ROMAN BUILDERS

A STUDY IN ARCHITECTURAL PROCESS

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PLANNING AND DESIGN

Let no one suppose that I selected an insignificant accomplishment, proposing to adorn it with my rhetoric. For I think it is a sign of no small intelligence to conceive of new patterns of beauty for common things; such is the accomplishment the marvellous Hippias provided for us. It has all the virtues of a bath: utility, convenience, good illumination, proportion, harmony with the site, provision for safe enjoyment; and furthermore, it is adorned with the other marks of careful planning: two lavatories, numerous exits, and two devices for telling time, one a water clock with a chime like a bellowing bull, the other a sundial.[1]

– Lucian, *Hippias* or *The Bath*

All these works should be executed so that they exhibit the principles of soundness, utility, and attractiveness. The principle of soundness will be observed if the foundations have been laid firmly, and if, whatever the building materials may be, they have been chosen with care but not with excessive frugality. The principle of utility will be observed if the design allows faultless, unimpeded use through the disposition of the spaces and the allocation of each type of space is properly oriented, appropriate, and comfortable. That of attractiveness will be upheld when the appearance of the work is pleasing and elegant, and the proportions of its elements have properly developed principles of symmetry.

– Vitruvius 1.3.2

Vitruvius' principles of good design continue to resonate. Even today his triad *firmitas, utilitas, venustas* adorns the emblem of the Society of Architectural Historians. In themselves they are strong and enduring principles (despite attempted repudiations of the third); but they are not immune to the vicissitudes of taste and cultural change. To varying degrees, all three are subject to semantic drift. Suitably, soundness is the least culturally encoded of the principles. We all obey the law of gravity and design our buildings accordingly. But although every building benefits from a good foundation and high-quality materials well applied, these alone do not complete the idea of soundness. As I suggest below, structure has a psychological as well as a physical dimension. It must withstand the test not only of time and travail but of human reception. Attractiveness is of course the criterion most likely to change its rules over time and distance. Little has been written on aesthetics of the Roman period, perhaps because our own culture tends to view Roman architecture (and to a lesser extent Roman art) with an approving and sympathetic eye. The reaction of a Roman like Lucian to a kind of architecture that we like rather well – even if it is sadly fragmentary today – would seem to approximate our own. Roman architecture, which for all its bursts of genius and ferment was never a vessel of social revolt, was firmly embedded in mainstream culture. Moralists like Cicero and Seneca might rail at the built *luxuria* of the idle rich, but when it comes right down to it, an archaeologist would be hard pressed to distinguish the villas of one breed from those of the other.

UTILITY AND SOCIAL FUNCTION

Let us briefly discuss Vitruvius' second criterion of successful architecture, utility. For the architect this was the primary concern in the early phases of design. What use would a projected building have, and how would the building maximize its usefulness? Buildings of importance were never useful in just one way. Beauty was itself utility; an ugly building was likely to be avoided, especially if it was eclipsed by competing structures. Martial's epigrams are full of plaudits and indictments of one bath or another according to appearance, clientele, or water quality. As I have already suggested, signification was another form of utility. Whether or not an architect was aware of the fact, every building's form, function, and decorative scheme were steeped in cultural meaning. Some structures, such as honorary arches and triumphal monuments, functioned *principally* as signifiers; their function was to engage one's attention and convey an ideological message. Another way in which architecture made itself useful in Roman cities was to articulate a larger urbanistic scheme. Thus the built environment could serve as a catalyst of movement through the fabric of the city.[2]

Vitruvius is concerned primarily with utility as it is commonly understood, the ability of a building to meet its preassigned role as a place for enabling, sheltering, and organizing human or divine activity. Certainly function is one of the most important determinants of form. A structure must be envisioned in terms of the ways people will use it. Will it be a multifunction facility, like a basilica? Or will it serve a narrow range of functions, like a theater or odeum, or a single function, like a latrine? What special uses has the building's sponsor stipulated? The architect, then, will start with a known plot of land, a designated building type (temple, amphitheater, villa, bath, etc.), the patron's stated wishes, and probably a variety of other factors that will condition his design (building codes, geological and hydrological conditions, availability of labor and materials, etc.).

In his studies of the divisions of private architectural space in Pompeii and Herculaneum, Andrew Wallace-Hadrill has developed a simple but practical matrix for evaluating the social uses of the Roman house.[3] His two scales of social functionality – public–private and grand–humble – operate independently to form the axes of a sort of Cartesian plane. This model can be adapted to Roman architecture outside the private sphere, but with different axes of differentiation. The grand–humble scale is still applicable, especially in contrasting discrete parts of a building; however, depending on the circumstances, one might choose instead a scale of social integration (segregated–integrated). Roman class-consciousness, which was extreme, was not always manifested by absolute physical separation. Seating at spectacles was rigidly segregated according to class or sex, but people of all classes (and occasionally both sexes) bathed together, and the systems of slavery and patronage ensured regular interaction between the grand and the humble in the same space. The public–private scale is less useful outside of houses and villas, and could profitably be replaced by a scale of specificity of purpose (dedicated–multipurpose). Roman building types generate a scatter in at least three quadrants of the new Cartesian plane: dedicated + segregated (amphitheaters, theaters, etc.); dedicated + integrated (baths, markets, etc.); and multipurpose + integrated (basilicas). The social reasons for this variability are too complex to pursue here, but it is obvious that the architect had to be aware of them and of the special wishes of his patron. In segregated buildings he would be responsible for establishing not only physical barriers but also psychological ones, such as a change in decoration, ceiling height, or corridor width to suit the social status of those in spaces of especial privilege or ignominy.[4] And he must account for the positioning and distribution of human beings within his building, both visitors and those who controlled them. In the Colosseum, one of the most segregated of all buildings, one can see the diminution of grandeur in decoration as one passes from the grand stuccoed senatorial entrance at ground level to the upper corridors, though the architectural armature remains impressive throughout. A network of gates, grilles, and guards would have helped to reduce ambiguity for the spectator entering at a numbered gate and climbing to his seating section. In equal measure a skilled Roman architect would have been expected to create *integrated* spaces that were psychologically inclusive by emphasizing their public nature. Roman baths are famously "democratic" in this respect; even emperors were known to share an occasional bath with their subjects in the great thermae of Rome. We must not forget, however, that these establishments were operated by a huge service staff, which remained largely unseen by the bathers.

VITRUVIUS AND DESIGN

Vitruvius identifies six components of architecture: ordering (*ordinatio*), design (*dispositio*), shapeliness (*eurythmia*), symmetry (*symmetria*), correctness (*decor*), and allocation (*distributio*).[5] These terms have been the subject of endless debate.[6] Whether they merit such scrutiny is itself a point of contention. One thing is relatively certain: Vitruvius is not interested in characterizing Roman architecture as we have defined it. Except in domestic architecture, his most important models were Greek; on the most "Roman" of all building types, such as amphitheaters and triumphal arches, he is silent, while he expounds at length about some of the great temples of the Greek world. His adherence to Greek traditions carries over to his intellectual system as well, which borrows terms and ideas from Greek rhetorical and aesthetic theory.

Not that his six "components" are systematic. Shapeliness, symmetry, and correctness seem to be *properties* of structures; design and allocation are *processes* involved in building them. Ordering (*ordinatio*), depending on how it is interpreted, could fall into either category. It pertains to the common use of a *module,* usually a unit of measurement used for some iterative purpose such as the spacing of columns. In the Vitruvian scheme this became the standard unit by which many other features were determined: width and height of columns, height of capitals, and so on.[7] As a principle by which to design a whole building it was rarely used outside of temples. Whatever the precise meaning of *ordinatio,* one must remain skeptical of attempts to marshal Vitruvius' ragged sextet into two symmetrical triads in which each property is the imagined result of a congruent process in the other.[8]

Vitruvian *symmetria* is not symmetry in the modern sense but a carefully proportioned relationship among elements. Since each element has its own inherent proportions (e.g., a column's height-to-width ratio), symmetry can be understood, at least in some passages, as the proportioning of proportions.[9] A pediment must not be too large, too small, nor too steeply or shallowly pitched for the columns on which it stands; thus the correct symmetry of a temple facade is a function of both variables (columns and pediment), among others. Shapeliness (*eurythmia*), probably a notion borrowed from Plato,[10] seems to refer to the simple, inherent proportions of each element, such as the aforementioned height-to-width ratio of a column. It has recently been argued that these Vitruvian qualities do not inhere in buildings but are rather processes involved in their creation. They are physically evident in a number of Roman buildings as refinements made upon established plans or rules.[11]

It is unclear how symmetry and shapeliness should be distinguished from ordering, or sometimes even from each other. Vitruvius himself, who often seems to be talking over his head, may have been unequipped to explain himself.[12] But plainly all three terms presuppose an unmediated aesthetic process governed by psychological principles. Correctness (*decor*) is something again, having more to do with cultural convention or received common sense than to first principles of cognition. It is the component of reception drawn from outside the object itself. In Vitruvius' opinion, a correct design must not mix Doric elements with Ionic, or match masculine gods like Mars or Hercules to a "feminine" order like the Corinthian: Such mismatches would offend the sensibilities of a culturally conditioned Roman.[13] And common sense or functionalism would dictate "natural" correctness: The orientations of various rooms should suit their functions. Winter quarters should face west to gain the benefits of the afternoon sun in the winter, bedrooms should face east to make full use of the morning sun, and so on.

There is nothing mysterious about allocation (*distributio*). It is, in Vitruvius' words, "the efficient management of resources and site and the frugal, principled supervision of working expenses." Like Plato's *architektôn,*[14] Vitruvius' architect oversees all aspects of the job from start to finish. Such was common practice in the Roman world, but not necessarily the norm.[15] While keeping within a budget may seem an obvious necessity today, it was not always obvious in antiquity. Large building projects of earlier and later times were often open-ended, either enjoying unlimited royal sponsorship or occupying generations of master builders and patrons who could each vouch for only a fraction of the overall budget. Many of the grandest Greek temples were never completed at all.[16] In the Roman period it became possible as never before (and rarely thereafter until the Renaissance) to complete a large project on time and on budget. And for this, one needed a fairly comprehensive plan.

For our purposes, the most important of Vitruvius' six elements is design (*dispositio*). In a sense, it encompasses most of the others, for one cannot envision the act of laying out a building without constant attention to aesthetic principles. And it is only through design that one can make meaningful projections of time, labor, and materials. Vitruvius tells us that design is manifested in three ways: *ichnographia* (floor plan), *orthographia* (elevation), and *scaenographia* (perspective drawing). These are still essential tools of the architect today. A *plan* shows the disposition of walls and floors as seen from directly above. It is the natural first step for an architect who is dealing, after all, with a relatively horizontal plot of land enclosed within definite boundaries. An *elevation* is a drawing of the upright structure without perspectival distortion. It may take a frontal view, as Vitruvius says, or in more complex projects, a view of another exterior surface or of a section cutting through the proposed building on a flat plane. An elevation usually is derived from the plan;

yet its proportions may cause one to rethink the plan, for a building's vertical substance is as fundamental to good design as the treatment of the horizontal plane. *Perspective* drawings have a more analytical purpose; they strive to give the viewer a "feel" for a building in space. They are uniquely valuable for the representation of interiors, which are so important in Roman architecture.

I am not suggesting that Vitruvian drawings were the lingua franca of all Roman architects. Romans probably designed a wider repertory of buildings than any society before the nineteenth century.[17] Quotidian structures could have been planned on site from experience and rules of thumb with the help of simple surveying and leveling tools and perhaps a scale drawing of the ground plan. Even some large-scale imperial structures show evidence of on-site planning in the form of optical or structural corrections.[18] A certain amount of improvisation was to be expected in every project; but occasionally a builder's failure to use drawings effectively got him into serious trouble. The Sanctuary of the Deified Trajan at Pergamon, it would seem, was surrounded on three sides by colonnades, the two lateral examples of which were adjusted in height after construction had begun in order to harmonize them with the back colonnade.19 Lapses of this kind, while not exactly rare at the sites of imperially sponsored building projects, are not common either. Most changes that leave traces in the remains – and there are many – have other causes, such as shifts in resources or ideology.

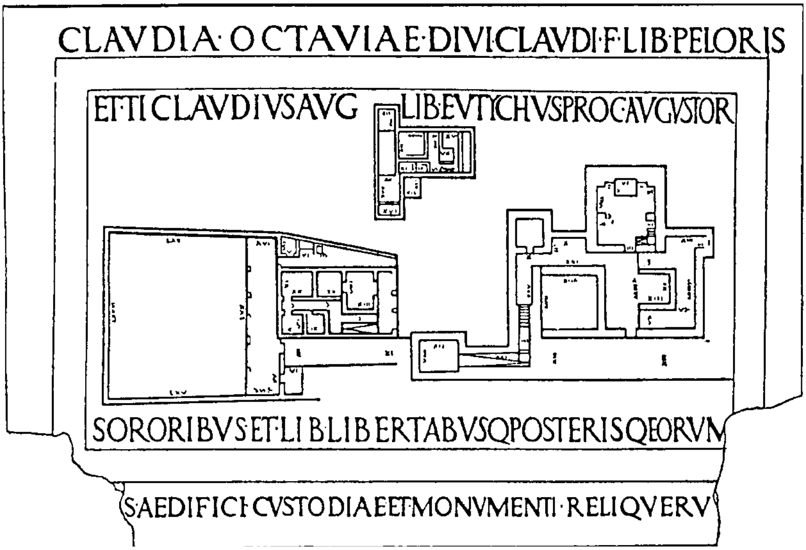
DRAWINGS AND MODELS IN ROMAN DESIGN

According to a well-known story, the famous imperial architect Apollodorus of Damascus, annoyed at the architectural pretensions of the future emperor Hadrian, told him, "Be off, and draw your pumpkins."[20] The reference is to the pumpkin-shaped domes of the sort that Hadrian later employed in his villa at Tivoli. Whether or not the story is true, its implications are clear: Hadrian and the architects in his circle saw the value of thorough designs, not just of floor plans but of elevations and vaulting structures too.

In recent years much attention has been given to the mechanics of ancient architectural design in general, and specifically to the techniques applied to architectural drawings and models. We now have a much better understanding of the ways in which ancient architects and builders communicated spatial ideas nonlinguistically.

Drawings, used at least as early as the Egyptian and Mesopotamian periods, appear also in the Roman era. They survive in various scales and with varying degrees of care, etched in stone or drawn on papyrus, even in one instance appearing on a mosaic.[21] Relatively crude area maps, showing buildings without wall thicknesses, are known from Rome and other sites. A much finer effort appears on a funerary plaque from Rome, now in Perugia (Fig. 4). Plans had varying purposes and functions. Some were used in building contracts.[22] Some were maps; that is, they represented an actual, not a planned, state. The Perugia inscription, however, may be a direct transcription of architectural plans, for the three buildings represented on it are all on different scales and show many of the wall measurements. There seems to be no good explanation for this unless the inscriber was copying three separate plans directly. This plaque and the fragment from Rome, showing the floor plan of the Temple of Castor and Pollux near the Tiber River, reveal that even in the cumbersome medium of stone plans could be rendered with apparent accuracy.[23]

It has been suggested that Roman elevations were drawn on a larger scale and in greater numbers than plans, just as they are today, to account for the many more details of vertical surfaces – column capitals, moldings, friezes, and so on.[24] Certainly elevation drawings with some degree of detail were used in ancient Egypt; a beautiful, and rather meticulous, elevation of two faces of a shrine has come down to us on carefully gridded papyrus from the eighteenth dynasty.[25] On the other hand, matters of detail in stonework may have been left to the master craftsmen, just like the later phases of decoration such as mosaics and plasterwork. Greek craftsmen seem to have relied on templates (*anagraphês*) or full-scale models (*paradeigmata*) for detailed stone carving, not on drawings.[26] At both Greek and Roman sites full-scale drawings of architectural features in elevation have been found etched onto stone or plaster surfaces, where they served as templates for preassembly of building features.[27] It is much more likely that elevations, rather than plans, were resolved in medias res by means of such templates or drawings. But in certain situations, such as the hillside construction of the Esquiline Wing of the Golden House (Domus Aurea) of Nero, which was built on the ruins left by the great fire of 64 A.D., even some of the plan may have been improvised on site.[28] We have no evidence that drawings in antiquity were ever granted the kind of

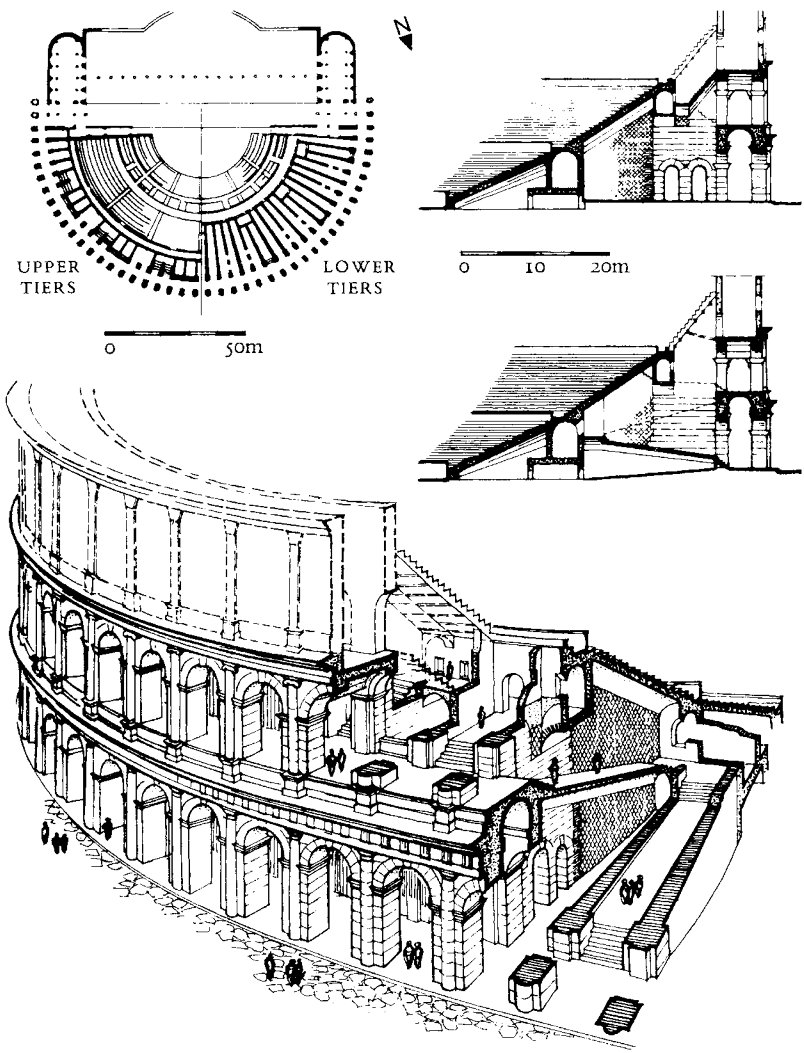


4. Perugia: funerary plaque found near Rome. *Corpus Inscriptionum Latinarum.*

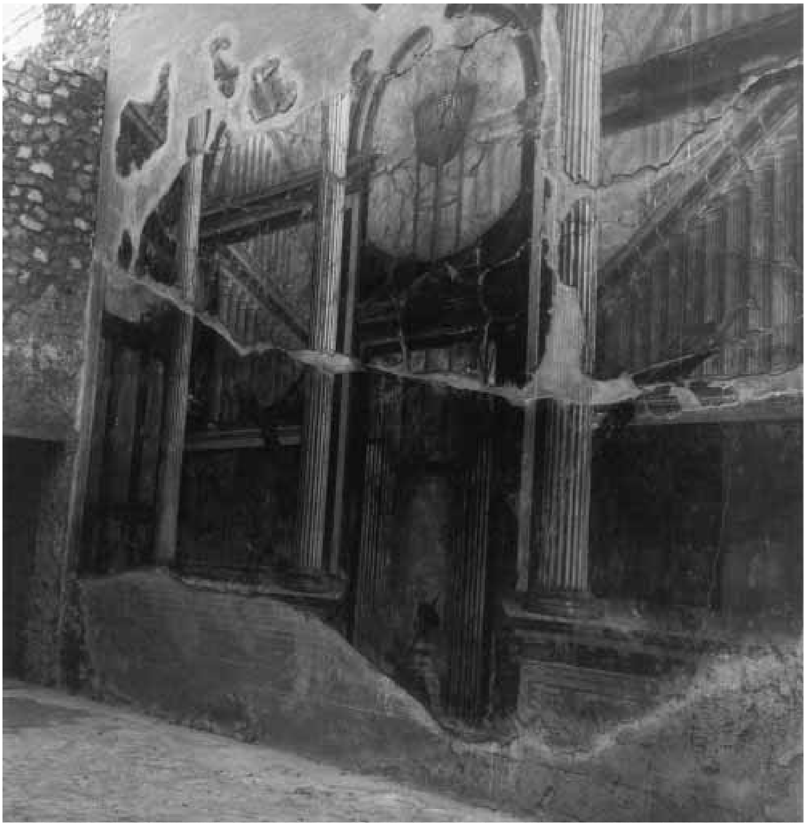
autonomy they acquired in the Italian and Spanish Renaissance and still hold today.[29] The tyranny of design at Sydney would have held feeble court in Sardis or Syracuse. The Roman way was not to generate a design of perfect refinement and supreme authority but to establish a finite set of objectives pictorially. The means to accomplish the ends, sometimes utterly unpredictable, were a matter of daily dialogue and improvisation on the site; it is these means that occupy most of this study. Drawings alone can never plot a path to completion; they can only set the destination.

It is possible to envision how great stone temples, stoas, arsenals, and other rectilinear structures were built in antiquity without plans. One may even conceive of a Gothic cathedral or a middle-Byzantine church being raised without them, bay by bay, overseen by a master builder of great skill and experience.[30] But grand bath buildings, theaters, and amphitheaters of the Roman period exceed these in volumetric complexity, and the sheer speed of their realization would not have allowed the careful cross-checking or methodical pace of some Greek or Western medieval construction. It is inconceivable that such complex buildings as freestanding theaters or amphitheaters – veritable warrens of tubular voids wending through the building's swooping fabric, wrapped about one another, carefully penetrating or bypassing their neighbors – were given form without detailed plans and elevations (Fig. 5). While published handbooks may have existed to aid in design and planning, ultimately every project was unique. Any structure with so many rising diagonals or conic surfaces – seating banks, ramps, stairways – presents a supreme challenge to the draftsman. A few sections in elevation may suffice, but planimetric (horizontal) sections must be made in quantity, for none resembles the next. Each drawing must to some extent have generated a logistical plan for construction; many issues of building material, method, and sequence would only have occurred to the architect during this expository phase of the creative process.

Exposition – the elaboration and communication of ideas – comes only after those ideas are in place. Plans, elevations, and sections



5. Rome: plan, elevations, and reconstructed cutaway view of Theater of Marcellus. Ward-Perkins 1981. By permission of Yale University Press.

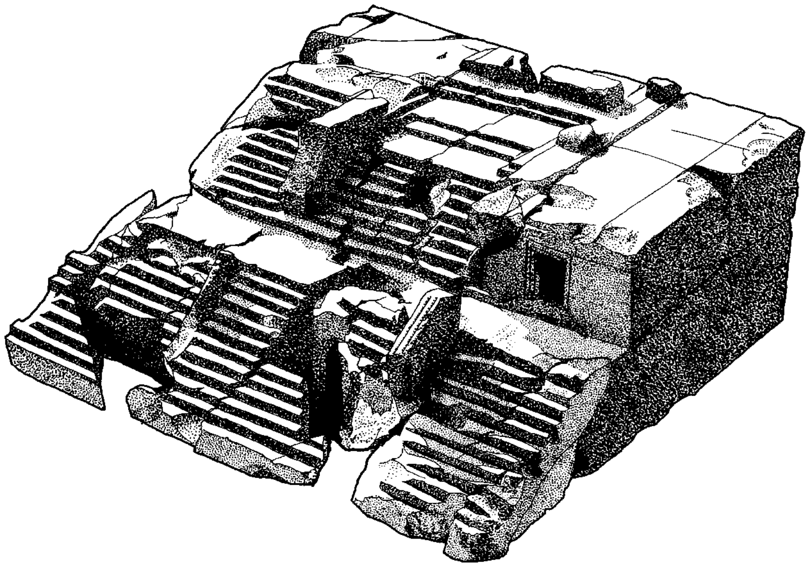


6. Oplontis: megalographic fresco. Deutsches Archäologisches Institut, neg. 74.2689. Photo: Sichtermann.

carrying the authority of blueprints tend to be generated toward the end of the design phase, when a fairly complete general concept is well in hand, even if logistical and constructional details are still uncertain. For the *development* of ideas and envisioning the whole one needs a more dynamic medium in which the creator can experience the emerging building as a living environment. Vitruvius' term *scaenographia,* often translated as perspective drawing, is generally thought to designate a technique that renders buildings as they would appear optically, replicating the entire cone of vision. Approximations of the latter technique appear in many Pompeian wall paintings (Fig. 6).[31] *Scaenographia* probably had two functions, as an aid in the design process and as a means of presenting a concept to the client. Drawings for clients are mentioned several times in the literary sources,[32] and Pierre Gros has made a good case for the use of *scaenographia* as a perceptual aid in the design process.[33] Roman architects were fond of establishing horizontal corridors of vision ("enfilades") through multiple spaces by the artful alignment of doorways, intercolumniations, and windows. Such effects, along with sensations of verticality, could have been tested and "experienced" with perspective drawings, even if the principles of perspective were not fully realized.

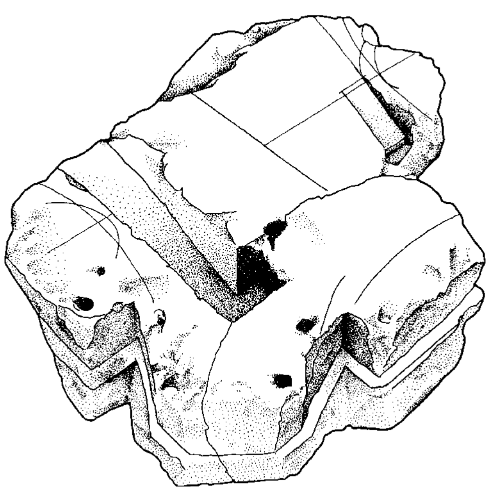
Scale models are the most direct, paradigmatic means of developing and conveying architectural ideas. Plutarch's bidders for public works may have used presentation models, though his term *paradeigmata* could simply refer to drawings.[34] It is only natural that the semieducated artisans who spent their lives working in three dimensions would have been able to read and comprehend models far more directly and completely than the comparatively schematic shorthand of drawings or diagrams. Michelangelo evidently built elaborate limewood (i.e., linden) and poplar models for the Medici Chapel for similar reasons.[35] Indeed Plato seems to suggest that a builder (*oikodomounta*) of his own time should be trained by playing with "toy houses" (*paideia oikodomêmata*).[36]

The preferred material for working architectural models has always been wood,[37] which rarely survives from antiquity. Fortunately we possess a number of partial scale models in stone which, even if simple in conception, probably served as design tools and perhaps as blueprints for the craftsmen as well.[38] The finest example, found adjacent to the building it represents, is a carefully carved 1:24 stone replica of the podium and stairs of a temple at Niha, Lebanon (Fig. 7). The superstructure, now lost, was probably made of wood. It would appear at first sight to be a presentation piece, but a closer look reveals otherwise. Several steps on the model are inscribed with dimensions in feet. These refer not to the model itself but to the actual building. Evidently the model was a conceptual aid onto which the builder inscribed his modifications for the final design. A polygonal design is inscribed on the model's cella floor, and this too was realized in the temple itself (after yet another phase of modification) as a sort of columned baldachin to shelter the cult statue. Another marble model, in the museum at Ostia, also represents a temple podium and stairs. It too was a working model: Two variant positions of the column bases are represented. Dowel holes in the preserved bases indicate that the superstructure was separate. Again, the latter was probably of wood, and most likely was detachable from the podium so that the builder or client could examine its ground plan and interior.

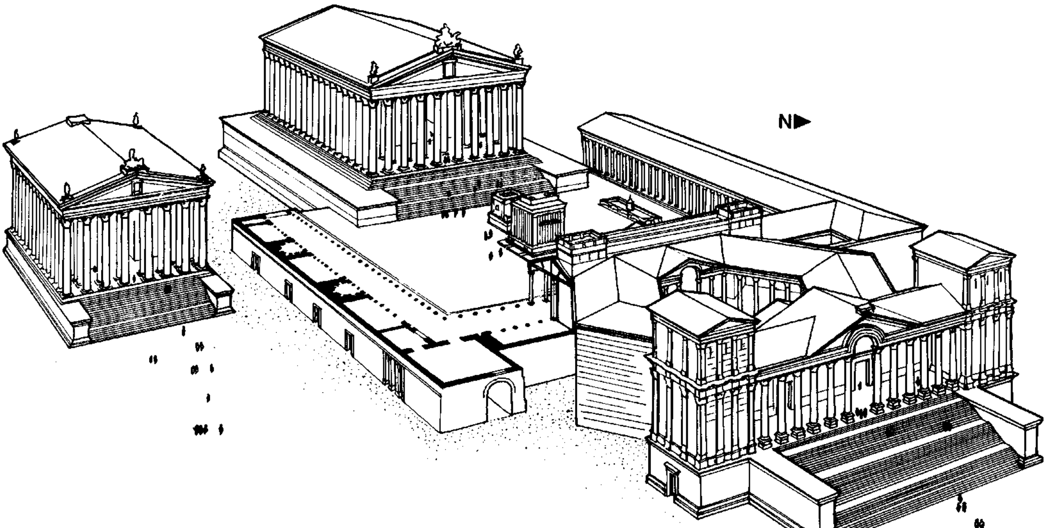


7. Niha: marble model of temple. Illustration: R. Taylor after Will 1985.

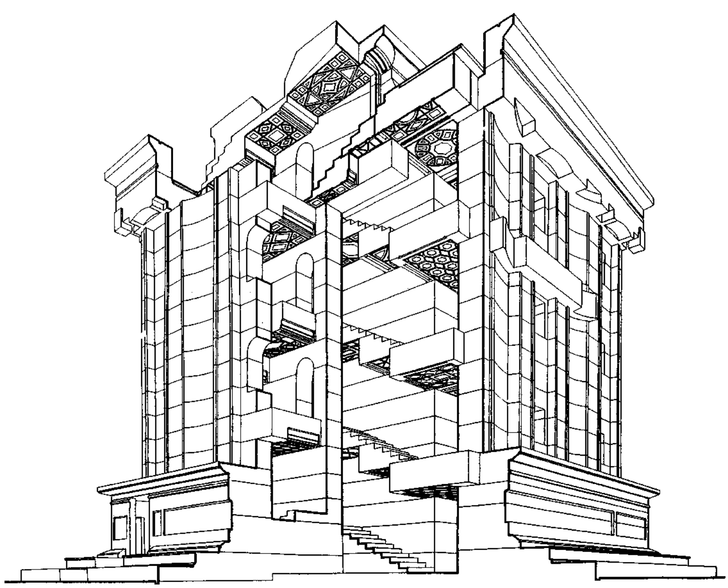
Perhaps the most precious and least remarked of all known Roman models is the 1:30 fragment of the elaborate Great Altar of Baalbek. It appears to be one of several stacked sections that could be dismantled to reveal the staircases inside (Fig. 8).[39] Its form is schematic but unmistakable. The two tower-altars opposite the Temple of Jupiter at Baalbek are themselves tours de force of stereotomy, each among the most complex organizations of space ever realized in solid stone (Fig. 9, 10).[40] Their components are not, like most building materials, small modular units assembled around a void. Within the structure solid and void compete as volumetric



8. Baalbek: fragmentary stone model of Great Altar. Illustration: R. Taylor after Kalayan 1971.

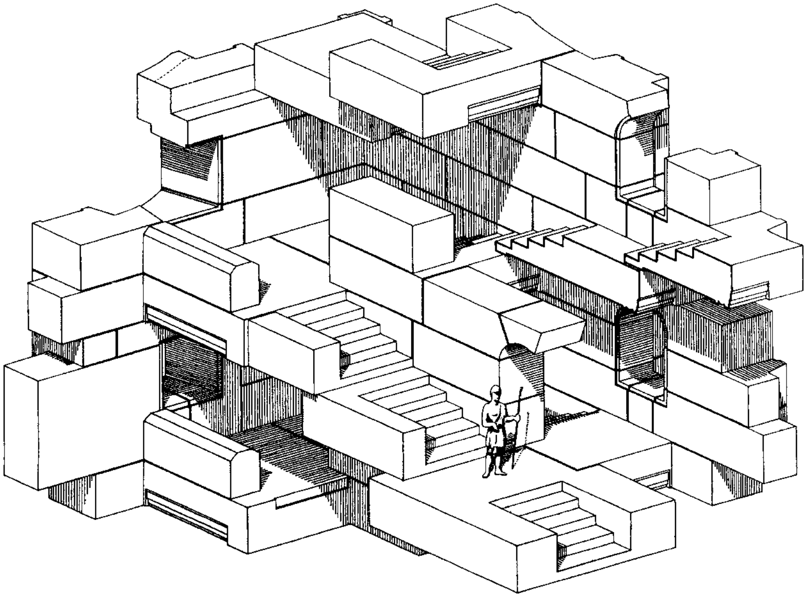


9. Baalbek: reconstructed bird's-eye view of Sanctuary of Jupiter Heliopolitanus. Great Altar shown in center of courtyard. Ward-Perkins 1981. By permission of Yale University Press.

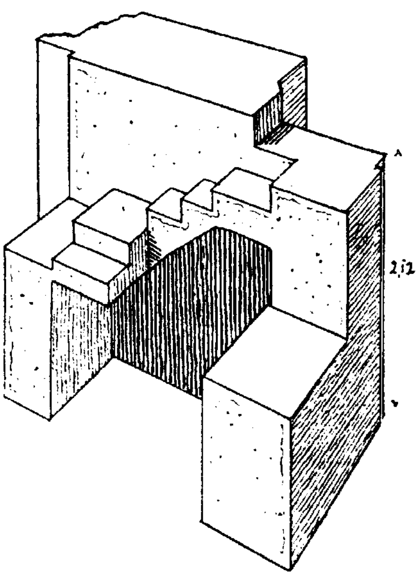


10. Baalbek: cutaway perspective reconstruction of Great Altar. Collart and Coupel 1951. By permission of Société Nouvelle Librairie Orientaliste Paul Geuthner.

equals, each interlocking with the other. Joints and seams cease to correspond consistently to edges; angles are incorporated into the solids themselves. A component block of the altars might comprise dozens of curved and planar surfaces defining both figures and voids and cut to a perfectly conceived analytical plan, their multiplanar



11. Baalbek: analytical view of interior components of Great Altar. Collart and Coupel 1951. By permission of Société Nouvelle Librairie Orientaliste Paul Geuthner.



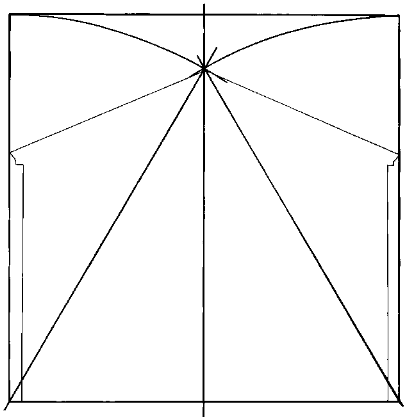
12. Baalbek: a single block from Great Altar. Wiegand 1921–5.

faces commingling as snugly as organs in an anatomical model (Figs. 11, 12). Taken separately, each part conveys a distinctive, identifiable fragment of the larger idea. Without models, indeed several generations of models, the Great Altar was unbuildable. The surviving model fragment reflects the principal formal ideas of the final product, but considerably simplified. It is a prototype, the first or second in a series that evolved from a medium of exploration into a tool of communication.

The obvious benefit of models should not obscure the likelihood that for Roman architects themselves, as opposed to the stonemasons and bricklayers, perspective drawings were the most important creative aids. Models are invaluable tools but they are expressively opaque, even misleading in the oblique bird's-eye perspective they force upon the beholder. Especially in such an interior-dominated architecture as the Roman, human perspective and scale, the interaction of body and building (even if both must be virtual) are paramount. You cannot get inside a model to experience it, to intervene in its volumes, to probe its voids. But you can read the script of a picture and imagine yourself in the action. No doubt this is why, in a well-known passage from Aulus Gellius, Fronto's builders presented rival plans and "specimens" for a proposed bath building in the form of paintings on parchment (*depictas in membranulis varias species balnearum*).[41]

GENERATING DESIGNS

A new building design emerges from such disparate concerns as site specifications, the patron's needs, traditional form, innovation, and available methods for building the mental construct. This final variable comprises a sort of visual phonetics of architectural language deeply embedded in Greco-Roman intellectual culture and tradition. The basic linear elements of planar design were the straight line, the simple curve, and the complex curve (such as a three-point oval or an ellipse), each with the capacity to project any of the others into the third dimension. The principles binding these elements together into coherent forms were the module (i.e., a relative measurement specific to a building), absolute measurements in standard units, and pure proportions derived from geometric and mathematical theory. All were used in Roman design, sometimes in combination.[42] Classic modules based on the distance of an intercolumniation, so essential to the Greeks and to Vitruvius, continued to govern many building designs, as did a host of other units and relationships in a process Mark Wilson-Jones calls aggregative composition.[43] Modules emerged in guises entirely apart from colonnades or arcades, such as a simple square or circle from which all other geometric designs of the ground plan emerged. Standard units of length based on the Roman foot (the *pes,* 0.296 m) were instrumental in beginning any design and were commonly used to

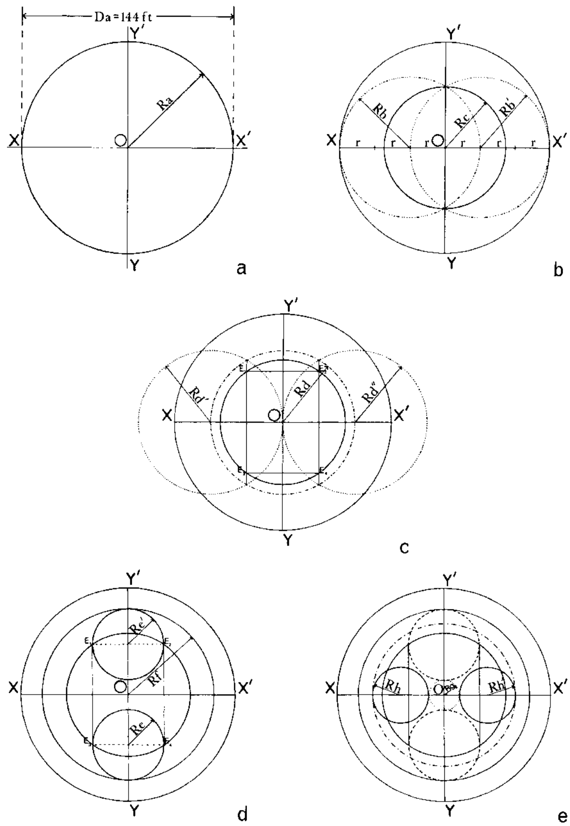


13. A common method of establishing an equilateral triangle in Greco-Roman architectural design. Illustration: R. Taylor.

round off lengths and distances that may have been established by proportional means.[44]

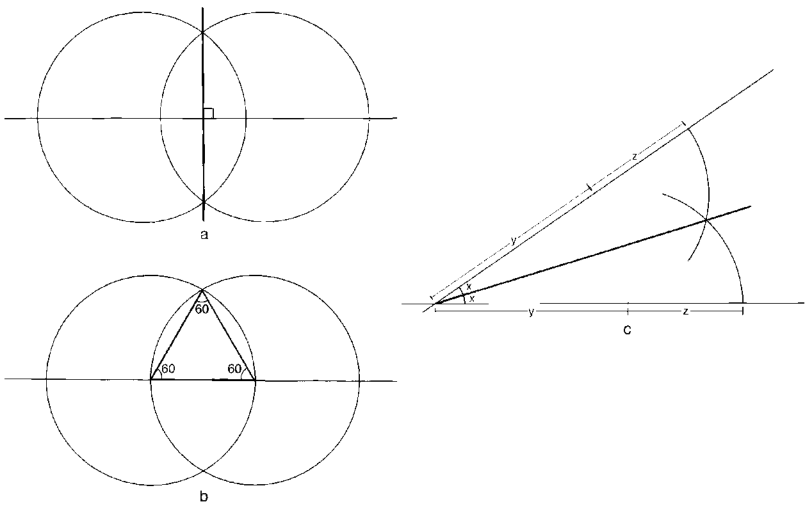
Let us then briefly examine proportions themselves, understood as the relative lengths of two separate elements or the relation of two dimensions of a single element. *Arithmetic* proportions, among which modules are counted, come in simple numeric relationships: 1 : 2, 2 : 3, 5 : 4, 9 : 1, and so on. Vitruvius works with arithmetic proportions, as when he prescribes the inner proportions of domestic atria or the sizes of subsidiary rooms in relation to them.[45] These continued to be important in columnar orders and in overall design; for example, the height of the colossal columnar order of the frigidarium at the Baths of Caracalla was equal to a third of its overall width.[46] *Geometric* proportions, usually manifested in the ratio of width and length of a room or building, or either of these measures in proportion to its height, were often based on popular irrational relationships in pure geometry – for example, the ratio of the side of a square to its diagonal, $1 : \sqrt{2}$. Many proportions were facilitated by the use of the compass, which could quickly transfer lengths of diagonals to the sides of rectangles, or turn side lengths inward to intersect with each other. A common proportion in Greek architecture is the length of a base of an equilateral triangle to its height ($1 : \sqrt{3}$).[47] The proportion could be easily drawn by turning the compass inward from one side of a square to the midline of the square (Fig. 13).

The extent to which such methods actually were used by the Greeks, especially in the design of the elevations of buildings, is still hotly debated.[48] There is no such disagreement about Roman architecture, even if there will always be uncertainty about the exact pro-



14. Tivoli: Hadrian's villa, hypothetical design sequence for Island Enclosure. Jacobson 1986. By permission of D. Jacobson.

cedures used in specific circumstances.[49] New architectural forms were devised on the basis of elaborate and even abstruse inner relationships comprising tangents and intersections of lines, circles, and polygons, as surely was the case with the fanciful buildings at Hadrian's villa (Fig. 14). Plans were drawn exclusively with a compass and a ruler[50] and were later transferred onto the ground, floor, or slope with larger versions of the same tools. Protractors seem to have been avoided; instead, angles were established by geometric tricks of the trade. Simple right angles could be produced with set squares forming a 3–4–5 triangle, a method that Vitruvius inverted for establishing the profiles of stairways.[51] A more precise method is to draw two intersecting circles centered on a baseline and then to connect their two points of intersection (Fig. 15, *a*).[52] If those two circles are made to share a radius along the baseline, then sixty-degree angles (and equilateral triangles) can be formed by running lines from the centers to the intersections (Fig. 15, *b*). Any angle can be bisected by swinging a cord of a uniform length from equal dis-



15. Simple geometric methods to establish angles in ancient planimetric design. Illustration: R. Taylor.

tances along its sides from the vertex and running a line from the vertex to the point where the two arcs intersect (Fig. 15, *c*). Many other similar procedures allowed architects to lay out buildings with very few actual measurements, either of angle or of distance. It has been proposed, for example, that the great bath block of the Baths of Caracalla was designed geometrically around a few initial linear measurements of a hundred-foot module.[53]

Although proportions are widely observed in Greek architecture, many temples of the Ionic order and some of the Doric seem to have been laid out in a sequential fashion, allowing them (at least in part) to be designed and modified as they went up.[54] Such may have also been the case for some conventional Roman stone temples. But concrete, and the operational problems and opportunities it created, fundamentally changed the old ways. First, its malleable nature and stonelike integrity enabled buildings to be increased in complexity. Second, the speed with which it was laid demanded efficiency. Concrete and worked stone, both of which continued to be used together in buildings of many types, took shape at different speeds in a nonlinear process. Stone entablature *A* had to be fully envisioned and its surfaces of contact dressed before its place in concrete wall *B* was realized. Otherwise it would not be ready to be positioned at the critical moment, in turn delaying concrete vault *C*, which would rest upon the entablature, and so on. Concrete demanded speed, and it inspired complexity. The corollary of speed and complexity is high design.

By high design I mean a reasonably comprehensive process in which numerous visual approaches to the building are played out at the drawing board, and by which multiple drawings are produced to be used as blueprints on site. The procedure is far from spontaneous: "designing is a process that proceeds from the simple to the more complex, in which an initial scheme may inevitably become compromised."[55] To the extent that complexity could be minimized up front, it was. Roman architects were fond of simple internal proportions and round numbers. But Vitruvius allows that a judicious designer will know how to compromise on principles of proportion for visual effect. The use of principles other than pure geometry was widespread. As buildings grew more complicated, merging straight lines and flat planes with curved surfaces, perfect inner logic retreated out of reach. A classic example of this is the mensural tension of circular and oval buildings such as rotundas, theaters, and amphitheaters. It is impossible to design a circular building with both diameter and circumference in round numbers of feet, for example. Usually one of the two core generative processes – geometry and arithmetic – will yield to the other.[56] As a general rule Roman plans seem to use a minimum of calculation, perhaps because a profusion of numbers invites error. If a circular colonnade has an irrational circumference, the intercolumniations can be determined either by division or simply by bisecting angles from the circle's center. The second method requires no units of measurement at all, and is far less prone to error.

Recent studies on amphitheaters have investigated how Roman designers tried to reconcile regularity of measurement and practicality with the elegance of pure geometry.[57] As so often happened, the very first design decision was a geometric one. How to generate the shape? Though amphitheaters look like ellipses in plan, very few of them – and none of importance – are true ellipses, because of the difficulty of producing a continuous grandstand with a perfectly uniform width around an elliptical arena. Almost all amphitheater plans comprise segments of circles with different radii, joined at carefully predetermined points where they share tangents. Typically there are four segments, two with longer radii forming the long sides and two with shorter radii forming the "ends." One of the most straightforward schemes is used for the amphitheater at Verona (Fig. 16). The basic units are two equilateral triangles sharing a side on the main axis. The four corners of these joined triangles are the centers of the four circles whose segments merge to form the oval. All