THE ROMANS ERECTED buildings side by side in two distinct manners. Their trabeated architecture, which was evolved chiefly from indigenous and Hellenistic Greek sources, is fundamentally different from their vaulted style, which was developed and perfected by Roman hands although some of its origins are to be sought in the pre-Roman Mediterranean world. The vaulted style is characterized by non-prismatic spaces, by the appearance of curves in both horizontal and vertical sections, and by walls and vaults constructed of smallish pieces of materials set in strong mortar. Columns were often used as working parts of these buildings, but they appear dissociated from their traditional orders, having been given new stational and visual functions. New types and combinations of vaults were developed, and the problem of the indirect transmission of thrusts was resolved. From those and other sources a new and spatially potent style evolved, an event of great significance and with many implications for the future of architecture.

A number of questions of the origin and interpretation of this late antique architecture provoked a ferocious scholarly argument which has lasted half a century, but in recent years the chief results of the controversy have been soberly and responsibly decanted, providing the historian with a welcome and secure foundation for further study. In this later work stress has been laid on the identity and importance of the vaulted style, and since new techniques of construction helped to make the style possible, the suggestions that follow may assist in properly defining the nature and boundaries of Roman architecture.

Concrete. One possible objection to the use of the word "Roman" to describe the architecture that follows after the death of the emperor Maxentius in A.D. 312 is the change that occurs in the materials used in vaulted buildings. Roman concrete, as developed in the late Republican period and perfected in the first and second centuries A.D., seems to disappear abruptly from monumental architecture after the completion of Maxentius' Basilica Nova. It seems possible, however, to see in the construction of post-Maxentian vaulted buildings a further extension of the long history of Roman concrete. From a rough and unpretentious association of stone and mortar in early times the methods of building in concrete became by the second century A.D. a perfected technology, characterized by precise laying of aggregate, full knowledge of the properties of pozzolana, and the expert use of brick facing on both flat and curved surfaces. By the early fourth century the use of brick and stone together in the facing (opus mixtum or opus listatum, probably both modern terms) becomes more common, and the wide mortar joints which then appear are reminiscent of the surfaces of concrete walls in the Republican period. In the great monuments of the sixth century the stone aggregate has disappeared almost completely, and the principal fabric of the buildings consists of only two components, brick and mortar.

During this long development the use of powerful mortar remains a constant, irrespective of the availability of pozzolana. What changes is the aggregate, and this is simply a change from pieces of stone to pieces of fired clay, to bricks. The great amounts of mortar employed in the cores of walls and the vaults of earlier imperial buildings continue to be used in the fifth and sixth centuries, and thus many of the later structures may reasonably be said to be made of concrete also. A comparison of the structure of the so-called "Temple of Mercury" at Baia, probably of the very late first century B.C. or the early first century A.D., with that of Hagia Sophia (largely 532-537) may be instructive (Figs. 1, 2, and 3). Fig. 1 is a section of the original masonry of the upper part of the Baia dome near the oculus, photographed when the vault was repaired about thirty years ago by Maiuri. Figs. 2 and 3 are details of the fabric of Hagia Sophia, Fig. 2 of the west front and Fig. 3 of the extrados of the crown of the apse vault. In both buildings the technical process is much the same: in the laying-up the solid materials have been disposed in a roughly radial fashion in a very considerable volume of mortar. Given the capacity to make the necessary wooden form-work, this fairly simple technique of construction is common to many styles of architecture, but its fullest exploitation took place in the Roman imperial period when the manufacture and use of kiln-fired brick with mortar...
of lime and pozzolana reached astonishing proportions. From the time between the two examples cited many variations in the composition of the concrete have been preserved, but the general principles of construction remain the same. In the later period Roman brick supplants the stone aggregate, but the end result, the construction of walls and vaults in a kind of concrete, is the same in the sixth century as in earlier times. It is interesting that at Baia and Hagia Sophia the vaults are thinner than those of monumental buildings erected between the middle of the first century A.D. and the beginning of the fourth.

More knowledge of the economy of local building procedures within the empire might help to establish the reasons for the substitution of brick for various kinds of stone; at present it is possible to point to some examples lying between the chronological extremes of the Baia “Temple of Mercury” and Hagia Sophia. At the Circus of Maxentius (A.D. 309), beside the Via Appia just outside Rome, the great north wall gives evidence of the tendency to revert to earlier practices (Figs. 4 and 5). This straight wall, 443.60 m. long, 0.90 m. thick and rising to 6.75 m. in height, has a core of concrete faced with alternating rows of brick and bread-loaf shaped blocks of local tufa. This work has been called an example of decadent later Roman construction, but it stands today without buttresses or modern restoration and is essentially the same in structure as the wall of the Poikile at Hadrian’s Villa. At the Circus of Maxentius the facing is no longer executed in the crisp and precise manner of the first and second centuries, but has taken on the appearance, and indeed the actuality, of the substance of concrete (Fig. 5). In this sense it is directly related to the Baia vaults and to the brick and mortar fabrics of the sixth century. A similar example, dating from the time of Constantine, could recently be seen in Constantinople along the northwest side of the site of the Byzantine Hippodrome, where a series of piers was uncovered. One of these is shown here (Fig. 6): the mortar joints are slightly thicker than the bricks. And this characteristic also appears in the late Roman fabric of San Lorenzo in Milan, built sometime between the middle of the fourth century...
and the middle of the fifth, where, in at least part of the structure, the bricks account for less of the total mass than the mortar.¹¹

What is the significance of this? Simply that one fundamental material used in Roman construction, the composition of which varied somewhat through the centuries, continued to be used in post-Constantinian times. Whatever credit may be given to eastern influences in the formation of sixth-century architecture, it remains to be shown that vaulting in the time of Justinian is not of earlier Roman inspiration insofar as its general technical composition is concerned. The light dome of San Vitale in Ravenna, made of tubular terra-cotta vases,¹² is not an exception to this but rather the logical culmination of the earlier and very widespread use of vases and pots to lighten Roman concrete vaulting,¹³ a development which may have been related to the search for light aggregates such as the pumice found in the dome of the Pantheon or the volcanic scoriae which appear in several Syrian vaults built during Roman times.¹⁴ None of this, however, answers the question of the reason for the substitution of brick for stone aggregate. Perhaps brick spread out through the vault fabrics, so to speak, from the rib-like arcs of brick that were incorpo-

Fig. 7. Rome. Pantheon. View from the dome of Sant'Ivo. (Author)

rated in so many Roman buildings, or perhaps the developed Roman forms were simply adapted by the later building economy about which so little is known. The brick vaults certainly required less wooden form-work. At all events there was a well-developed tradition of vaulted construction in brick in Asia Minor and Constantinople before the age of Justinian.¹⁵

Construction. The state of knowledge of later Roman construction is reflected in modern writing on the Pantheon. Piranesi's fanciful dome ribs of brick still enjoy a fairly wide acceptance, and one may easily find erroneous descriptions of the materials used in the building.¹⁶ There are unsolved problems concerning the structure of the Pantheon, but it is certain that there are no ribs in the dome, and the nature of the rest of the fabric is known. The ingenuity and intricacy of the structural system of the building, so important for the future of architecture, has received little attention outside of Italy.¹⁷ The not uncommon concept of the Pantheon as a very thick cylindrical wall of brick-faced concrete topped by a monolithic "pot lid" of concrete cannot be said to be accurate; the designer of the building sought a much more subtle structural solution than that idea implies. In both aesthetics and technology the building departed almost radically from previous concepts, and in spite of its apparently simple forms (Fig. 7), the origins of the Pantheon are not easy to name; probably they should be sought at Baia, in the Forum and Market of Trajan, and in the Neronian and Flavian palaces on and near the Palatine.¹⁸

From the locked rings of brick which define the oculus and perform the statical functions of a lantern, to the immense annular foundations of fine concrete, the Pantheon is a highly original building conceived by a most creative architect.¹⁹ It divides naturally into three structural zones: the dome above the top exterior cornice, the middle section of the building down to the lower interior cornice, and the
removing lower portion. The dome above the exterior cornice is of concrete without brick facing, containing an aggregate of tufa and pumice in the upper two-thirds of the zone and of tufa and broken brick below. The exterior "steps" solved the problem of providing falsework for the steeper part of the extrados; above the last or seventh step the pour could have been made without exterior shuttering. Also, during and after the drying-out of the concrete the ring-steps would counterweight some of the thrusts of the dome, for the great size of the building and the complexities of its construction make it unlikely that it is a monolithic structure free from thrusts. The nature of the interior wooden form-work that was used can only be surmised; in the "Temple of Mercury" at Baia there is fairly good evidence of the use of full centering, and it seems reasonably certain that the Pantheon, with somewhat more than four times the surface and eight times the volume of the Baia building, required a full forest of scaffolding and form-work.

The weight and probably the thrusts of the superstructure are transmitted to the ground through an elaborate system of semi-circular and segmental brick arches in the middle zone. Behind the interior attic course (Fig. 8) and the two lowest rings of coffers this system statically relates the dome to the lower parts of the building. The one hundred and twenty-eight brick arches, some of the larger of which are really barrel vaults, are disposed radially from the center of the building both in plane and on axis, and they distribute the pressures from above to the columns and wall below. Far from being a simple cylinder of concrete, the bottom or third zone is a form of sinuous wall, weaving around the external and internal niches and in effect including sixteen radial piers formed by the full thickness (6.05 m.) of the wall between the niches.

Thus the Pantheon can be said to possess an organic quality, a quality which was the product of a very considerable knowledge of engineering and probably also of a careful study of certain forms in nature. Within its fabric important structural methods are applied on a very large scale. The embedded brick arch is extensively used, and the internal columns are related to the outer wall by arches set along radial planes; both of these devices are of importance in later Roman architecture.

Embedded brick arches take two forms, one in walls and one in vaults; their functions have been variously interpreted. The wall arch has often been said to discharge pressures from above, but in simple concrete walls where the action of the mortar bonds all the fabric together this seems unlikely. In many cases these constructions barely fit the definition of the word "arch" because of their considerable irregularities. The illustration shown, from the so-called "Villa of the Quintilii" just southeast of Rome, is an example of this common condition (Fig. 9). The vault arch or rib has also been held to be structurally important, but once again most if not all of the known examples would be poor structural risks because of their very light and sketchy character. It seems probable that Middleton was right when he suggested almost seventy years ago that these arches were of use only during the construction of the building.

Between the completion of the Pantheon about 126 or 127 and the advent of monumental Christian architecture we can follow the development of Roman vaulted construction chiefly in the baths and in the pavilions and halls of the great villas. The concrete-vaulted bath buildings were the forerunners of the immense and massive Basílica Nova in Rome (largely 307–312), which marks the end of one line of development in Roman architecture, probably in part because it reached the very limits of construction in plain concrete. The evidence from the villas and pleasure gardens is by no means complete, but in these buildings of smaller scale there can be seen examples of that lightness and ingenuity of construction which will identify the later brick-vaulted architecture. At Hadrian's Villa, for example, vases appear in the half-dome over the sun-bathing room
In each of the exedrae an inner semicircular colonnade forms half of the basic kind of plan under discussion. The two symmetrically placed exedrae, each of which in plan has roughly an oval shape, as well as an annular vault penetrated by ramping vaults disposed radially. The large round domed chamber above this annular vault was lit by circular windows penetrating the mass of the vault above its springing line, and at the so-called “Temple of Minerva Medica” in Rome (early fourth century) the upper supporting walls of a domed decagon are opened up into large windows.

It seems not unreasonable to think that these buildings, from the point of view of their structural solutions, are steps in a general development that leads toward the sixth-century style. In the fourth and fifth centuries there were further innovations, and these were combined, in buildings designed for Christian use, with the methods perfected in the past.

Structures of two concentric walls. The next important type of vaulted building to be fully defined within the Roman empire was one of two concentric walls. In this kind of centralization the outer envelope or wall is the higher, and the outer, lower wall is connected to the inner by a vault which is usually of roughly annular shape. In all of these structures the form of the lower part of the inner cylinder or polygon is defined simply by piers or columns, so that the space of the outer ring is, on the lower level or levels, continuous with and radiating from the central volume. There are many variations on this basic type, and the number of examples standing is very large. Most of the western mediaeval buildings of this kind were inspired, however indirectly, by the Holy Sepulchre in Jerusalem, but that building is antedated by other examples, both eastern and western. The origins of the basic scheme are by no means certain, and the question has been much debated, particularly in terms of iconography and function. The structural evolution is clearer, however: most of the components and solutions existed in Roman architecture before the fourth century.

Very early in the development of concrete vaulted architecture, upon the rebuilding of Praeneste early in the first century B.C. by Sulla, a prototype of the concentric plan appeared. On the next to the highest level of the great axial complex that forms the sanctuary of Dea Fortuna there are two symmetrically placed exedrae, each of which in plan forms half of the basic kind of plan under discussion. In each of the exedrae an inner semicircular colonnade is surrounded by half of an annular vaulted and coffered corridor, whose longer side is a solid surface and whose shorter is identical with the row of columns. Although a curving vertical wall above the columns terminates in a cornice at about the level of the crown of the annular vault behind, and the inner semicircular space was left unroofed, there is in these forms a direct statement of one of the basic principles of the later type.

Another prefiguration appears in the Pantheon, in the structural relationship of the interior niche columns and their entablatures to the corresponding sections of the outer wall. This use in centralized buildings of arches set out along radii and spanning from inner to outer vertically concentrically arranged is also an essential element of the two-shell scheme. Something like this can be seen also in the structural dispositions around the octagonal room of the Domus Aurea, one of the very first monuments of the new vaulted architecture in brick and concrete (A. D. 65–68). There the semicircular arches are embedded in walls which are obliquely rather than radially arranged, and they are placed over lintels which are flat brick arches. But the creation of a nearly complete exterior ambulatory, cut through a dozen walls which abut on to and help support the central octagonal vault, is an early example of the general type of building under discussion.

Other parts of the two-shell building were derived from tholoi, from centralized buildings with niches radially set out, and from the arcade motive so common throughout Roman architecture. The full characterization of the type was accomplished in the fourth century in such buildings as Santa Costanza in Rome and the Holy Sepulchre in Jerusalem. In all examples the thrusts from the central vault to the ground are in part transmitted indirectly, travelling along an inclined or conical route, giving the buildings that stable structural system proclaimed by their silhouettes. When no drum is used the outer ring is directly related statically to the dome, and the ambulatory vault or vaults become a continuous buttress; Saints Sergius and Bacchus in Constantinople is an example of this type (Fig. 10). In all of these buildings the new solutions of the distribution of vault thrusts in depth produced space-shapes hitherto unknown in architecture, and made possible new and influential developments in lighting, scale and decoration. The insertions of colonnaded exedrae between the central piers became common, and combinations of centralized and longitudinal forms were tried, but in each case the inner, symbolic vault pushes up above the outer ring, bringing light into the central void.

Executed in brick and mortar and decorated with cornices and string courses of brick, the sixth-century structures of this class that have been preserved are of course the antithesis of trabeated architecture. Their exteriors have sometimes been dismissed as unimportant and unesthetic, but the outside of this kind of building reflects
its inner structural system and so suggests a new standard of design. The east end of the church of San Vitale in Ravenna, for example (Fig. 11), is a cascade of geometric forms from the tiled octagonal roof over the dome down to the lowest subsidiary chapel; these forms announce the structural logic and method of the building, and can properly be said to identify a new architecture.

Summary. Certain Roman techniques of construction continued in use after the collapse of the empire in the west, and were incorporated in many of the vaulted buildings of the sixth century. In the continuum of Mediterranean architecture vaulting was, if not always a commonplace, a widely known method of roofing, but it was the Romans who developed and perfected a technology for this tradition. They cannot be credited with the invention of vaulting itself, as understood in a general sense, but by exploring the subject and applying to it their particular talents they made it into something it had not been before. Many examples of the design and construction of Roman vaults have survived, chiefly in some form or other of what can quite properly be called concrete, and the form of these vaults and the spaces they shape have changed the history of architecture.

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3. E. B. Van Deman’s “Methods of Determining the Date of Roman Concrete Construction,” American Journal of Archaeology, 16 (1912), 230–251 and 387–432, is a study of the development of the composition of concrete. For pozzolana, see A. Maffei, “Pozzolana,” Enciclopedia Italiana (1935/1949 ed.). An example of a surface of double curvature built in brick can be seen in the Terme dell’Invidioso at Ostia, illustrated in Lugli, op. cit., Vol. II, Plate CXCIX.

4. The use of pozzolana seems to have been limited to central Italy, and it is difficult to believe in its indispensibility in later Roman vaulted buildings because of the preservation and stability of so many provincial examples.

Some Implications of Later Roman Construction 7
5. Most of the techniques developed for dating the structure of concrete monuments are based upon the evidence of buildings and materials found in and near Rome, and these techniques cannot with any confidence be applied much beyond the suburban limits. The Baia structures were built after the time of Sulla, but there is no certainty about their date.


7. This is the best preserved of all Roman circuses and has been inexplicably neglected since its name and date were established by A. Nibby, Roma nell'anno MDCCCXXXVIII (Rome, 1838), I, 622-644. A survey and study of the building has been made by the present writer.

8. By A. Nibby, Del circo volgarmente detto di Caracalla (Rome, 1825), p. 6; a similar opinion was apparently held by Van Deman, op. cit. (note 3, above), pp. 430–431, for whom thin mortar joints and carefully and regularly laid aggregate were the chief criteria of "good" concrete.


11. A. Calderini, G. Chierici, and C. Ccecchelli, La Basilica di S. Lorenzo Maggiore in Milano (Milan, 1951), pp. 91–92 and Plate XXXII.


14. For the basic literature on the Pantheon, see note 19, below; for the scoriae, H. C. Butler, Early Churches in Syria. Fourth to Sixth Centuries (Princeton, 1929), p. 18.


16. In the Near East there is a tradition of building vaults without any centering; see N. Eton, The Turkish Empire (London, 1799), p. 226; also A. Smith, Blind White Fish in Persia (London, 1953), where Fig. II shows such a vault under construction (I owe this second reference to Mr. Ward Perkins).


19. To seek the origins of centralized buildings in the prehistoric past seems gratuitous.


22. The question has not been resolved. A statical analysis (force polygon system) prepared by Milani and published by Vighi, op. cit., p. 56, would seem to argue against the monolithic concept. Compare Terenzio, "La restauration," p. 55.


26. This arch appears on the southeast side of building no. 14 according to the numbering of T. Ashby, "La Villa dei Quintillii," Ausonia, 4, fasc. 1, (1908), 77–80 and Plate III.

27. See for example the illustrations in Lugli, La tecnica (note 1, above), Vol. II, Plate CCC.


29. Few of these important villas have been properly studied, other than that called Sette Bassi; N. Lupu, "La Villa di Sette Bassi sulla Via Latina," Ephemeres Dacoromana, 7 (1937), 117–188.


34. Many baptistries and funerary monuments take this form. In Rome the outstanding examples are the Lateran Baptistry, Santa Costanza, and San Stefano Rotondo.


38. See the plan and axonometric drawing in Kähler, op. cit. (note 9, above), pp. 100–101.


40. Here also is the beginning of the Byzantine four-column church, which can be thought of as a variant of the two-envelope scheme.