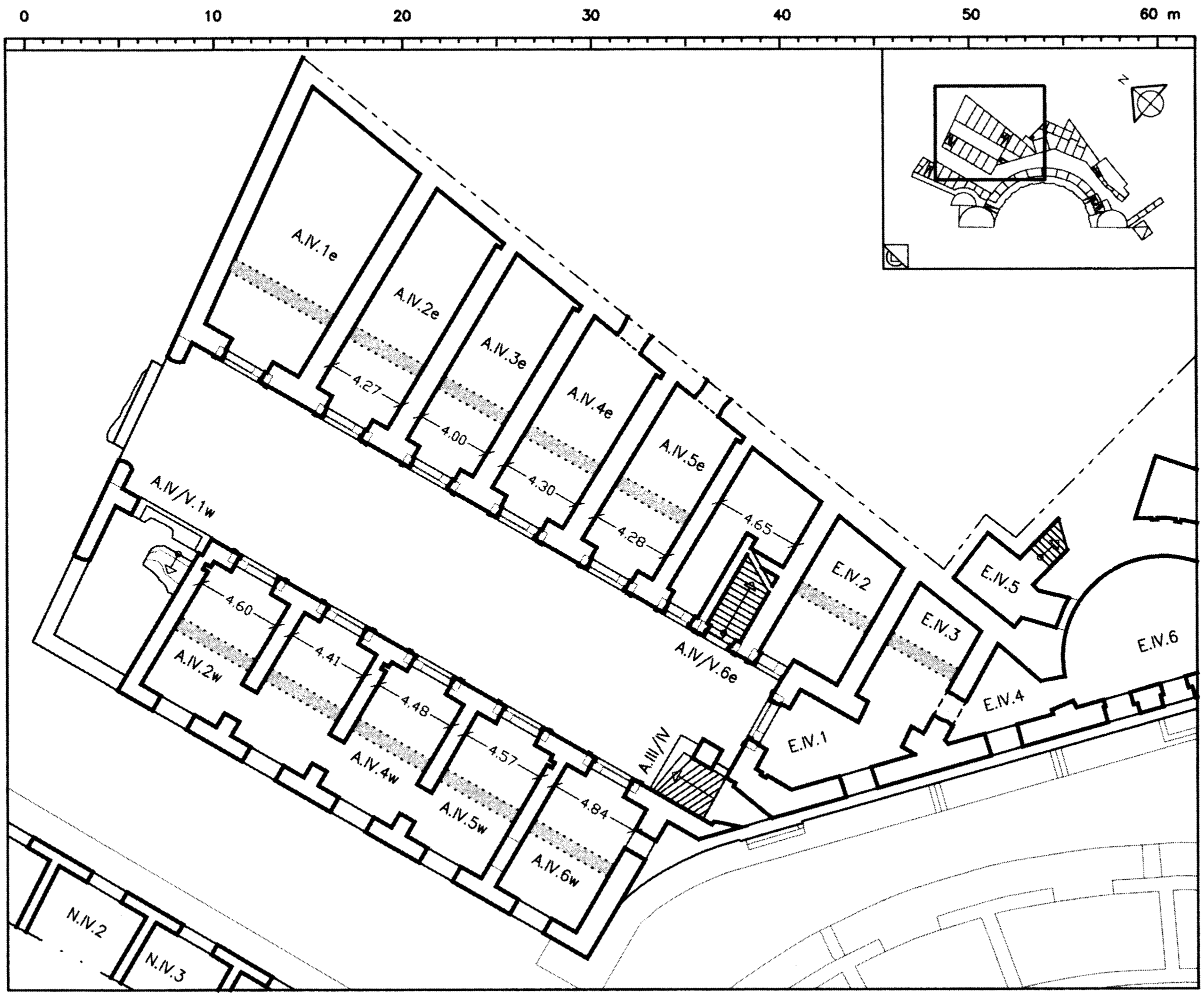

Fig. 19. Plan of level IV of the Aula. Brick vaulting ribs shown in gray. Locations of level V cross walls indicated by dotted lines. Scale 1:400.

[49] Measurements show that the width of the west rooms from north to south (not including bay 1) are: 4.60, 4.41, 4.48, 4.57, and 4.84 m; those of the east rooms are: 4.27, 4.00, 4.30, 4.28, and 4.65 m.

[50] Packer (1997, 471) found that a Roman foot of 29.38 cm consistently yielded round numbers of Roman feet at the Forum of Trajan. In translating the metric measurements at the Markets, I have used a slightly larger Roman foot of 29.40 cm.

[51] The wall thickness also varies from one side to the other: the dividing walls of the west rooms are 3 ft. thick, whereas those of the east rooms east walls are 4 ft. thick. The greater thickness of east walls is because they are buttressing the hillside as well as supporting an additional floor of rooms at level VI.

[52] The vaults of all the ground level rooms along the Hemicycle facade spring from a bipedalis course located 15 ft. above the foundation level bipedalis course. Below this level, intermediate courses of bipedales occur at five-foot intervals (Lancaster 1998a, 290, fig. 4).

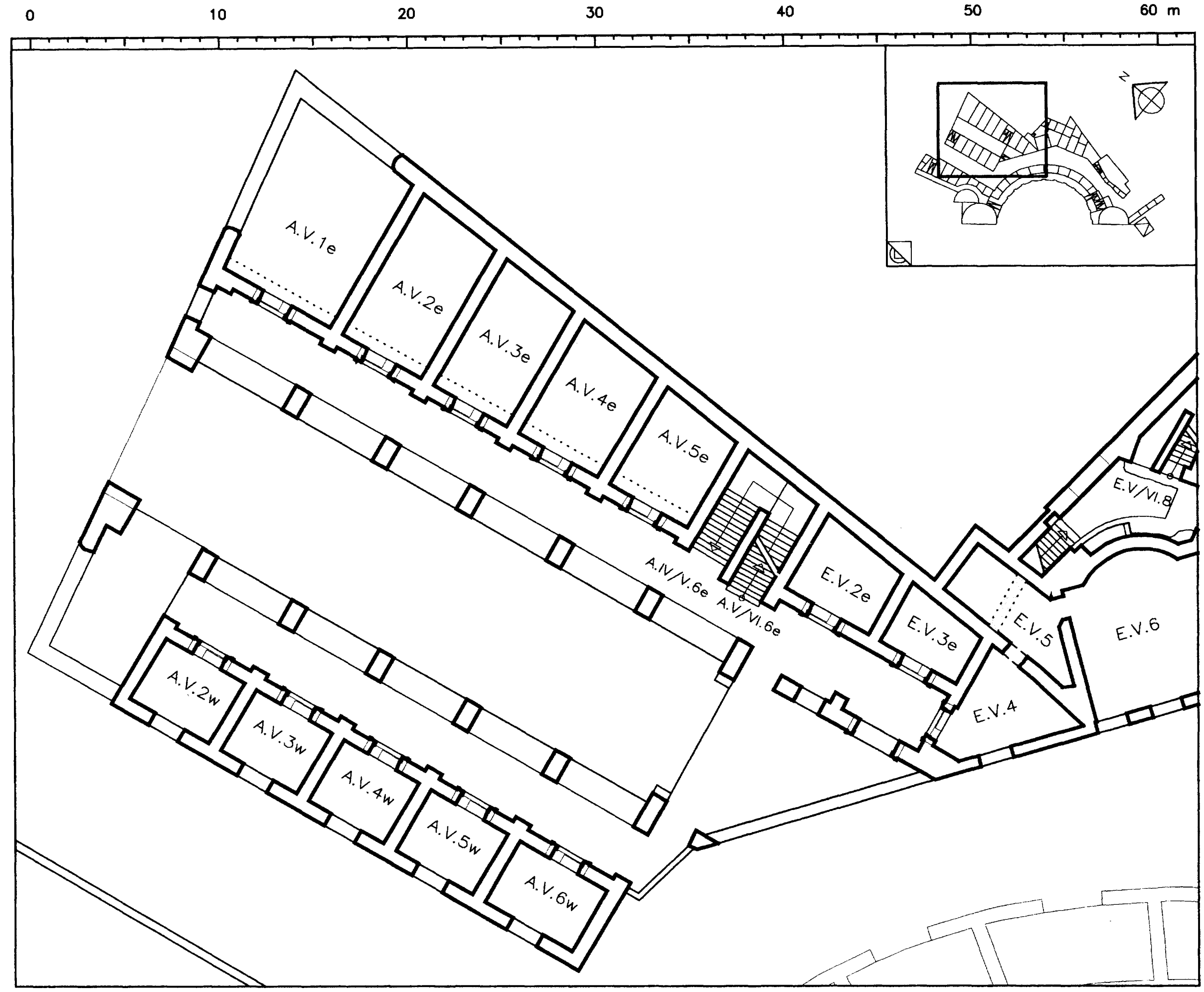

Fig. 20. Plan of level V of the Aula. Brick vaulting rib shown in gray. Locations of level VI walls are indicated by dotted lines. Scale 1:400.

above, the known marble plans of Rome were typically drawn at a scale of 1:240. If this was a common scale used by architects and builders, a unit of 15 ft. would have been represented by one digit on a standard ruler and would have been a very convenient planning unit.

The 15 ft. unit was not strictly applied in the layout of the built version. The incongruity probably lies in the translation of the plan to the site. The type of information recorded on the plan may help explain the variations in widths; for example, the few known plans that have room dimensions noted do not give the wall thickness.[53] Since the builders at Trajan's Markets typically used standardized wall thicknesses, noting them on the plans would not have been critical information, but this method of conveying only the basic information would naturally result in some discrepancy between the drawn and built plans.[54]

Brick Vaulting Ribs

The most consistent and calculated use of brick vaulting ribs at the Markets occurs in the Aula. In order to provide light and access to the level V rooms on either side of the central hall, the front

[53] E.g., on the marble plan from Urbino (supra n. 9), only the wall lengths are noted while the wall thicknesses are left out. Similarly, a rare example of a house plan (third century B.C.) drawn on papyrus seems to have measurements for interior wall lengths indicated without wall thicknesses, but the plan is not proportionally accurate, and there is some debate on the meaning of the numbers (Maehler 1983; Lobel et al. 1957, 142–5).

[54] On the variation between design and construction at the Baths of Caracalla, see also the discussion by DeLaine (1997, 47–52, 66–8).

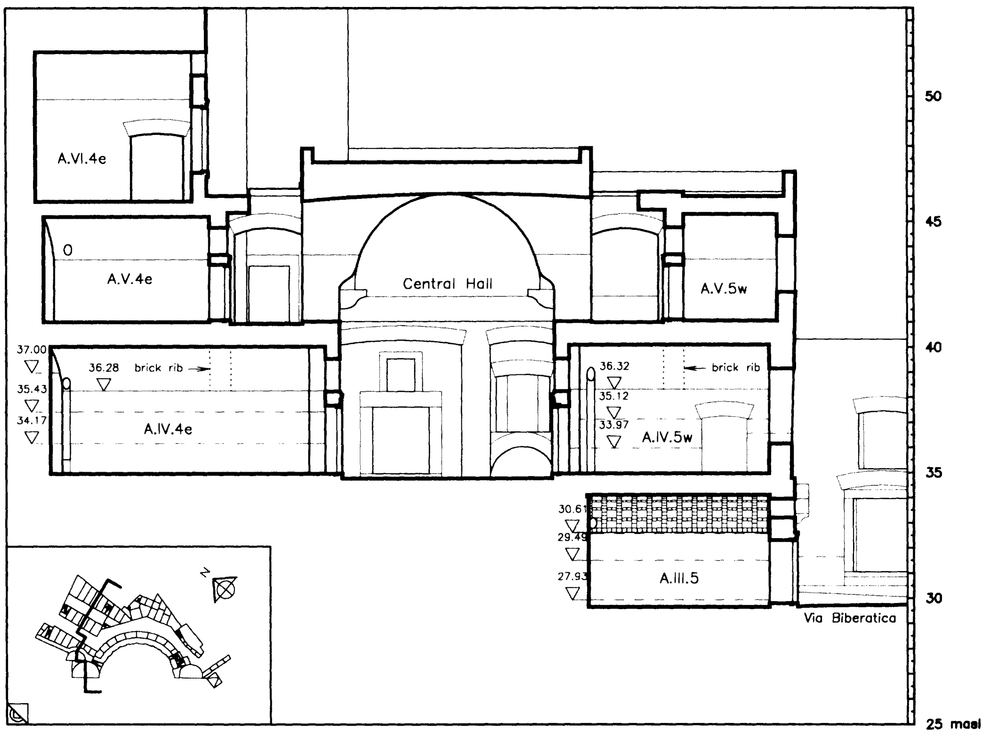

Fig. 21. Section through Aula. Location of bipedalis courses indicated in dashed lines marked with meters above sea level. Scale 1:300.

walls of these rooms were set back to form a gallery open to the sky. The vaulting ribs were built into the vaults of the level IV rooms precisely where the level V walls crossed above them (fig. 19).[55] The resulting situation is very similar to that of the level III North Wing rooms, where the double relieving arches were used (see above). In this case, however, using relieving arches to channel the load of the wall away from the vaults below would have been less effective (and more expensive), since they would have had to occur above the doorways into the rooms.

One example in the Aula where vaulting ribs or relieving arches might be found, but where neither was used, is in the facade wall of the level VI rooms. This wall is set back slightly so that it does not align with the facade wall of the rooms below, but the vaults were not reinforced with brick ribs as were the level IV vaults in a similar situation.[56] Given the other examples of their use, the absence of ribs in the level V Aula vaults is surprising. This suggests that the architects or builders had a degree of flexibility in deciding when and where to use certain techniques.

Buttressing

The vaults of the central hall of the Aula were elevated on travertine piers rising from the galleries on either side. This configuration had the advantage of allowing much more light to enter the space via the galleries, but it also created a rather precarious structural situation by detaching the cross vaults from the lateral rooms, which would have provided buttressing support for the vaults. The solution was to build arches over the gallery space to connect the dividing walls of the rooms to the cross vaults (fig. 21). The arches were intended to transfer any horizontal thrust from the vault to the dividing walls and are early precursors to the flying buttresses that later became the hallmark of French Gothic architecture.

Since the weight of the cross vaults was concentrated on the 14 travertine piers, the area resisting the forces generated by the weight of the vaults was reduced and the stress in the supports correspondingly increased. The load on each pier would have been ca. 87,125 kg, which translates to a compres-

[55] Each rib consists of a combination of whole and broken bipedales, carefully placed so that the edges are precisely defined. The East Wing rooms E.IV.2 and E.IV.3 on the south side of stair A.IV/VI.6e represent a similar situation. The vault of E.IV.3 has a rib underneath the level V wall. It is built slightly differently from those in the Aula rooms and may indicate that different builders were working on each side of stair A.IV/VI.6e (Lancaster 1998a, 297). The vault of E.IV.2 is currently plastered, but it probably has a similar vaulting rib.

[56] Bianchini (1985, 237–8) has also noted the lack of ribs here.

sive stress of 6.6 kg/cm^2, which is well within the capacity of the travertine piers; however, lateral thrusts could have developed from cracking in the vaults, creep in the concrete, or even wind pressure.[57] The use of the buttressing arches was a measure to counter factors such as these.

Choice of Materials for Concrete Vaulting

The choice of materials used in the concrete vaulting at the Markets suggests that the builders were particularly concerned about the stability of the central hall cross vaults. Roman concrete vaults, unlike modern ones, which are poured into place, were built manually by laying fist-sized pieces of stone or brick (i.e., the caementa) into a mortar made of lime and pozzolana. Most vaults at Trajan's Markets are constructed using caementa of *tufo lionato* (also known as Aniene tufa) sometimes combined with brick fragments. The vaults of the central hall of the Aula are the only ones at the Markets made with caementa of *tufo giallo della via Tiberina* (also known as Grotta Oscura tufa). The tufo giallo, which is a product of the Sabatini volcanic system and quarried north of Rome, weighs less than the tufo lionato, which is a product of the Colli Albani volcanic system and quarried to the south and east of Rome.[58] Roman builders had long recognized that the tufo giallo was lighter,[59] and it was employed in vaults as early as the Augustan period at the Basilica Aemilia and the Horrea Agrippiana, though its use then was not yet commonplace. By the Trajanic period, the use of tufo giallo tended to be reserved for the more structurally challenging vaults to reduce weight. The use of tufo giallo in place of tufo lionato in the cross vaults of the Aula would have reduced the weight of these vaults by about 10%.

Construction Sequence

Because the Aula consists of a variety of different parts structurally dependent on one another, the builders had to plan the order of construction carefully so that each element was supported and kept in equilibrium during the building process. They also had to plan for the construction and removal of the wooden centering necessary to build the vaults. A number of constructional details give an indication of how this was accomplished.

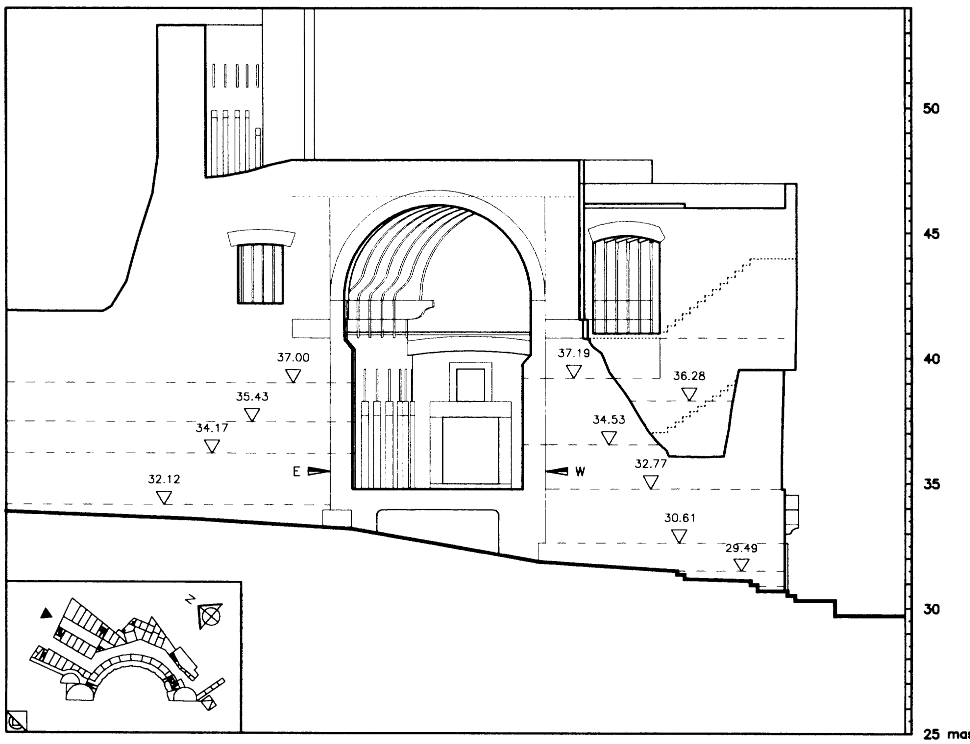

Fig. 22. Elevation of north facade of Aula. Location of bipedalis courses indicated in dashed lines marked with meters above sea level. Scale 1:300.

[57] Mark 1986, 32.

[58] The tufo giallo typically contains more pieces of light scoriae, which account for the reduction in weight over the tufo lionato. For the location of the quarries of tufo giallo, see Ashby 1924, 135–9. For tufo lionato, see Strabo 5.3.11 and Quilici 1974, 62–78, 105–18, 143–69.

[59] Tufo giallo = 1320 kg/m^3; tufo lionato = 1600 kg/m^3.

On the north facade of the Aula (fig. 22), two vertical construction joints are visible. At the base of the wall to the west, a bipedalis course (30.61 masl)[60] extends 29 cm past the westernmost vertical construction joint (fig. 22W), which aligns with the inner facade wall of the level IV west rooms. The easternmost construction joint (fig. 22E), which aligns with the inner facade wall of the level IV east rooms, is marked by an 86 cm (ca. 3 ft.) setback formed by a travertine block inserted into the foundations. These two vertical construction joints show that the east and west sides of the Aula were built separately and that the foundation wall for the central hall was added afterwards, since it was built up to and over the setback formed by the travertine block to the east and the bipedalis course (30.61 m) to the west (fig. 23).

The joints on either side of the central hall continue up the north facade into the uppermost part, where the wall has been heavily restored. Much of the central section of this wall has now been cut away, but it would originally have been closed with an entrance in the center and an open lunette above formed by the intrados of the cross vault.[61] The two vertical construction joints imply that the north facade was the last element built before the vaults were added. If, in fact, the main access for workers, materials, and equipment was from the north, the north wall would have been added last so as not to impede access while the centering was erected. The wall had to have been added before the central hall centering was removed, but all of the centering from the side rooms could have been removed before the wall was added.

The two vertical construction joints abut the outer edges of the bipedalis arch that terminates the cross vaults on the north facade of the Aula. These joints can also be seen on the opposite side of the piers supporting the northernmost cross vault (fig. 24E). Significantly, none of the other piers has such a joint. Of the 14 corbels, the other 12 to the south were each clamped to the lower travertine block using

Fig. 23. Detail of west joint (W on fig. 22, indicated with arrows) on north facade of Aula

[60] Individual courses of bipedales are identified by the number of meters above sea level (masl).

[61] The existing road running in front of the Aula, which is paved with selce, follows the course of the ancient Roman road, but the present paving was laid in the second half of the 10th century (Meneghini 1995a, 48). The remains of what was probably a central staircase project onto the road under the modern bridge providing access to the Aula from Via IV Novembre. The only clue to the original door opening in this facade comes from a small sketch from the mid-16th century by Sallustio Peruzzi, which shows an opening flanked by two columns and topped by a pediment (Bartoli 1919, pl. 395 fig. 708). Since the bipedalis courses (37 and 37.19 masl) in the central part of this wall do not align on each side, the original opening in this facade must have reached to at least the level of the uppermost one. The lunette of the vault would have been open with its bottom surface ca. 15 cm below the bottom face of the travertine corbel blocks (ca. 39.40 masl), as can be seen from the remains of the brick facing on the side walls.

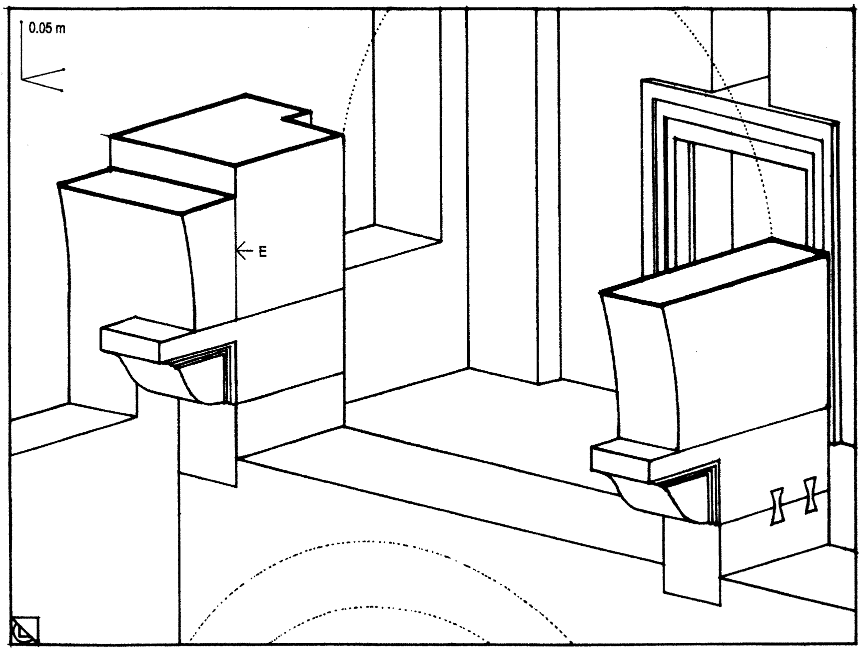

Fig. 24. Isonometric drawing of the two northernmost piers on the east side of the Aula. Construction joint (E on fig. 22) shown on left pier. Right pier has swallowtail clamps connecting the corbel block to its base.

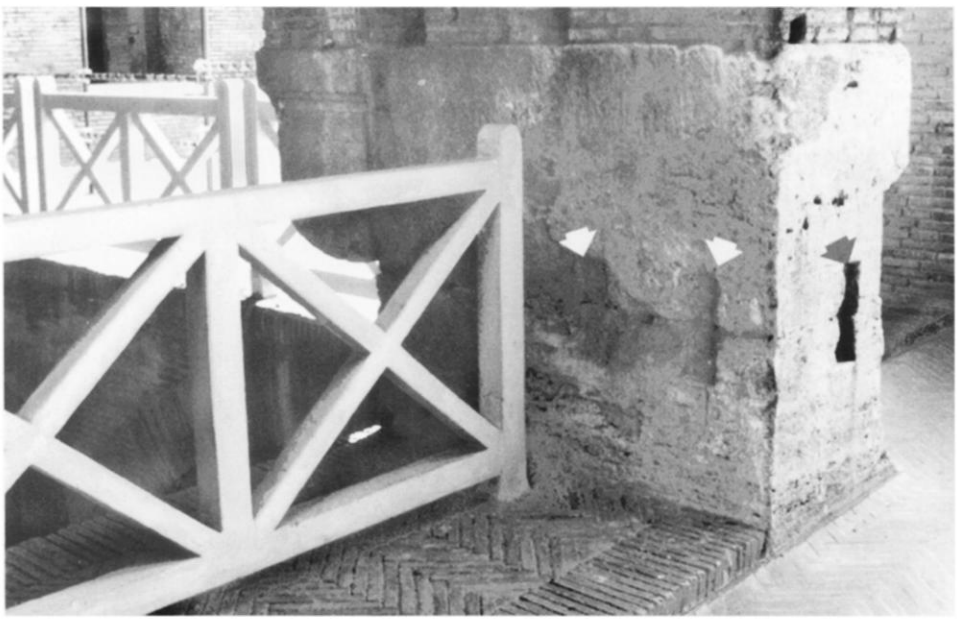

Fig. 25. Detail of travertine pier and corbel with swallowtail clamp cutting remaining (indicated with arrows)

five dovetail clamps (two on each side and one on the rear face), the cuttings of which are still visible (fig. 25); only the two northernmost piers lack clamps.[62] The joints in the brickwork of these two piers may explain the difference in detailing. On the two north corbels, the first phase of brickwork

[62] The clamp cuttings are 28–33 cm long and 13 cm wide at the ends. Since they are on the outer surface of the piers, they could have been added at a later date, but the consistency in the positioning, size, and shape of the cuttings suggests that they were part of the original construction. The clamps themselves could have been iron or wood. No trace of lead remains in any of the cuttings.

was built up only over supported portion of the piers, whereas on all the other piers the brickwork forming the lower part of the cross vaults was built up over the cantilevered portions as well, thereby creating an unstable situation. The clamps attaching the two blocks would have helped stabilize the corbels.[63] In the case of the two north corbels, the rear portions of the blocks were embedded in the wall of the phase 1 brickwork before the destabilizing parts were added over the cantilevered section during phase 2 (fig. 24), which would have occurred after the wooden centering for the vaulting had been erected but before the vaults were added.

Wooden Centering

The amount of wooden centering required to build the Aula would have been substantial, as is shown in the reconstruction in figure 26. The centering for the cross vaults, the buttressing arches, and the vaults of the lateral rooms would have been difficult to erect but even more difficult to disassemble. A critical factor regarding centering is that once it was in place and the concrete laid on top, it could have been disassembled only from below.[64] This means that the frames had to be slightly narrower than the width between the walls so that they could be easily lowered or, alternatively, that they had to be made in sections so that they could be taken apart. For cross vaults, which consist of intersecting barrel vaults, the centering structure was more complex than for arches or barrel vaults. In most cases, the centering for Roman cross vaults was probably erected by building the primary form for the major barrel vault using continuous planking attached to frames defining the curve and then building secondary frames resting on the formwork of the primary vault.

The fact that the vaults were supported on the projecting travertine corbels would have complicated matters. The projecting ends of the corbels that support the vaults could have served to support the centering frames, and the fact that 12 of the 14 corbels were clamped to their support blocks lends credibility to this idea. The corbels, however, would also have impeded the lowering of the centering once the vaults were built. In this case, the most likely reconstruction consists of some type of structure that could have been dismantled from below. No evidence exists for the configuration of ancient centering other than the impressions of the boards or bricks left along the intrados of vaults, but illustrations of the centering for large barrel vaults from later periods show that it was often made so that it could be disassembled from below.[65] For large vaults, principles of trussed construction, which were known by the Romans in this period,[66] would have been employed. The formwork as well as transverse struts between the frames would have served to stabilize the structure laterally. The centering frames of the side bays would have been built onto the sides of the main barrel vault.

Once the concrete was laid on the formwork, some means of loosening formwork and lowering the centering was necessary. A common method described by Alberti in the 15th century and probably also used by the Romans was to lower the frames by placing wedges under them so that they could be hammered out later.[67] Reducing the weight on each set of wedges was critical, since minimizing the bearing weight also minimized friction between the blocks when the time came to knock them out. Consequently, many wedges placed as high in the structure as possible would have been preferable to fewer wedges placed lower down. After the frames were loosened and lowered, the secondary frames for the transverse vaults could have been removed from the main barrel vault.

CASE STUDY 2: THE LATRINE AT THE FORUM OF CAESAR

The Forum of Caesar was renovated at the same time the Forum of Trajan complex was built, and the same brick stamps found at the Forum of Caesar renovations and at Trajan's Markets show that they were contemporary.[68] The Trajanic latrine added during these renovations is of particular interest when compared to the level II North Wing rooms at the Markets. Two construction techniques used in both places are similar and deserve some comment.

---

[63] Adam (1994, 58) suggests that the clamps were used to reinforce the blocks because the building was constructed on a slope, but this is not a convincing explanation.

[64] A very useful discussion of the complexities involved in assembling and disassembling centering structures is found in Fitchen 1961. In addition, the recent NOVA film "Secrets of Lost Empires: Roman Bath" (aired on PBS, 22 February 2000) has an informative sequence showing the construction and decentering process of the centering used for building Roman vaults.

[65] E.g., see the drawing of the centering of the nave St. Peter's basilica (early 17th century) (Zabaglia 1743, pl. 5; Potenza 1996, 99).

[66] Vitruvius (*De arch.* 4.2.1) describes what was probably a truss (Gros 1992, 93–6). The spans of some spaces such as the nave of the Basilica Ulpia (ca. 24 m) suggest that the principle was certainly known and applied by the second century A.D. (Packer 1997, 239–40; Adam 1994, 209–12).

[67] Rykwert et al. 1988, 3.14. See also G.B. Piranesi's drawing of Blackfriars Bridge in London (Penny 1978, 81 no. 70).

[68] Bloch 1947, 61–7.

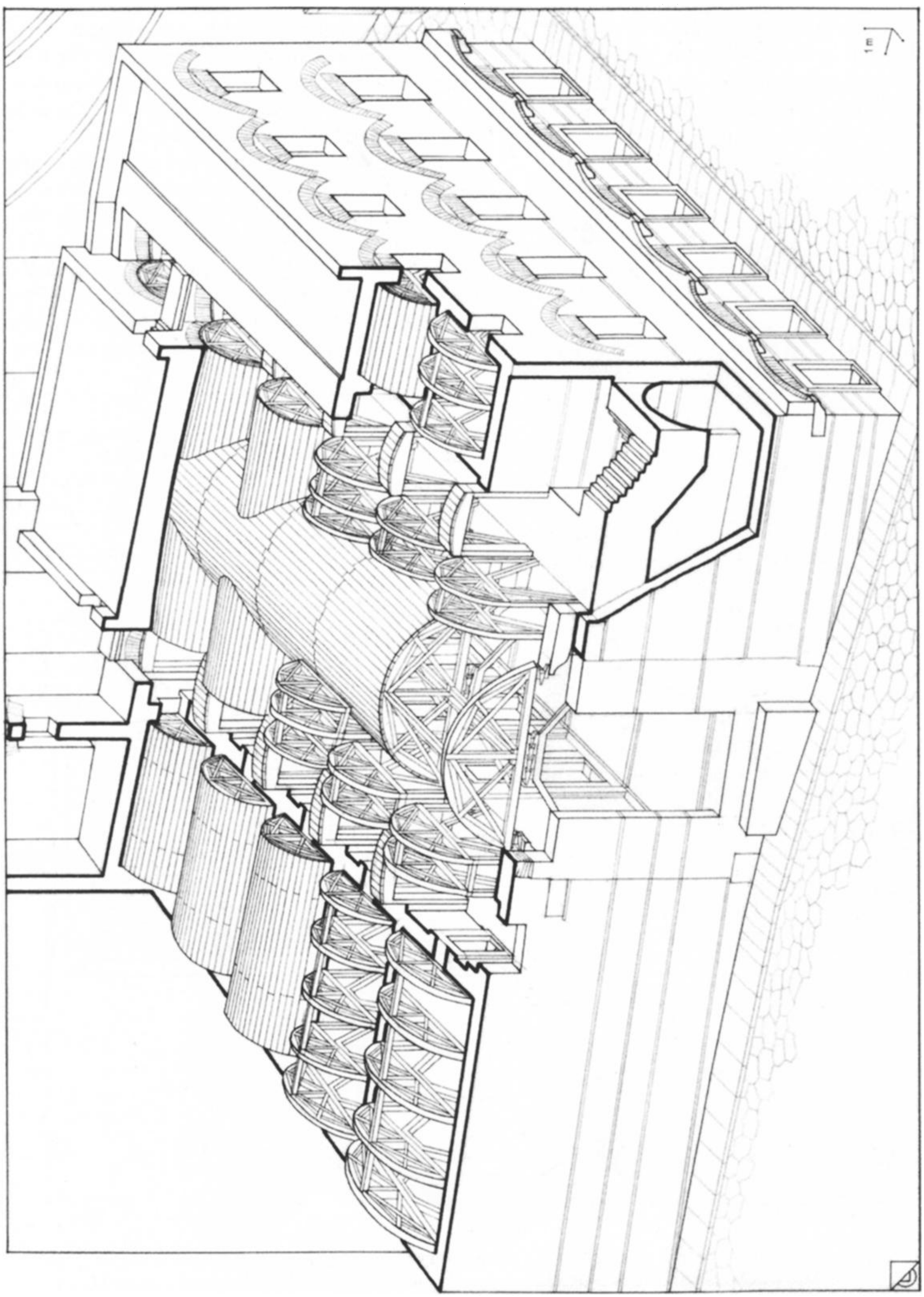

Fig. 26. Author's reconstruction showing the wooden centering used to construct Aula rooms. The form of the centering shown here is modeled on similar structures shown in an 18th-century drawing (Zabaglia 1743, pl. 13). The decentering wedges are modeled on those shown by G.B. Piranesi in his drawing of Blackfriars Bridge in London (Penny 1978, 81 no. 70).

The first technique is the use of brick formwork consisting of large bricks, usually either *sesquipedales* (1½ ft. square) or bipedales (2 ft. square) with smaller *bessales* (⅔ ft. square) covering the joints. The bricks were left adhered to the vault when the centering was removed. The same technique was used for the vaults of the level II North Wing rooms at the Markets. An unusual feature occurs in both places: a small hole was chipped into each of the bessales of the brick linings. The hole is unique to these two monuments, and its presence could indicate that the same crew of builders was working at both places.[69]

The second technique common to both monuments is the use of vaulting ribs and relieving arches to channel the loads through the structure. At the Forum of Caesar, the two techniques are combined into a more sophisticated form than is found at the Markets. The latrine at the Forum of Caesar is a rare example of an elevated latrine in the Roman world, and the use of ribs and relieving arches to accomplish this is one of the most complex examples of these building techniques in Rome. Though not as grand in scale or prestige as the Pantheon, the sophistication of the planning and layout of the latrine is comparable.

The complicated nature of the latrine structure was necessary because its curving form did not coincide with the parallel walls of the preexisting *tabernae* on which it was built. The latrine consisted of a semielliptical wall into which were embedded the travertine corbels that supported the seats for the visitors (figs. 27–28). A portico concentric with the outer wall covered the seating area. Only one of its

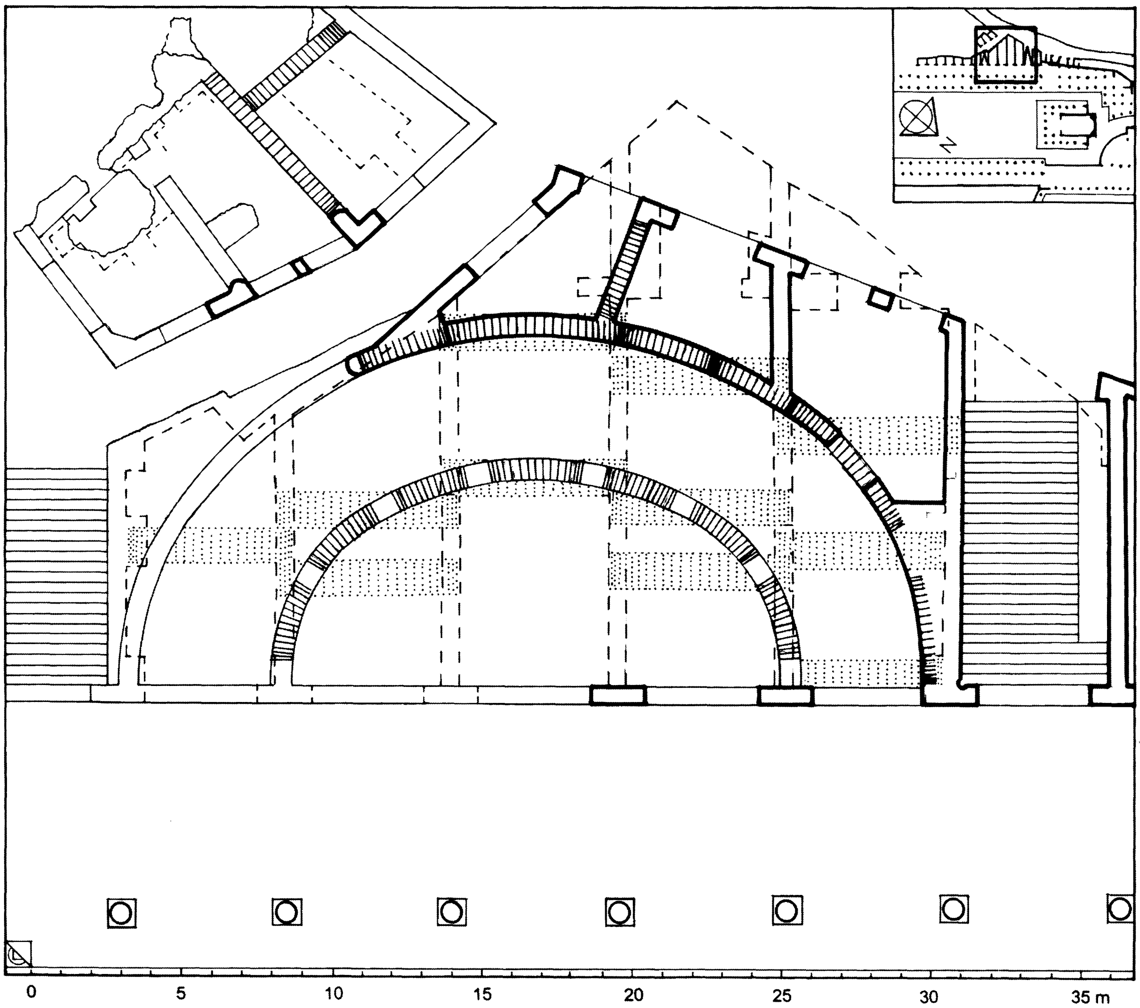

Fig. 27. Plan of the latrine at the Forum of Caesar with relieving arches indicated by lines within the walls. The plan of the tabernae below the latrine (dashed lines) is shown along with the locations of the vaulting ribs (dotted lines). Scale 1:250.

[69] Lancaster 1998a, 299–305.

original travertine column supports remains; the others have been reconstructed in brick. Since the semielliptical plan of the latrine did not coincide with the supporting walls below, certain precautions were taken to distribute the load of the upper walls to those below. The new Trajanic vaults of the tabernae were reinforced with brick ribs positioned underneath the travertine column supports and in places where the semielliptical wall passed above (figs. 27 and 29).[70] The latrine wall itself was further reinforced with relieving arches of sesquipedales to channel its weight onto the *opus quadratum* walls below or onto the ribs, which in turn directed the load to the lower walls. Further precautions were taken by carving each of the travertine column supports in the form of a trapezoidal impost block to accept the shallow relieving arches of sesquipedales that protected the vaults below from the weight of the low elliptical wall running between the columns (fig. 28).[71] The result was an intricate network of ribs and relieving arches intended to direct the loads of the latrine to the supporting structure below.

Like some of the spatial configurations at Trajan's Markets, the noncongruent plans of the Forum of Caesar latrine and its supporting tabernae resulted in a condition that was structurally very complex. In some places at Trajan's Markets vaulting ribs were used, and in other places relieving arches were used, whereas at the latrine both techniques were used together. If the same group of builders were working at both places (as suggested by the hole in the bessales of the brick linings on the vaults), the unusual ribbing in the corridor of the level II North Wing (discussed above) could be seen as a type of experimentation by a particularly innovative group of builders.

The Forum of Caesar and Trajan's Markets later functioned as parts of two different monuments, but the construction of both was intimately connected with that of the Forum of Trajan. Today they are separated

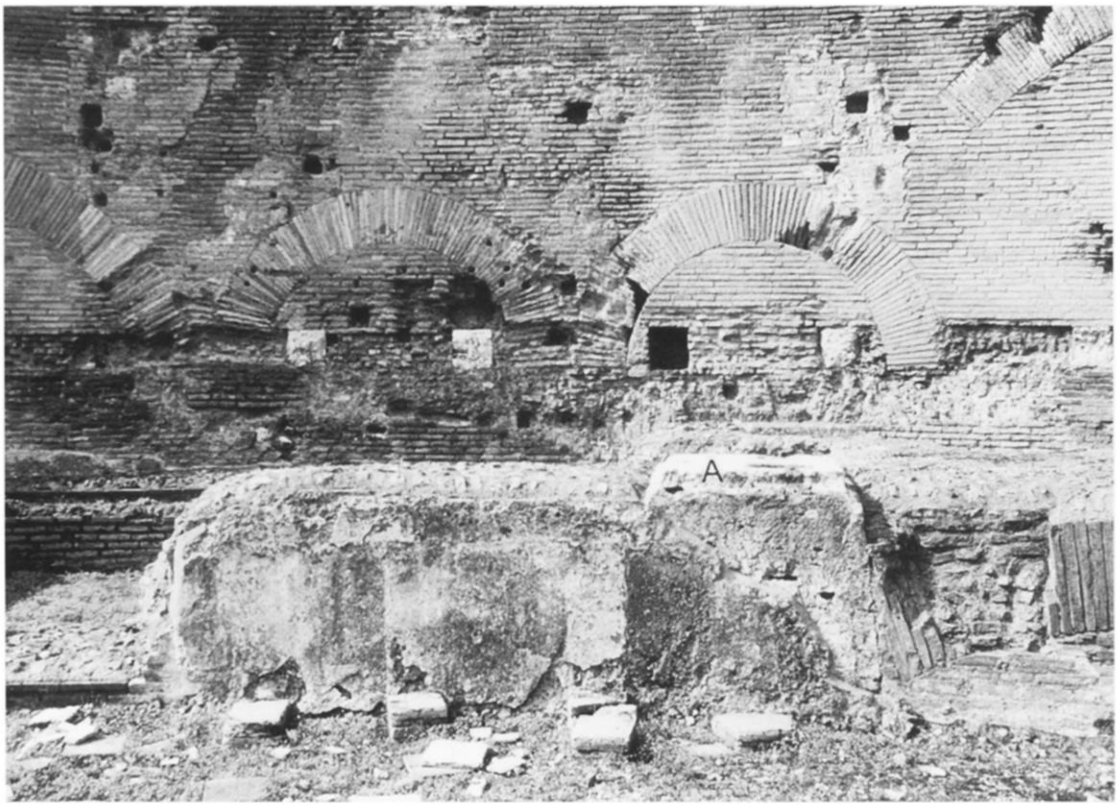

Fig. 28. Latrine at the Forum of Caesar with relieving arches in back wall. Trapezoidal travertine support (marked A) shown in foreground.

[70] Amici 1991, 118, fig. 210.

[71] These column supports would have been hidden by the floor raised on *suspensurae* to make room for the necessary drainage channel. Amici (1991, 118) has shown that it was not a hypocaust as has been suggested in the past.

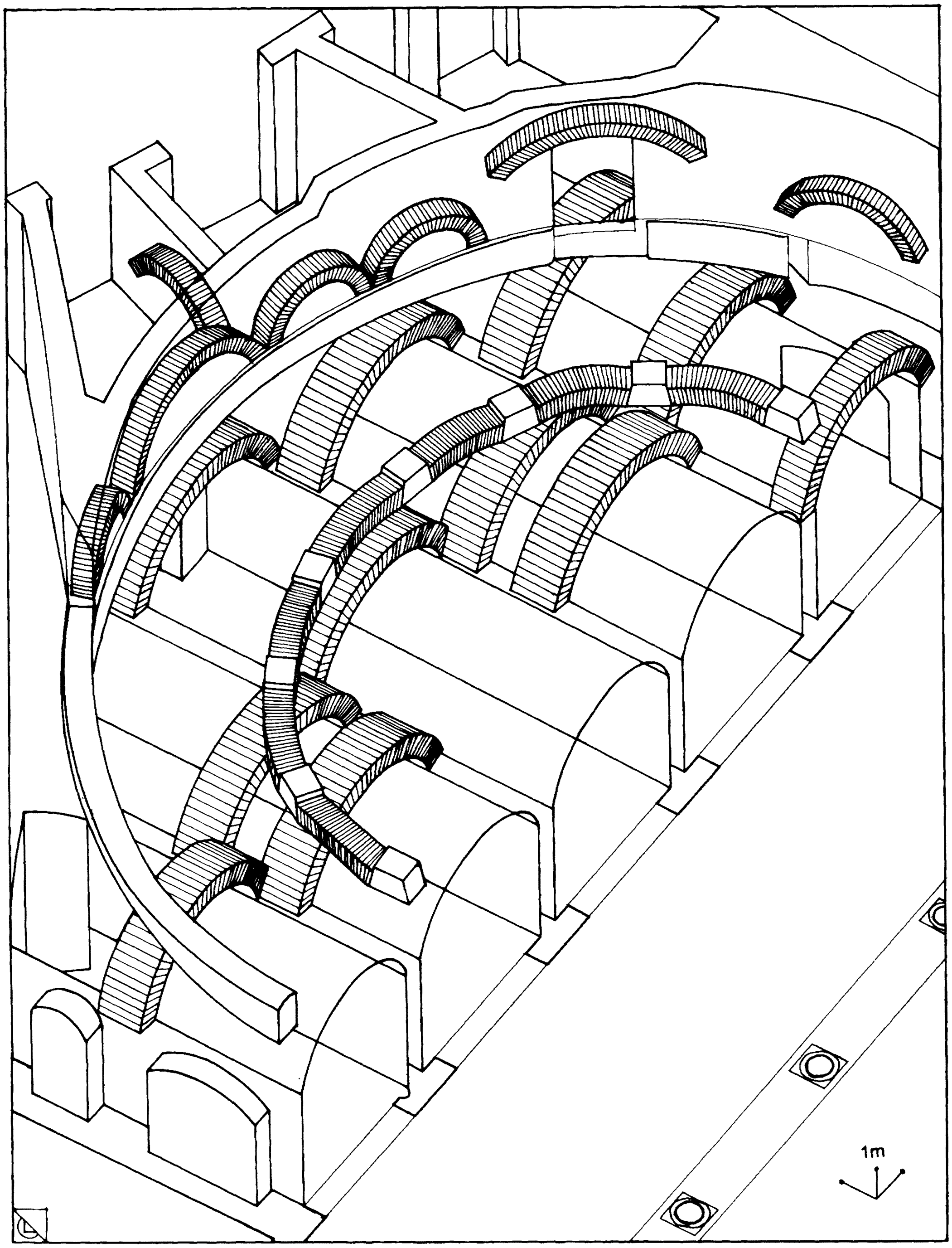

Fig. 29. Isonometric drawing of the latrine and tabernae at the Forum of Caesar showing the relationship between relieving arches and vaulting ribs

by the Via dei Fori Imperiali and are controlled by different offices of the Soprintendenza Archeologica of the Commune di Roma. Consequently, there is a tendency to consider the Trajanic renovations of the Forum of Caesar, Trajan's Forum, and Trajan's Markets as separate building projects. We know from the *Fasti Ostienses*, however, that the Column of Trajan and the Temple of Venus Genetrix in the Forum of Caesar were dedicated on the same day in May A.D. 113.[72] In addition, a recently discovered travertine inscrip-

[72] Vidman 1982, 48, pls. 10, 13.

tion in the area behind the Aula mentions a *procurator* in relation to the Forum of Trajan during the Severan period. If this inscription was originally set up in the area of the Markets, as has been argued by the excavator,[73] it suggests that at least some parts of the "Markets" were probably used as the administrative center for the Forum and were considered part of it in antiquity.[74] Regardless of how the buildings functioned later, all three monuments should be seen as belonging to the same construction project, and the execution of such an extensive urban intervention would have required, if not a single vision, at least a coordinated one.

CONCLUSION

This study is the final article of a "Trajanic trilogy" in which I examine the logistics of construction involved in projects relating to the construction of Trajan's Forum,[75] which was one of the largest coordinated urban projects in ancient Rome, comprising Trajan's Forum itself, the Basilica Ulpia, the Ulpian Libraries, Trajan's Column, Trajan's Markets, and parts of the Forum of Caesar. The core of Trajan's Forum including the Basilica and Libraries has survived only in bits and pieces, but fortunately the other subsidiary projects along the edges have fared better, and with careful examination of details these provide a great deal of information about the urban project as a whole. In all three articles I have tried to highlight the types of problems encountered by the architects and builders in organizing and bringing to fruition such a large urban project—issues such as the coordination and distribution of labor, the transition from drawn plans to built structure, the movement of workmen and materials into and out of the site, the scheduling of work, and the protection of the building site during construction. Many of the building techniques discussed in these articles are the immediate precursors to ones used a decade later at the Pantheon,[76] a building generally considered to represent the apogee of Roman concrete construction. Today at Trajan's Forum and Markets these techniques are not visible in the impressive package that we see at the Pantheon, but in ancient times the scope of the massive undertaking involved in constructing Trajan's complex was not lost on visitors. The emperor Constantius's reaction to the Forum of Trajan upon visiting it for the first time in A.D. 357 was described by Ammianus Marcellinus:

> But when he [Constantius] came to the Forum of Trajan, a creation . . . which even the gods themselves must agree to admire, he stood transfixed with astonishment, surveying the gigantic fabric around him; its grandeur defies description and can never again be approached by mortal men. So he abandoned all hope of attempting anything like it, and declared that he would and could imitate simply Trajan's horse, which stands in the middle of the court with the emperor on its back.[77]

CLASSICS DEPARTMENT
ELLIS HALL
OHIO UNIVERSITY
ATHENS, OHIO 45701-2979
LANCASTE@OHIOU.EDU

Works Cited

Adam, J.-P. 1994. *Roman Building: Materials and Techniques.* Translated by A. Mathews. London: Batsford.
Amici, C.M. 1991. *Il Foro di Cesare.* Florence: Leo S. Olschki Editore.
Ashby, T. 1924. "La via Tiberina e i territori di Capena e del Soratte nel periodo romano." *MemPontAcc* 3 (1.2):129–75.
Badawy, A. 1948. *Le dessin architectural chez les anciens Egyptiens.* Cairo: Imprimerie Nationale.
Bartoli, A. 1919. *I monumenti antichi di Roma nei disegni degli Uffizi di Firenze.* Vol. 4. Rome: C.A. Bontempelli.
Bianchini, M. 1985. "La grande aula dei Mercati Traianei." Diss., University of Rome "La Sapienza."

[73] Meneghini (1995b) has argued that the block with the inscription, which was found embedded in the threshold of a doorway of a cistern, was originally the architrave of the same doorway, based on its size and the cuttings for door hinges on its lower surface, and that it had been reused in the post-Severan period as the threshold of the same doorway.

[74] The name "Trajan's Markets" is not attested in antiquity and was only coined in the 1920s, when the monument was excavated. There is little evidence to suggest that the complex was a commercial establishment. G. Lugli (1929–1930, 527–51) recognized this fact soon after excavation and suggested that it could have been some sort of state distribution center, though his argument has its problems as indicated by M. Bianchini (1992). We may never know exactly how the individual spaces in the "Markets" were used, but they were likely connected with the workings of the Forum in some way and were not simply a collection of independent shops rented or owned by individual merchants. This is a complex issue involving the interpretation of both the architectural remains and written sources and will be the subject of a subsequent publication.

[75] Supra n. 1.

[76] E.g., the use of lighter stones in the Aula vaults, the use of ribs and relieving arches to channel loads through the latrine at the Forum of Caesar, the construction of complicated wooden centering structures in the Aula, the use of brick linings as formwork at the Markets and at the Forum of Caesar, and the lifting of the massive stones of the Column of Trajan.

[77] Ammianus Marcellinus 16.10.15. Translation from Hamilton 1986, 102.

———. 1991. "I Mercati di Traiano." *Bollettino di Archeologia* 8:102–21.

———. 1992 (pub. 1995). "Mercati Traianei: La destinazione d'uso." *Bollettino di Archeologia* 16–18:145–63.

Blake, M.E. 1973. *Roman Construction in Italy from Nerva Through the Antonines.* Edited by D.T. Bishop. Philadelphia: American Philosophical Society.

Bloch, H. 1947. *I bolli laterizia e la storia edilizia romana.* Rome: Comune di Roma. Originally published in *BullCom* 64–66 (1936–1938).

Brunt, P. 1980. "Free Labour and Public Works at Rome." *JRS* 70:81–100.

Bruun, C. 1991. *The Water Supply of Ancient Rome: A Study of Roman Imperial Administration.* Helsinki: Societas Scientiarum Fennica.

Burford, A. 1969. *The Greek Temple Builders at Epidauros.* Liverpool: Liverpool University Press.

Calza Bini, A. 1953. "Il teatro di Marcello: Forma e struttura." *BCSSA* 7:1–44.

Carettoni, G., A. Colini, L. Cozza, and G. Gatti. 1960. *La pianta marmorea di Roma antica.* Rome: Comune di Roma.

Cerný, J. 1952. *Paper and Books in Ancient Egypt.* London: H.K. Lewis.

Ciarallo, A., and E. De Carolis, eds. 1999. *Homo Faber: Natura, scienza e technica nell'antica Pompei.* Milan: Electa.

Conticello de' Spagnolis, M. 1984. *Il Tempio dei Dioscuri nel Circo Flaminio.* Rome: De Luca Editore.

de Fine Licht, K. 1968. *The Rotunda in Rome: A Study of Hadrian's Pantheon.* Jutland Archeological Society Publications 8. Copenhagen: Jutland Archeological Society.

———. 1974. *Untersuchungen an den Trajansthermen zu Rom. AnalRom* Suppl. 7. Copenhagen: Analecta Romana Instituti Danici.

Daguet-Gagey, A. 1997. *Les Opera Publica à Rome (180–305 ap. J.-C.).* Paris: Institut d'Études Augustiniennes.

DeLaine, J. 1990. "Structural Experimentation: The Lintel Arch, Corbel and Tie in Western Roman Architecture." *WorldArch* 21:407–24.

———. 1992. "Design and Construction in Roman Imperial Architecture: The Baths of Caracalla in Rome." Ph.D. diss., University of Adelaide.

———. 1997. *The Baths of Caracalla: A Study in the Design, Construction, and Economics of Large-Scale Building Projects in Imperial Rome. JRA* Suppl. 25. Portsmouth, R.I.: Journal of Roman Archaeology.

De Pasquale, G., and V. Marchis. 1996. "Alcuni considerazioni sul pes romanus." *Nuncius. Annali di storia della scienza* 11:669–75.

Donati, A., ed. 1998. *Romana Pictura: La pittura romana delle origini all'età bizantina.* Milan: Electa.

Eck, W. 1992. "*Cura viarum* und *cura publicorum* als kollegiale Ämter im frühen Prinzipat." *Klio* 74: 237-45.

Frézouls, E. 1985. "Vitruve et le dessin d'architecture." In *Le dessin d'architecture dans les sociétés antiques: Actes du Colloque de Strasbourg, 26–28 janvier 1984,* 213–29. Leiden: E.J. Brill.

Fitchen, J. 1961. *The Construction of Gothic Cathedrals: A Study of Medieval Vault Erection.* Oxford: Oxford University Press.

Gros, P. 1992. *Vitruve: De l'architecture, livre IV.* Paris: Belles Lettres.

Hamilton, W., ed. and trans. 1986. *Ammianus Marcellinus: The Later Roman Empire.* New York: Penguin.

Haselberger, L. 1983. "Apollontempel von Didyma." *IstMitt* 33:90–123.

Incisa della Rochetta, G. 1961. "D'un cartone di Giulio Romano e dell'aula coperta dei Mercati Traianei." In *Miscellanea Bibliothecae Herzianae,* edited by L. Bruhns, F.G.W. Metternich, and L. Schudt, 198–206. Munich: A. Schroll.

Kolb, A. 1993. *Die kaiserliche Bauverwaltung in der Stadt Rom: Geschichte und Aufbau der cura operum publicorum unter dem Prinzipat.* Stuttgart: F. Steiner.

Lancaster, L.C. 1995. "The Date of Trajan's Markets: An Assessment in the Light of Some Unpublished Brick Stamps." *PBSR* 63:25–44.

———. 1998a. "Building Trajan's Markets." *AJA* 102:283–308.

———. 1998b. "Reconstructing the Restorations of the Colosseum after the Fire of 217." *JRA* 11:146–74.

———. 1999. "Building Trajan's Column." *AJA* 103: 419–39.

Lewis, N. 1974. *Papyrus in Classical Antiquity.* Oxford: Oxford University Press.

Lobel, E., C.H. Roberts, E.G. Turner, and J.W.B Barns, eds. 1957. *The Oxyrhynchus Papyri,* pt. 24. London: Egypt Exploration Fund.

Lugli, G. 1929–1930. "I Mercati Traianei." *Dedalo* 10: 527–51.

MacDonald, W.L. 1982. 2nd ed. *The Architecture of the Roman Empire.* Vol. 1, *An Introductory Study.* New Haven: Yale University Press.

Maehler, H. 1983. "Angang III: Der Hausgrundriss aus Oxyrhynchos." In *Das römisch-byzantinische Ägypten, Akten des internationalen Symposions 26.–30. September 1978 in Trier,* edited by G. Grimm, H. Heinen, and E. Winter, 136–7. Aegyptiaca Treverensia 2. Mainz: P. von Zabern.

Mark, R. 1986. "On the Structure of the Roman Pantheon." *ArtB* 68:24–34.

Martin, S.D. 1989. *The Roman Jurists and the Organization of Private Building in the Late Republic and Early Empire.* Brussels: Latomus.

Meneghini, R. 1995a. *Il Foro e i Mercati di Traiano, Roma.* Rome: Istituto Poligrafico e Zecca dello Stato.

———. 1995b. "Mercati di Traiano: scoperte nell'area della Torre delle Milizie." *ArchLaz* 12 (1):163–6.

Packer, J.E. 1997. *The Forum of Trajan in Rome: A Study of the Monuments.* Berkeley: University of California Press.

Penny, N. 1978. *Piranesi.* London: Oresko.

Pestman, P.W. 1980. *Greek and Demotic Texts from the Zenon Archive.* Leiden: E.J. Brill.

Potenza, U. 1996. "Gli acquedotti romani di Serino." In *Cura Aquarum in Campania,* edited by N. de Haan and G.C.M. Jansen, 93–100. *Babesch* Suppl. 4. Leiden: Stichting Babesch.

Quilici, L. 1974. *Collatia. Forma Italia I.x.* Rome: Danesi.

Rizzo, S. 1999. "Un frammento rivelatore." *Archeo* 15.6 (June):10–11.

Rykwert, J., N. Leach, and R. Tavernor, trans. 1988. L.B. Alberti's *On the Art of Building in Ten Books.* Cambridge: MIT Press.

Vidman, L. 1982. *Fasti Ostienses: Edendos, illustrandos, restituendos, curavit.* Prague: Academia.

Zabaglia, N. 1743. *Castelli e Ponti di maestro Niccola Zabaglia.* Rome: Niccolò and Marco Pagliarini.