James "Athenian" Stuart and the Geometry of Setting Out

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A characteristic feature of the neoclassical attitude to Greco-Roman architecture that ran from the middle of the eighteenth century to the middle of the nineteenth has long been held to be the minute surveys of ancient buildings that were undertaken and published during that period. Ultimately inspired by Antoine Desgodetz's *Les édifices antiques de Rome* (1682), measured surveys of antique buildings across the Mediterranean world became a staple part of architectural and antiquarian study from the 1750s, especially in relation to the growing interest in Greek architecture. The British were especially assiduous in framing these surveying activities as part of a discourse about "truth" (as Robert Wood put it in 1753) and "accuracy", a term used by James Stuart in the preface to the first volume of *The Antiquities of Athens* in 1762.[1] Later eighteenth- and early nineteenth-century architects appear to have accepted that these surveys did indeed represent ever-more refined attempts to establish absolute sets of dimensions for the great monuments of Athens and Greece. In his eleventh lecture to Royal Academy students, for example, first delivered in 1815, John Soane spoke unquestioningly of "the accurate and laborious

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representations of Stuart and [Nicholas] Revett, who measured those proud remains of ancient glory to the thousandth part of an inch."[2] This tradition reached its culmination in the extremely fine measurements made in Athens in the 1840s by Francis Cranmer Penrose, who described the purpose of his 1851 *Investigation of the Principles of Athenian Architecture* as having been "to fill up what had been left imperfect by Stuart and Revett."[3]

Since that time, architectural historians have tended to accept at face value the claims of protagonists from Stuart to Penrose that their surveys tended towards an ultimate goal of absolute accuracy of measurement, locating them within a framework of Enlightenment scientific research that contrasts with broader and perhaps more Romantic contexts of coeval history and anthropology. However, in 1956, Jacob Landy, writing in the journal *Archaeology,* pointed out that while the measurements in *The Antiquities of Athens* were indeed "more accurate than those of any previous publication," Stuart and Revett were also "not concerned with as complete a presentation of the facts as they pretended," being "burdened with literary, mythological and historical allusions."[4] While we should indeed now see *The Antiquities of Athens* as a work conditioned by the cultural circumstances of the later eighteenth century, there is another dimension to the question of accuracy that has not yet been studied and that this chapter explores. Recent research on the case of Stuart's survey of the Tower of the Winds in Athens has shown, thanks to the fortuitous survival of a proof plate showing the plan of the roof, that at least one of the dimensions appearing on the version finally published was not measured at all but calculated trigonometrically.[5] It is possible that such an intervention amounts to no more than a pragmatic way of providing data that Stuart realized he had not collected in Athens when he was working on the surveys in London many years later, but the same plate also suggests that Stuart was systematically double checking all measurements in order to ensure geometrical coherence.

We cannot be certain, then, that the figures offered in *The Antiquities of Athens* by Stuart—and perhaps by others involved in the same type of pursuit—represent measurements physically made. The process Stuart followed in preparing this plate of the Tower of the Winds was not a simple one of transcribing dimensions taken in the field onto the image but one that involved some computation, and this realization now presents the historian of neoclassical architecture with significant problems. We know that architects in ancient Greece and Rome would have used geometrical rules to design their buildings, and we are now learning that men like Stuart, by measuring those early buildings that survived, sought to understand those rules, both to ensure the consistency of their reconstructions and to use them in their own designs.[6] However, the process of surveying an existing structure is by no means commensurate with that of setting it out in the first place, since some dimensions are effectively concealed by the fabric of the building itself. Further still, methods appropriate for drawing on the smooth surface of a drawing board may be quite different from those appropriate for the staking out of the plan in the field or the marking of stone by the mason. This situation raises a number of related conundra: How did Stuart take measurements in the field? How did they get translated to published form? What assumptions did he make about Greek setting out, and how did these assumptions color his measurements and his reconstructions?

This paper probes these questions by close consideration of cases taken from Stuart's surviving papers. Of the large number of his field notebooks in circulation in the early nineteenth century, only one integral version is now known: the "Edinburgh Notebook" in the Laing Collection of the University of Edinburgh.[7] This source provides useful data in the form of Stuart's field notes and musings on two large classical buildings: the Temple of Rome and Augustus at Pola in Istria (early first century) and the Theater "of Bacchus" (actually of Herodes Atticus, c.162) in Athens. We have also been able to examine problems of geometry at the smaller scale of a building component, the Ionic capital, thanks to the survival of a number of loose sheets on which Stuart analyzed the problem of the setting out of the volutes.

Whereas the surviving sheets on which Stuart studied the Ionic capital are loose and difficult to date, it seems reasonable to assume that the Edinburgh Notebook is typical of the way he kept his records whilst in the field and resident in Athens. It was essentially a commonplace book, used to record a variety of notes on different subjects. There are descriptions of different parts of Athens and other places that he visited, a few drawings, and many calculations (Fig. 1). The notes usually begin on the right-hand page and only sometimes continue on the left. This doubtless reflects Stuart's method of working in the field, holding the book in the left hand or resting it on the right knee, and using the right hand side of an opening.[8] It is not always clear what dimensions were measured nor how accurately. In his description of some buildings, he left gaps for the dimensions that he presumably intended to measure at a later date, or which he was content to delegate to Revett. We know something of their working practice, as Stuart mentions measurements with a chain (presumably with a trained assistant) that Revett would later check with a rod, which he specified, "will be more accurate."[9] The measurements Stuart recorded in his notebooks are by no means straightforward, as Joseph Woods found when editing the fourth volume of the *Antiquities* in 1816: "The following list of heights of these buildings are given by Stuart; they are not always consistent with the figures on the sketches, nor do I always understand the exact application."[10] Whereas Woods thought "it would be best to give them just as I found them," Stuart, as we have seen at least in the case of the Tower of the Winds, went to considerable effort to make them consistent when preparing his work for publication.

The Temple of Rome and Augustus at Pola

The Edinburgh Notebook contains memoranda on the temple at Pola, the Roman city in Istria to which Stuart and Revett made an excursion from Venice in 1750 while waiting to travel to Athens (which they did in 1751). Their work at Pola thus stands as something of a rehearsal for the methods they would deploy when in Greece. There is a small plan showing the general scheme of the temple and then two larger sketches (fol. 14), all of which can be combined for convenience into Fig. 2. The arithmetic accompanying Stuart's sketches is simply the addition of the various measurements that were made to obtain overall lengths and widths.

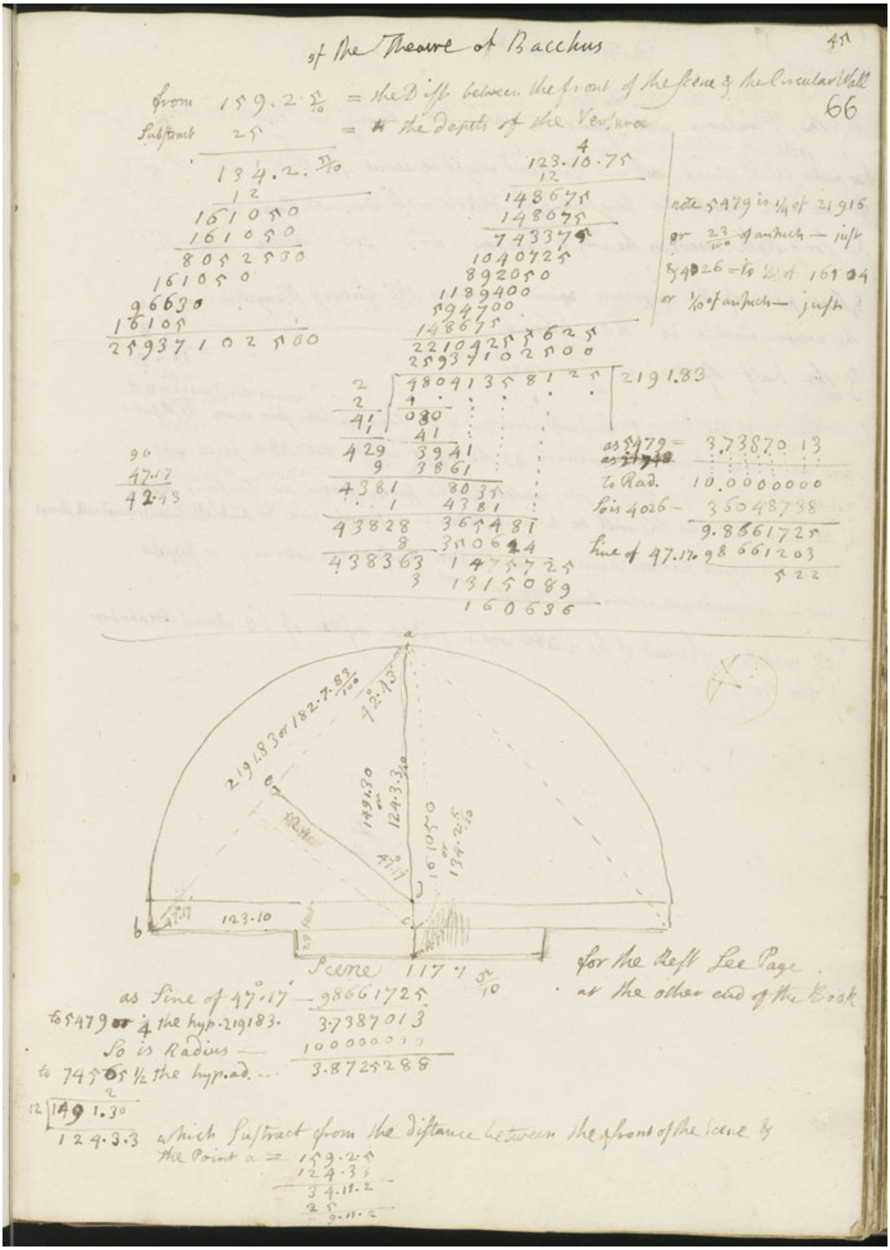


Fig. 1 James Stuart's "Edinburgh Notebook," fol. 66v, Laing Collection, University of Edinburgh

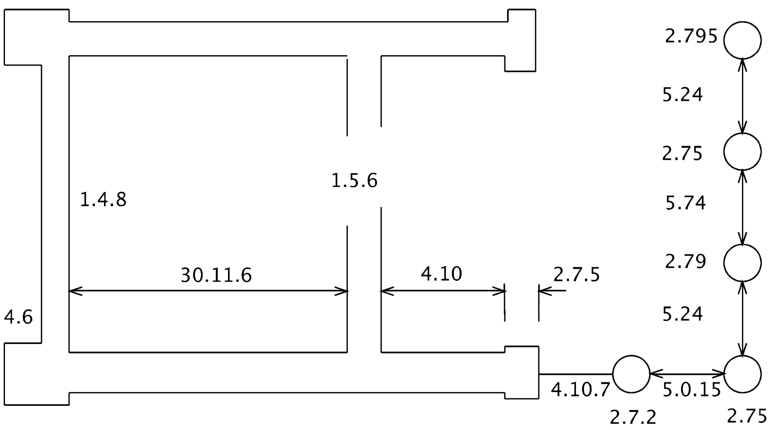


Fig. 2 Plan of the Temple of Rome and Augustus at Pola with inscribed measurements, based on sketches and field notes in the Edinburgh notebook

Table 1 James Stuart's arithmetic for the dimensions of the temple at Pola, from the Edinburgh Notebook (fol. 14)

		4.	6	
	1.	4.	8	
	30.	11.	6	
	1.	5.	6	
	4.	10.		
	2.	7.	50	
	4.	10.	70	++22 7. 05
	2.	7.	20	
	5.	0.	15	
	2.	7.	50	/100
Entire length of the temple	56.	9.	65	

Reproduced here are the measurements for the length of the temple, in which Stuart has made a division between the cella and the pronaos (Table 1).

The figures are in English feet, inches, and decimals of an inch up to the hundredth, the standard Stuart had adopted when surveying the Obelisk of Psammetichus II in Rome, probably in 1748, for his first major archaeological publication *De Obelisco Caesaris Augusti* of 1750.[11] For the Athens expedition, the authors were able to achieve this level of accuracy with the aid of a brass yard rule engraved by the foremost mathematical instrument maker of mid-eighteenth century London, John Bird. Other than a chain and a compass, this was the only piece of surveying equipment we know them to have had.

The arithmetic for the parts of the Pola temple is correct, but changes were introduced between the Notebook and the published version that appears in Chapter II, plate III of the fourth volume of the *Antiquities*. This was published after Stuart's

Table 2 James Stuart's arithmetic for the dimen-sions of the temple at Pola, from the Edinburgh Notebook (fol. 14)

To the length of the cell	30	11.	6
Add the thickness of the wall at the front	1.	5.	6
	32.	4.	2
Subtract the width of the cell including the walls	26.	1.	85
	06.	2.	35
			4
	24	9.	4

death, and Woods's introduction to the volume indicates that he was working from Stuart's drawings. The value 1.4.8 for the thickness of the end wall of the cella in the Notebook was reduced by just over an inch to 1.3.6, while the overall length of the building was increased by just under an inch to 56 ft, 10.6 in. There is nothing to indicate why these changes were made. The most likely explanation is that Woods was working from more than one version of the plan and needed to make a choice between them. Whatever the reason, this maneuver certainly made the correct arithmetic of the Notebook record incorrect on the published plate. Woods almost certainly noticed the discrepancy, but he evidently considered it more important—as he stated—to maintain editorial neutrality than to try to reconcile the numbers.

A second area of Stuart's concerns raised by his Notebook observations involves the issue of proportional relationships. Although Stuart was to make a clear statement in the introduction to the first volume of the *Antiquities* that he had avoided any system of design based on modules (and to imply that previous surveys had made errors because of the preconceptions that modules brought with them), that did not mean he never considered the possibility of proportional relationships. On the same page as the calculations above appears a set of other figures, where Stuart seems to be checking possible relationships that might have determined the actual dimensions. The following example, taken from folio 14, shows Stuart engaging with Vitruvius on this question. Disregarding the Roman author's modular starting point (using the diameter of the column as the generator of the design), he concentrated instead on the relationship of length to width of the cella (Table 2).

Stuart was checking that the Pola temple was in line with Vitruvius's prescription (Book 4, Chapter 4) that "the cella itself will be longer by one fourth than its width, including the wall in which the doors are to be located."[12] The dimensions evidently did not match Vitruvius's recommendations, at least in terms of a common module. A presumed module of 6 ft 2.35 in. would produce wall dimensions about 5 % shorter than those built. A second set of calculations shows Stuart trying to relate the length of the cella to that of the whole, also presumably to compare the result with Vitruvius's recommendation. Here, too, Stuart would have noticed a significant deviation from the text. As built, the cella is closer to 4 parts of 9 than the 5 parts in 8 that Vitruvius allows.[13] The notes and calculations made at Pola thus stand as evidence of the approach Stuart intended to adopt at Athens, which was, as he put it in the 1751 "Proposals" for the *Antiquities,* to analyze buildings "by pointing out the relation they may have to the Doctrine of Vitruvius."[14]

The Theater of Bacchus

The notes for the Theater of Bacchus are divided between the front and the back of the Edinburgh Notebook, probably reflecting work done at different dates during Stuart and Revett's stay in Athens, which lasted from 1751 to 1754. The plate with the plan of the theater was eventually published in volume two of the *Antiquities,* which appeared in 1789–90 under the editorship of William Newton (Stuart having died in 1788).

In Athens, Stuart and Revett were confronted with a ruin. The remains of the *frons scaenae* and the flanking *versurae*—the tower-like buildings that provided access to the scene from the corners of the hemicycle—were all that remained of the structure. A grass-covered hollow lay where the seating had been cut into the hillside, but none of the tiers remained intact, almost certainly because the site had been quarried for building stone in the centuries since the classical era. The ensemble can be seen in Stuart's perspective view, which also features Revett in the right foreground at work drawing the masonry of the *frons scaenae* (Fig. 3). As an added difficulty, the surveyors were unable to excavate inside the ruin because of its proximity to an Ottoman garrison, though some digging behind the *versura* wall was permitted.[15] The Notebook records Stuart's aim in surveying the site. He hoped to elucidate Vitruvius's description of the setting out of Greek and Roman theaters, improving on the accounts of earlier editors, in particular Claude Perrault and Daniele Barbaro:

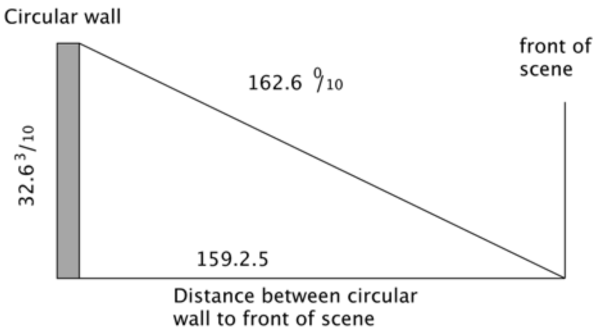
> The Theater of Bacchus is so ruined that only the front of the scene, the versurae & the exterior circuit appear above ground naked of ornament and the upper parts entirely ruined. The pulpitura above [lies more than] 16 feet below the present surface of the ground. Yet what remains may serve to explain Vitruvius better than all his commentators[.] Lett [sic] us see his words & comparing the designs of Barbaro[,] Perault & theatre of Bacchus observe which agrees best with his description and documents[.][16]

Of the Vitruvius commentators mentioned here, Stuart does not seem to have made further use of Barbaro. The published text makes reference to the Italian translation of Marchese Berardo Galiani, which superseded Barbaro when it appeared in 1758. The Perrault translation, however, was much more important. It was on this French source that Stuart depended for his understanding of Vitruvius. The Notebook contains a transcription and translation of this section of the text (Book 5, Chapter 8) for quick reference. As Stuart reports, Vitruvius differentiates between the layout of Greek and Roman theaters. In his published comments, Stuart appeared to recognize that the date (actually second-century AD) and identity of the builders was open to question. Nevertheless, for the purposes of the reconstruction, he proceeded on the assumption that what Vitruvius "had said concerning the Greek Theaters [was] applicable to this building."[17]

Stuart's first task in describing the theater was to obtain true dimensions from the surfaces that he could directly measure. A schematic cross-section in the form of a sketched triangle shows two of these: the descending slope of the seating and its height at the back (Fig. 4). Neither of these measurements was easily obtained.

Fig. 3 Nicholas Revett drawing the *frons scaenae* of the Theater "of Bacchus" (Herodes Atticus) (From Stuart and Revett 1762–1830)

Fig. 4 Schematic cross-section of the Theater of Bacchus, based on Stuart's fieldnotes in the Edinburgh notebook



The slope was hardly constant, as is evident from the published view. Likewise, with the theater built into the hillside, the height of the seating could only be measured from the side. This was the area they had to excavate, which Stuart referred to in his notes as the "corridor going from the wings of the Theater to the Orchestra or gate of the Versura."[18] With these two dimensions, Stuart was able to find the horizontal depth of the theater in plan from the *frons scaenae* to the back wall. For this, he simply used Pythagoras. The Notebook contains a clear calculation for that, where the squares of the two distances 162 ft 6 in. (the measurement along the

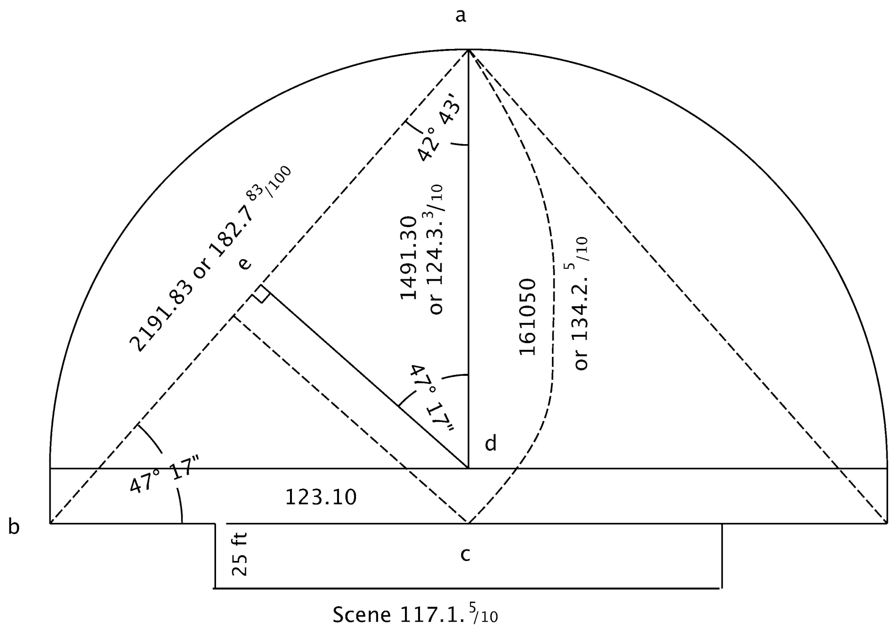


Fig. 5 Schematic plan of the Theater of Bacchus, based on fol. 66v of the Edinburgh notebook (Fig. 1)

slope) and 32 ft 6 in. (the height of the seating at the back wall) are reckoned and the second subtracted from the first. The square root of the result is the horizontal distance to the wall. Stuart extracted this root by hand, a calculation that fills a considerable portion of the page. This is the first of several instances where it is evident that Stuart used derived dimensions rather than those directly measured.

According to Vitruvius, the design of theaters was based on a semi-circle touching the far edges of the *versurae*, but with a center some distance before the *frons scaenae*. If Stuart was to demonstrate the use of this principle in the design of the Theater of Bacchus, it would be necessary to find the centre of that circle. Figure 5 simplifies the plan that Stuart sketched in his notebook (Fig. 1, fol. 66v) to find the point *d* and the accompanying dimensions. His first step was to measure the width of the theater from the far edges of the *versurae* and halve it to give *cb* as 123 ft 10 in. He also measured the depth of the *versurae* from the *frons scaenae*: 25 ft. These were the only directly measured values that Stuart used for this reconstruction. The rest were derived from trigonometric operations on the plan. The length of the perpendicular center line *ac* was established by subtracting the depth of the *versurae* from the horizontal value determined in the previous calculation (Fig. 4: 159 ft 2.5 in.). Applying Pythagoras, Stuart could then calculate the length of the hypotenuse of the triangle *abc* and from this, the sine and the opening of the angle *bac*. Because the hypotenuse was a chord of the large semi-circle formed by the back wall of the seating, a line bisecting that chord (*ed*) would pass through the required point at the center of the circle. At this stage, Stuart had all he needed to calculate the distance *ad*, thus finding the position of the setting-out point suggested by Vitruvius ($ad = bd = ae/\sin ade$).

In carrying out his calculations, Stuart used a table of logsines, which allowed him to avoid tedious multiplication and to perform the calculations with simple addition. As it would have been simpler to do the calculations involved with a table of tangents, we must assume that he did not have one available. The other point to note here is that the table of logarithms that he was using provided seven figures in the mantissa, which would have given him more accuracy than he needed.

Armed with this information, we can check Stuart's measurements against those generated by Vitruvius's method. The most readily verifiable dimensions were the size of the orchestra circle, the width of the scene, and the depth of the *versurae*. Stuart explained Vitruvius's construction in the text accompanying the published plan of the theater (Fig. 6):

> On this we must observe, that the exterior wall is the portion of a circle, the centre of which being found, it will follow from the precepts of Vitruvius, if we suppose what he has said concerning the Greek Theater applicable to this building, that the extent of the Procenium, with the situation and dimension of the Orchestra, may be determined. For the distance *a.b.* from the centre *a.* of the exterior circle, to the front of the Scene *C.B.D.* will be the radius of a lesser concentric circle, in which three squares being inscribed, after the manner he has directed, the side of the square *e.f.* [sic *g.f.*] nearest to the Scene and parallel to it, will then mark the limit of the Procenium, and the remaining part of the circle, if we do not mistake Vitruvius, will form the space assigned by him to the orchestra; within which space, I am persuaded, the Pulpitum or Logeum projected at least as far as to the centre *a.* for I cannot imagine, that the actors were confined to the narrow space assigned by this scheme to the Procenium.[19]

Vitruvius's instructions, interpreted here largely via Perrault, call for the radius of the orchestra circle to determine the other elements. The first step, as shown in simplified form on the right side of Fig. 7, is to inscribe a square into the orchestra circle. As Stuart relates, extending the side parallel and closest to the *frons scaenae* provides the forward edges of the proscenium, the raised platform for performers. The width of the scene is obtained by setting the radius of the orchestra circle at the outer edge a' and rotating it until it meets the line of the proscenium at *h*. The depth, finally, of the *versurae* is determined by rotating the same radius around the upper corner of the inscribed square e' until it meets the orchestra circle at c'. It should be clear that the side of the square $a'h = ab/\sqrt{2}$ and the total width of the *frons sceanae* $= ab(2+\sqrt{2})$. Likewise, the depth of the *versurae* (H in Fig. 7) will be $ab - ab.\sin 15°$ or $0.74ab$.

Recognizing these relationships, we can check to see whether Stuart would have been able to confirm Vitruvius's method by a simple calculation. Using the published figures, which differ slightly from those in the Notebook, Stuart and Revett record the distance *ab* as 35 ft 0.3 in. On that basis, the width of the scene should be about 119 ft 6 in. In fact, Stuart and Revett have it as only 117 ft 1.5. The depth of the *versurae* is marked as 25 ft 4.5 in. Calculated from *ab*, however, it would be 7 in. longer. In both cases, the discrepancy is about 2 %. Although the published plan suggests a close correlation between the built remains and Vitruvius's setting-out method, Stuart's measurements do not bear it out.

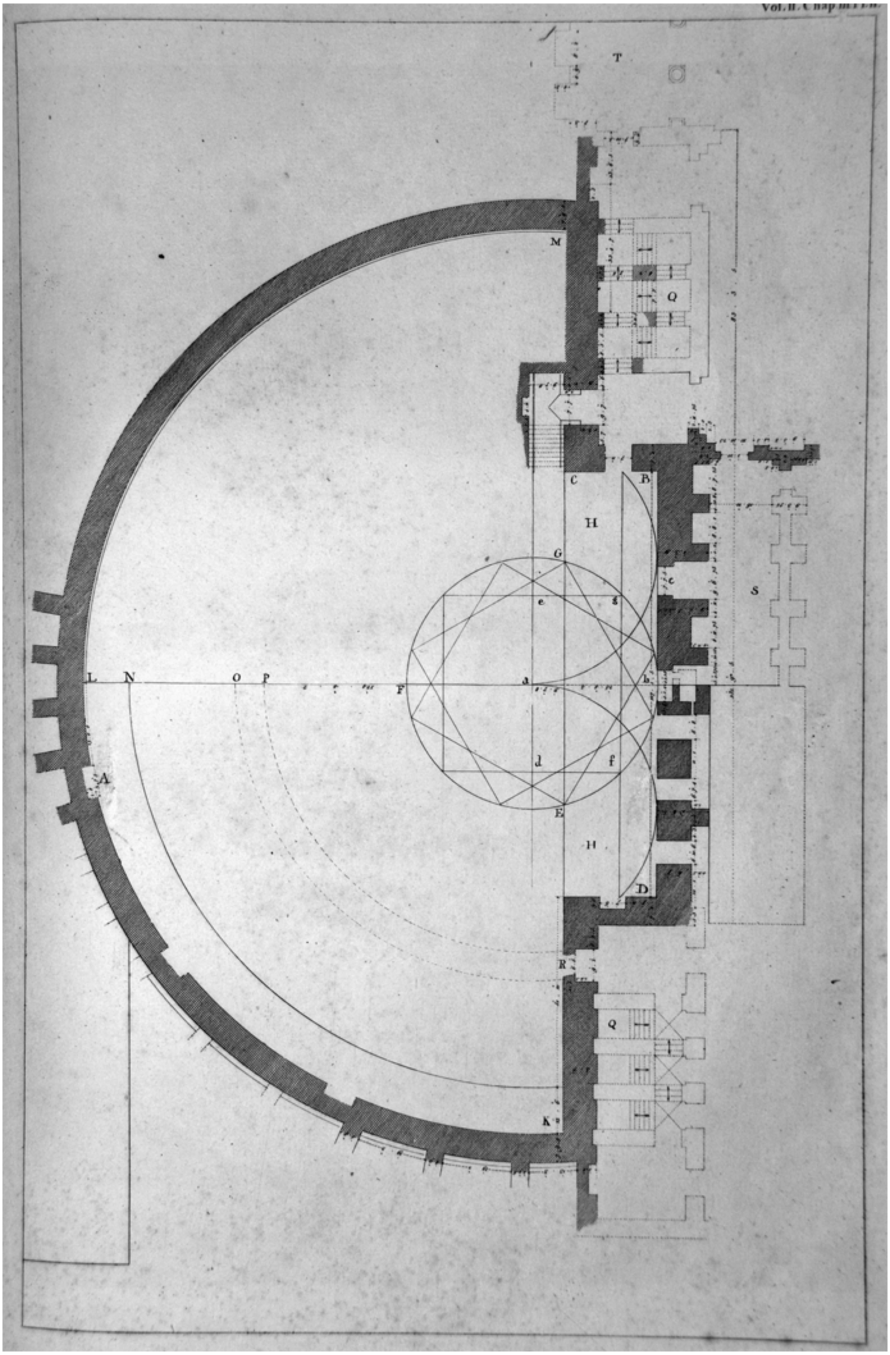


Fig. 6 Plan of the Theater of Bacchus, with reconstruction of Vitruvius's setting out method (From Stuart and Revett 1762–1830)

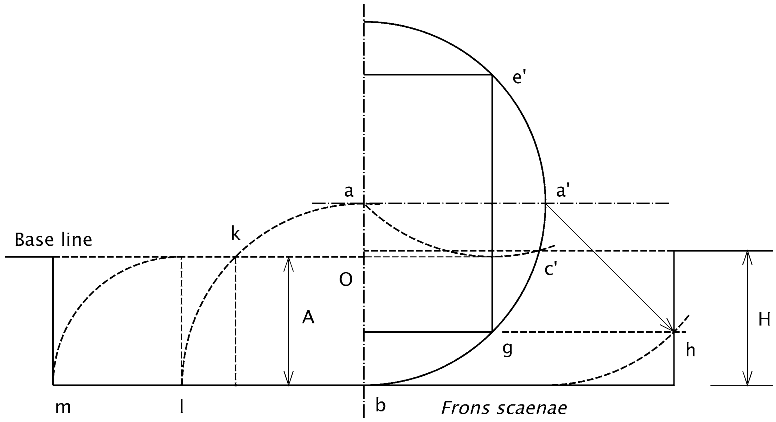


Fig. 7 Setting out the Greek theater. The right side shows a simplified version of Vitruvius's setting out method, which involves inscribing a square in the orchestra circle, and the left a simpler and more feasible method of achieving the same results

Had he carried them out, these calculations might have given Stuart some reason to doubt Vitruvius's authority as a source, at least for the Theater of Bacchus. In fact, there are other reasons to discount Vitruvius's suggested procedure. His approach, with whirling squares and many extraneous lines and found points, appears little more than a drawing board exercise. What is missing from Vitruvius (and hence from his commentators, including Stuart) is any consideration of the practical operations necessary to transform the geometry of design into setting out marks on site using stakes and string lines. In the first place, it would be extremely difficult to set out the theater using the center of the circle as a starting point, and it is difficult to imagine that builders would have begun there. Not only is *a* itself a found point, it also requires several intermediate steps to inscribe the square before determining the location of the proscenium, the *frons scaenae*, and the *versurae*. Rather than unfolding the plan from a point, a builder would surely begin with the longest lines in order to ensure that the building fit on the site.

Could Stuart have recognized the practical problems with Vitruvius's method? Perhaps not: aside from the Roman author's still-powerful authority both as a designer and a source for ancient design methods, Stuart was at this early point in his career still an inexperienced architect. The left side of the diagram in Fig. 7 suggests a simpler alternative, with the more believable starting point *O*. It assumes that the depth of the *versurae* (*A*) is derived, not from a complicated construction, but from the radius of the orchestra circle. *Ok* equals *Ob* and *ab* equals *kb*, the diagonal of the square drawn on *Ob*. The length *bl* is the same diagonal rotated towards the *frons scaenae*. The point *m* is obtained by adding the length *Ob* to *l*. This method produces almost the same layout that Vitruvius recommends. The width of the *frons scaenae*, $ab(2+\sqrt{2})$, is the same and the depth of the *versurae* very nearly so, but this operation is much simpler and also more workable at full scale.

The Ionic Volute

The volute of the Ionic capital presented Stuart and Revett with a series of problems that, for modern scholars, illuminate the complexities of Enlightenment measurement. The problems stemmed from the fact that their aims as both architects and archaeologists were often at cross-purposes. The conflicting epistemologies that spurred their research provoked questions that, while distinct to the modern researcher, were complementary or even integrated in the minds of Enlightenment researchers. The first question was methodological: how should one measure the Ionic volute? If the purpose of their research was simply the empirical description of classical architecture, then their approach would be quite different from that of Desgodetz, who sought to uncover the hidden language of classical architectural proportion. The second question was practical, with application both to archaeology and architecture. How could Stuart and Revett work back from their on-site measurements and observations to deduce the working methods of ancient architects and masons? Their interest here was not purely academic. The reintroduction of the Greek Ionic order formed part of the "improvement" Stuart hoped to see in later eighteenth-century architecture and to which he himself was to make great contributions in his own designs of the 1770s and 1780s. In this sense, his studies of Greek Ionic capitals had greater relevance in the context of neoclassical design than did the public building types we have been able to study here.

On the subject of the Ionic order, Stuart and Revett found their predecessors' works incomplete. While Vitruvius discussed the Doric and Ionic styles at some length, the moderns had virtually ignored them in favour of the Corinthian. The reason for this was the centrality of Rome to the mental landscape and travel itineraries of early modern scholars, artists, and antiquarians. Palladio's *I Quattro Libri*, for example, the central text of British architectural classicism, was replete with examples of the Corinthian, but included only one description of an Ionic temple: the Temple of Manly Fortune, now known as the Temple of Portunus (Fig. 8). Even Desgodetz, to whom Stuart and Revett looked with nearly uncritical admiration, failed them here. Stuart dismissed all three of the examples that Desgodetz examined: the Temple of Manly Fortune, the Theater of Marcellus, and the Colosseum (Amphitheater of Vespasian). To Stuart, following Fréart, the Temple of Manly Fortune was "ill wrought" and "covered with Stucco." Although it was the best surviving example of the Ionic order in Rome, its features were "not only incorrect, but they are likewise so decayed, that the original form and projection of these Mouldings cannot now be ascertained."[20] In contrast, Greek examples of the Ionic, like the temple on the Illissos, were "simple", "elegant", "well executed", and "among those Works of Antiquity which best deserve our Attention."[21]

Such statements provide important insight into the influence of Vitruvian rationalism that dominated many early modern architectural debates. Stuart and Revett worked from the assumption, then prevalent, that ancient Greek architects abided by the strict laws later transcribed by Vitruvius in *De Architectura*. The Greco-Roman architects who followed the Greeks borrowed their proportional principles, corrupting them into the variations that could be seen in Rome, such as the "incorrect" Ionic

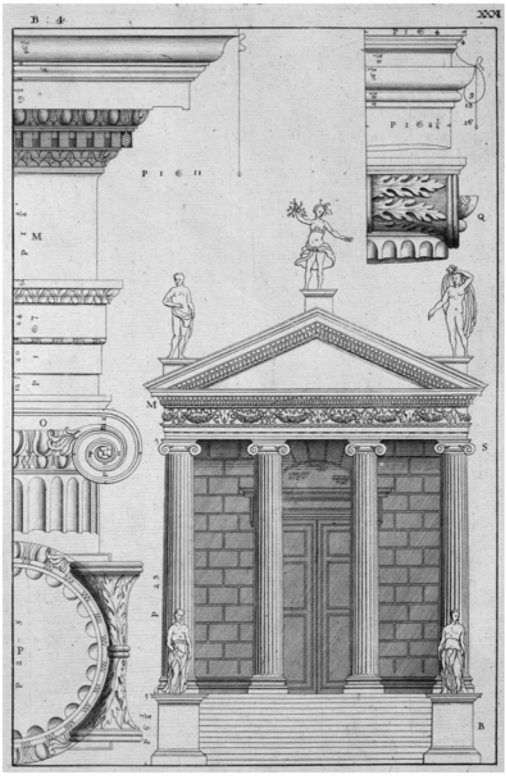


Fig. 8 The Temple of "Fortuna Virilis" (Portunus), Rome (From Ware 1738)

capitals of the Temple of Manly Fortune. That said, Stuart and Revett were not entirely satisfied with rationalist dogma. True to the empiricism that then dominated British intellectual circles, both men recognized the need to survey the remaining examples of Ionic architecture in Athens. It is here that their assumptions and desires worked at cross-purposes. On the one hand, the architects-in-training sought an abstract system of beauty, preferably one based on Vitruvius's system of modular proportion. Furthermore, their role as architects encouraged them to inquire into the practicalities of ancient architectural practice. There was, on the other hand, the physical evidence of the buildings themselves. These measurements, as it turned out, did not allow easy rationalization, much less conversion into convenient rules-of-thumb.

Measuring the Volute

The setting out of the volute was a problem that had engaged architects long before Stuart and Revett. A close approximation to an Archimedean volute—which uncoils at a constant width—can be obtained by unwinding a cord from a cylinder, but what

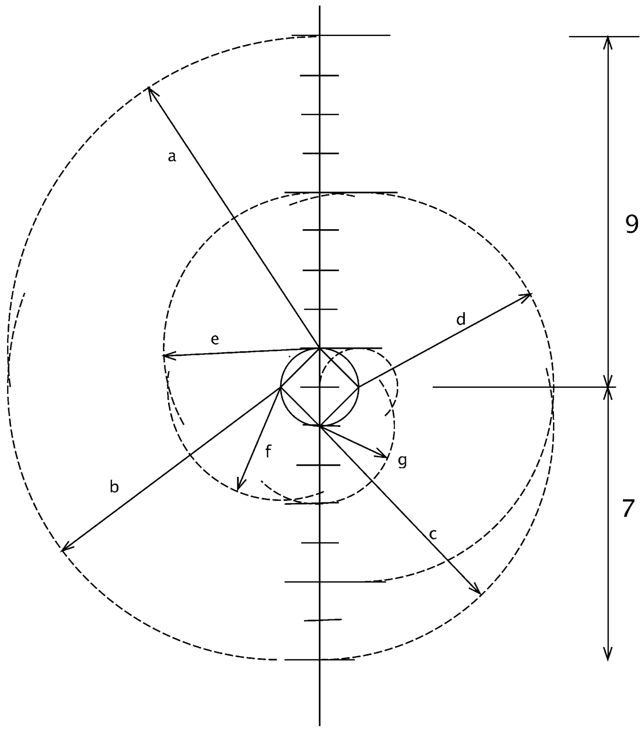


Fig. 9 Vitruvius’s method for setting out the spiral of the Ionic Volute (From *De Architectura*, Book 3, Chapter 5.5–6)

was more usually wanted was a logarithmic volute, which widens as it uncoils. Moreover, the volute had to be drawn inwards within a block of stone of known size. Once the centre of the volute and the size of the oculus have been found, the method usually involves drawing a series of arcs of diminishing radius, each subtending 90°. Vitruvius describes a method of this sort (Book 3, Chapter 5), with the point of the compasses stepped round a square inscribed inside the oculus. However, the figure that originally accompanied his account was lost, so subsequent architects had to imagine several unstated elements of his method. For example, if one were to draw ever-shorter radii from a fixed centre for each arc, the diminution of the scroll would not be smooth and each new arc would create a noticeable break. Moreover, a literal translation of Vitruvius’s text resulted in an Archimedean volute of only two revolutions (Fig. 9).[22]

Renaissance architects were well aware of these deficiencies, and using the Roman remains as guides, they created improved and often sophisticated systems for laying out volutes. The most important refinement to Vitruvius’s method involved manipulating the centers of the arcs to give a smooth transition from one to the next. Sebastiano Serlio provided a simple solution in 1537. His adaptation stayed very close to Vitruvius’s text, with semicircular arcs plotted from points set within the oculus and along the vertical axis of the volute.[23] Further refinement came from a

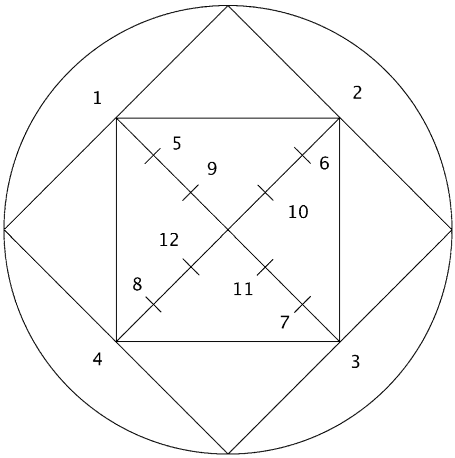


Fig. 10 Method for setting-out the compass points in the oculus of the Ionic volute (From Salviati 1552)

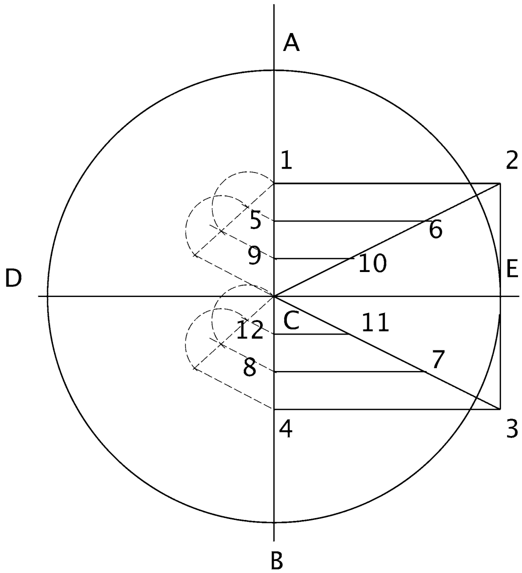


Fig. 11 Method for setting-out oculus centers (From Goldmann 1649)

text by Giuseppi Salviati in 1552. His technique—simplified and popularized by Philibert de l'Orme, Giacomo Barozzi da Vignola, and Andrea Palladio—placed the centers of the arcs along diagonals at 45° to the vertical axis (Fig. 10). The points could be found geometrically, inscribing squares within the oculus and dividing the diagonals into thirds.[24] Their approach remained popular into the eighteenth century, having the sanction of both Fréart and Perrault.[25] However, many practicing architects, especially in Britain, found Nicolaus Goldmann's seventeenth-century solution preferable, as it minimized the breaks between the spiraling arcs (Fig. 11).[26]

According to William Chambers, Goldmann's technique was the best, because the arcs "have their radii… in the same straight line; so that they meet, without forming an angle: whereas in that of De l'Orme, the radii never coincide; and consequently no two of the curves can join, without forming an angle."[27] For Stuart, these researches must have created an almost unrealizable expectation of what the Ionic volute was or should be. If the Greeks did possess the secrets of ancient architecture, they too must have understood the volute not merely as a decorative form, but as a highly elaborated and coherent geometrical construction.

The proper setting out the Ionic volute concerned architects both before and after Vitruvius. The two problems faced by Stuart and Revett were more specific. They had to determine how to measure particular examples *in situ* and how to draw them for the plates in their book. Fortunately, we know something of their methods in confronting both of these tasks, thanks to the survival of several of Stuart's preparatory sketches, notes, and drawings in the British Library and in the Drawings Collection of the Royal Institute of British Architects.[28] The former group of papers includes field notes of the measurements for the volutes they found in Athens, along with some accompanying calculations. The latter archive contains a number of different recipes for finding a series of centers from which curves could be drawn through their measured points.

The most practical method of measurement would entail climbing a ladder and measuring with calipers, while calling out the results to an assistant on the ground. This procedure is perhaps easier described than executed, for one, because it requires the two collaborators to agree beforehand on a set series of points to measure. The field drawings suggest the use of just such a formula. What Stuart and Revett measured were the distances from the center at which the spiral intersected with the vertical and horizontal axes, as well as with diagonals struck at 45° intervals. In this respect, the field notes provided the basis for the plates of the published work, which appear in much the same form. The method may have been inspired by the setting-out technique of Guillaume Philandrier (1544), whose construction called for preset lengths measured out along diagonals in the same manner (Fig. 12).[29]

Four of the field drawings can be associated with a single temple, that of Minerva Polias, corresponding to the western part of the Erechtheion and specifically its north-facing portico. The numbers recorded on the drawings match or nearly match the published plate (Vol. II, Ch. II, plate IX), with each of the sketches reporting slightly different data (Table 3). The published figures give the radii of the volute at successive points measured from the center, and two of the drawings (fols. 63 and 65) almost exactly match these figures. However, a third drawing (fol. 64) accords with only some of the published values. It appears that the others are running dimensions taken from the outside toward the center; these are not shown on the published plate but can be deduced from it. The change suggests that Stuart and Revett began their surveying with this drawing, but altered their method of measurement mid-course, shifting to the center of the volute only at the 135° mark. The figures on fol. 68 also appear to be running dimensions from the outside, but with less general agreement with the published figures. These discrepancies may reflect slightly different measurements of the same capital or—perhaps less likely given the minute

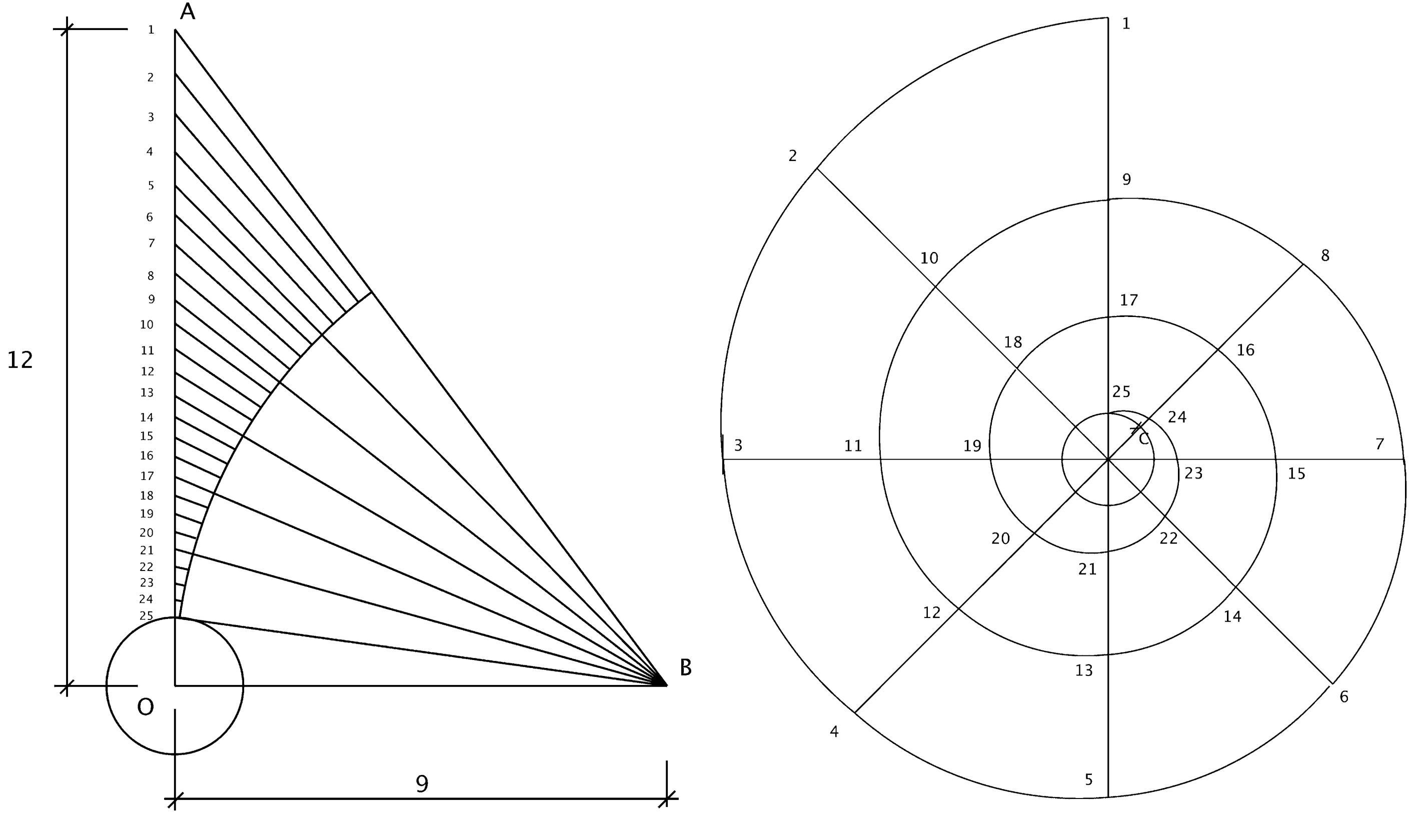


Fig. 12 Method for setting-out the Ionic volute, according to Guillaume Philandrier (1544). A preparatory drawing produces line segments that are then transferred to the oculus at 45° intervals

Table 3 Comparison of the measurements for the Ionic Volute of the temple of Minerva Polias, (Vol. II, Ch. II, Plate IX) with Stuart's field notes in the British Library: Additional Manuscripts 22153, fols. 63–65, and 68

	Plate IX	Toward center	f.63	f.65	f.64	f.68
0°	11.8	5.734	11.8	11.8		6.034
	6.066	8.024	6.06	6.066		9
	3.776	10.375	3.1	3.1		10.501
	1.425	11.8	no data?	no data?		no data?
45°	11.2	**5.45**	11.2	11.2	**5.4**	5.4
	5.75	**8.35**	5.374	5.374	**8.3**	8.3
	2.85	**11.2**	2.834	2.834	**11.15**	11.15
	–					
90°	9.725	**4.615**	9.725	9.725	**4.15/4.612**	4.615
	5.11	**7.484**	5.11	5.11	**7.234**	7.234
	2.241	**8.341**	2.4/2.491	2.404	**8.3**	8.3
	1.384	9.725			9.725	9.725
135°	–		no data	no data		8.42
	8.475	4.041	no data	no data	8.475	4.434
	4.434	6.341	no data	no data	4.434	2.314
	2.134	8.475	no data	no data	2.154	no data?
180°	7.35	3.7	7.35	7.35		3.7
	3.65	5.925	3.65	3.65		5.8
	1.425	7.35				1.35
225°	6.766	3.106	6.766	6.766		3.4
	3.66	6.766	3.366	3.366		6.766
	–					
270°	6.4	3.134	6.4	6.4		3.134
	3.266	5.016	3.266	3.266		4.925
	1.384	6.4	no data?	no data?		6.4
315°	6.25		6.25	6.25		3.1/3.225
	3.15		3.15	3.15		6.25

The figures given on the plate (column 1) are running dimensions *from* the center. Column 2 gives the running dimensions calculated *towards* the centre. The figures in *bold* very nearly match those from fol. 64, which suggests that Stuart and Revett began the survey with this drawing, before altering their method of measurement for the others

differences—another capital from the same set of columns. It is also worth pointing out the curious prevalence of dimensions with three decimal places, normally an impossible level of accuracy for direct measurement. Such figures could have been generated arithmetically, but the drawings do not suggest the use of any intermediate constructions or calculations. One possible explanation, in the absence of any other, is that the surveyors used calipers and a diagonal scale to obtain such fine readings.

Stuart was interested here, as with the Pola Temple and the Theater of Bacchus, in reconciling his own measurements with the prescriptions of the *De Architectura*. Although he published no attempt along these lines, at least one of Stuart's surviving manuscripts shows him actively searching for correspondences. Fol. 61 of the British

Table 4 James Stuart's arithmetic for columns from the Minerva Polias temple (the Erechtheion), from the Edinburgh Notebook, fol. 61

18. 5.05	Height of the columns of Min. Polias
..........12	
9) 221050	(24.56 + 2.0.56 diameter at bottom of columns
8) 2456	
3.07	
2. 3.60	
9) 27.63	Length of abacus
3.07	=1/9
6.14	=2/9 which subtracted from the number below it
27.63	
21.49	
Or feet 1.9.49	Distance by calculation from centre to centre of the eye of the volute.

Library papers records the following calculations, which pertain to Vitruvius's recipe for setting out the Ionic capital (Table 4).

Here Stuart first calculated the diameter of the base, making it—per Vitruvius—1/9 the height (Book 4, Chapter 1.8). He then calculated the length of the abacus, the uppermost slab of the capital. Although this particular column is shorter than 19 ft, he used the author's prescription for a column taller than 25 ft, for which the abacus was to be "as wide as the bottom of the column with one eighth added on (Book 3, Chapter 5.7)."[30] He then checked the result (2 ft, 3.6 in.), dividing it by nine to produce a repeat of the Figure 3.07. The length of the abacus determines the distance between the centers of the two volutes, the latter shorter than the former by 2/9.

It is difficult to know what to make of these calculations. In the first place, the figures do not correspond to the columns of the north porch of the Minerva Polias temple. They seem, rather, to match—but only partially—the dimensions of the engaged columns on its enclosed western flank (Vol. II, Ch. II, plates XI and XII). The lower column diameter is given there as 2 ft, 0.55 in. and the abacus length as 2 ft, 3.6 in., that is, within .01 and .03 in. of the values in the calculations. The column height, however, is far greater than that recorded on the published plate, which registers at a mere 17 ft, 7.5 in., including the capital. Given these circumstances, it is possible that the calculation represents an attempt to determine a potential column height and its corresponding abacus by working backwards from some of its other dimensions. That might also explain Stuart's departures from Vitruvius, not only for the length of the abacus, but also for the distance between the volute centers. The ratio for the latter of 7/9 the abacus length is not given by Vitruvius, but it does result in a value very close to the capital's actual measurements (1 ft, 9.49 in. versus 1 ft, 9.68 in., a difference of about .2 in.).[31] Stuart seems to have been applying a rough Vitruvian logic to see which dimensions were related and which not.

Reconstructing Greek Volutes

Measuring existing capitals was one problem. Reproducing those capitals in visual form was quite another. In essence, Stuart had to reconstruct the method that the original craftsman had used to set out each volute, finding in the process the correct centers for all the arcs and ensuring that they fit the measured points. His aim here was not merely antiquarian. If Stuart had any hope of accurately reproducing the volutes for publication, so that the engraved curves actually corresponded to the recorded measurements, he had to find the original setting out procedure. For this task, however, he faced a significant obstacle: he was unaware of the techniques with which Greek architects worked and had, if anything, an overdeveloped view of their geometrical complexity. A brief review of what we know today about these techniques reveals two factors that may have aided Stuart in his own reconstructions. First, there were multiple ways that the ancients constructed the volute; some were very elaborate, but others were much simpler. Second, efficiency in the building process was often just as or more important than geometrical coherence.

Classical architects were on site to provide direction to the craftsmen. In all cases, these architects would have negotiated budgets and general designs (*syngraphai*) with their patrons—often with the city-state itself. The lead architect determined the non-essential elements of design on site. He could determine the decorative details, such as the volute, only after constructing the base of the temple, most importantly the stylobate and intercolumniations. These dimensions determined the proportions of the upper elements. Once the ground plan of the temple was established, the architect was responsible for overseeing specific elements of the design, providing *paradeigmata*, or templates, for his craftsmen to copy. In the case of the Ionic capital, a craftsman under the supervision of the architect would have created a wood, clay, or possibly stone model of the volute. This prototype served as the basis from which all the capitals would then have been carved. Making it was a simple task of transferring its outline, via calipers, to new stone blocks.[32] The *paradeigmati* would have had much the same function as workshop drawings do today. For a repetitive element such as a volute, they had the advantage that the complex process of setting it out only had to be undertaken once.

Modern archaeologists have discovered several examples of *paradeigmati*. The Temple of Apollo at Didyma, for example, houses an extensive set of full-scale "blueprints," as Lothar Haselberger has described them.[33] He identified thin inscriptions on the walls and floors as construction drawings for elements of the temple's architecture. Other massive *paradeigmati* have been found in Pergamon, Priene, Baalbeck, and Rome, among other locations.[34] Likewise, prototype *paradeigmati* for small details have also been uncovered, including examples of Ionic capitals. One exemplary specimen, now at the University Museum, Berne, comes from an unknown location in Greece and still includes the inscribed vertical axis, vertical and horizontal tangents, as well as 11 compass points within the oculus. Thomas

Loertscher has analyzed this example in detail, and his conclusions point to a setting-out system not described by early modern architectural writers.[35]

In addition to *paradeigmati*, surviving elements of ancient architecture also point to the working methods of ancient architects. Unfinished capitals from Priene and Didyma suggest at least two of the ways that ancient architects designed their volutes. The first method was used at the Temple of Apollo at Didyma (ca. 330 BCE), designed by Paeonius of Miletus and Daphnis of Ephesus. Several of these examples include the craftsmen's inscribed guidelines, including a series of intersecting lines to divide the oculus into eighths.[36] These capitals were likely the *paradeigmati* for the other capitals at Didyma to which craftsmen could have turned as a reference. While a detailed investigation of the Didymaean volute is wanting, it is probable that the centers rest along the diagonals, as there would be little need to inscribe them otherwise.

Another surviving fragment is from the Temple of Athena Polias at Priene (ca. 350–330 BCE), studied by Gorham P. Stevens in 1931.[37] Although the volutes on this capital are finished and the method of laying out erased, Stevens was able to reconstruct 63 points along the spiral. Applying Euclid's theorem that only one arc—with, of course, only one centre—can pass through any three points, he discovered the system used for creating the volute, which was set out from 16 centers along the diagonals to the vertical axis. Similar to Vignola's method, the Priene capital was laid out with a square inscribed within the oculus, the corners bisected by 45° radii. Each diagonal was divided into 16 units, with the centre of each arc steadily rotated towards the centre, in fact, partly following an Archimedean spiral.

Stuart's task was the same as that later taken up by Stevens, namely to find the centers from which an existing volute has been set out and to determine from these the sequence in which the arcs were drawn. For the first of these tasks, he probably used the same method that Stevens did, by bisecting two or more chords in each arc and extending perpendiculars from them. This elementary procedure, known since Euclid, was also an implicit part of Guillaume Philandrier's method of volute construction. Once the centers were located, however, a recipe for connecting them still had to be found. This problem was not at all straightforward, and Stuart met it with only mixed success. The first volute that he and Revett published was that of the unnamed Ionic temple on the Illissos river (destroyed in 1778), included in the first volume of the *Antiquities* (Ch. II, plate VII). Their measurements must have been reasonably accurate, for they served as the basis of a convincing reconstruction by their friend and colleague Stephen Riou. Riou had travelled with the two men to Athens and, on his return, worked out a method for laying out the temple's volute, transforming the published dimensions into a system of modular parts (Fig. 13). He published the reconstruction in 1768.[38]

Riou's achievement may have given Stuart an unjustified confidence. As he began preparing his notes for the second volume—which contained the volutes of the several temples in the Erechtheion—Stuart struggled to make sense of the measurements they had taken. We are able to follow his attempts thanks to the survival of a number of his papers in the RIBA Drawings Collection. These diagrams are accompanied by written notes, consisting of numbered sequences of steps for laying

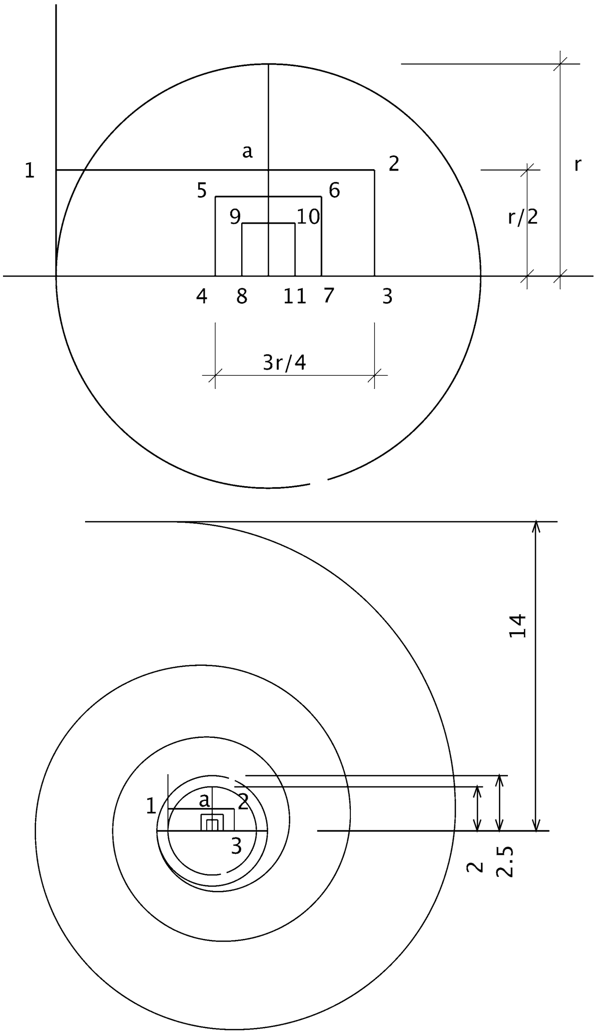


Fig. 13 Reconstruction of the volutes from the unnamed Ionic temple on the Illissos river (now destroyed) (From Riou 1768)

out the construction in the eye of the volute. The centers of the arcs are numbered, and corresponding numbers are to be found on the volutes themselves, indicating the limits of each arc. The latter are also found on some of the published plates, marked with a small asterisk. Their presence suggests that the engraver followed one or more of Stuart's recipes to draw the volutes. However, it is not clear why he might have retained numbers on the arcs without the construction diagrams in the eye of the volute, for the former are meaningless without the latter.

What stands out about Stuart's reconstruction attempts is how cumbersome, impractical, and hard to follow they are. The unidentified construction reproduced in Fig. 14, for example, requires 17 different steps with a compass and ruler, and

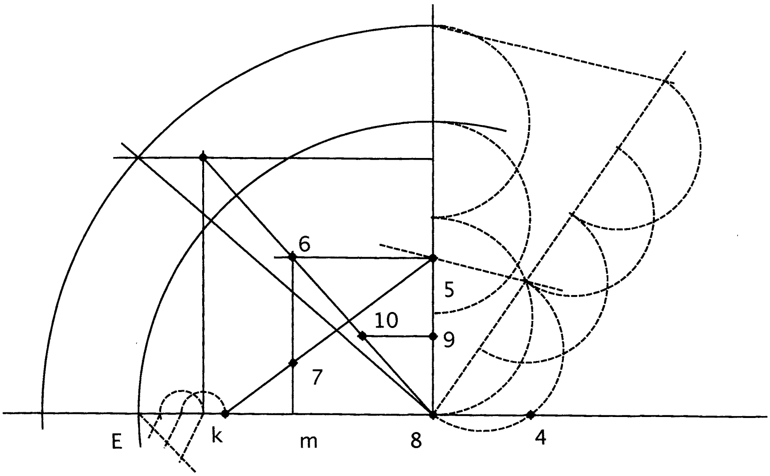


Fig. 14 Stuart's attempt to reconstruct the setting out of the volute of an unidentified Ionic capital, from his papers in the RIBA Drawings Collection, SD 93/4/3

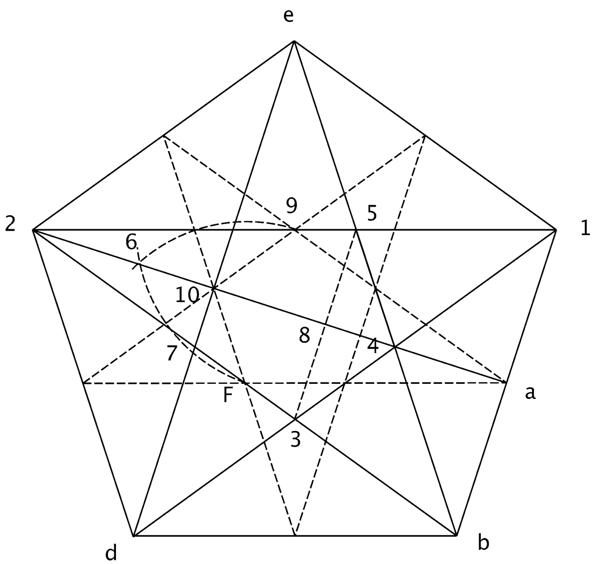


Fig. 15 Stuart's attempt to reconstruct the volute of the engaged columns of the "Temple of Minerva Polias" (the western flank of the Erectheion), from his papers in the RIBA Drawings Collection, SD 93/4/3

even one with a protractor. The fine dotted lines are used to make the numerous divisions called for in the recipe. Even more curious is that the prescribed compass centers follow no obvious pattern for their sequence or placement in the eye. A second diagram for the volutes on the engaged columns of the western flank of the Erechtheion is only marginally more sensible. The construction takes the recognizable—if complicated—form of pentagons nestled in five-pointed stars (Fig. 15).

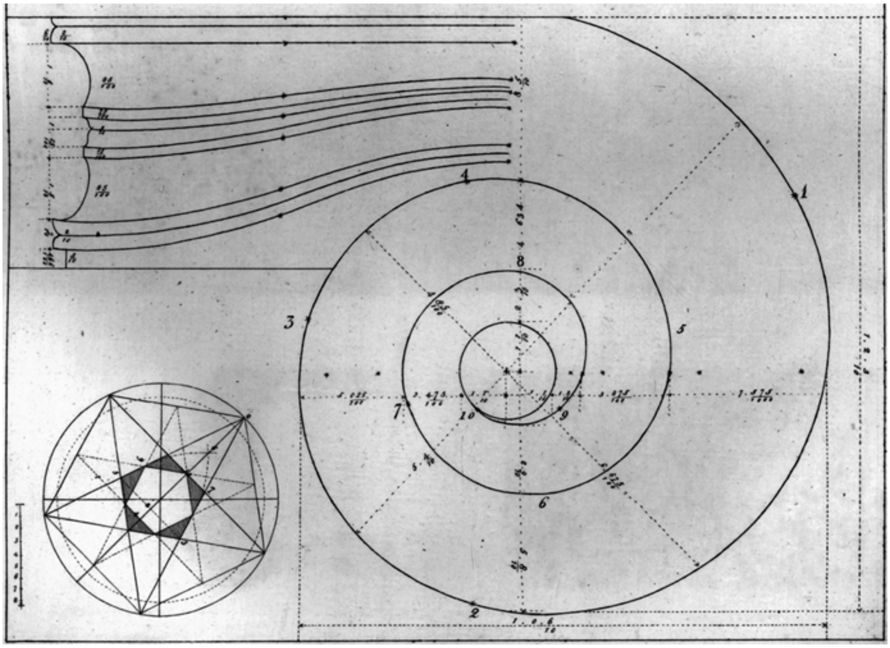


Fig. 16 Pentagonal diagram (*lower left*) based on Stuart’s attempted reconstruction in Fig. 15, as published in Stuart and Revett (1762–1830)

In principle, such shapes could help to form arcs of 72° (360/5), diminishing from one pentagon to the next at a regular rate. Yet the construction does not follow this process. Instead, the compass centers leap randomly about the whole construction, from the outer points of the larger star and back and forth between the larger and smaller inscribed pentagons. In general, the prescribed radii diminish as they progress, which is what one would be looking for. The distance 2–3, for example, is shorter than the distance 1–2 and 3–4 is smaller than 2–3, but Stuart does not stick to this pattern. Moving the compass point from 4 to 5 produces no reduction in the radius of the curve. Moreover, the curious step that leads to point 6 appears to have no logic whatsoever, for it results in an *increased* radius. William Newton, the editor of this second volume of the *Antiquities*, published the construction (Fig. 16), but it is unlikely that the engraver actually used it to produce the accompanying volute. A third method, for the capital of the “Temple of Erectheus”, or the eastern portico of the Erechtheion, is even more complex.[39] In the first place, it requires the construction of a heptagon, which is not strictly possible with a ruler and compass alone. Even apart from this difficulty, the recipe is so convoluted that it resists attempts to follow it, even with the aid of the corresponding sketch.

How can we explain Stuart’s thinking here? None of these procedures is credible as the method by which the original volutes were set out, and it is difficult to understand why Stuart felt it necessary to look for and propose such unlikely recipes. One has the distinct impression that he was not able to fit a curve to the measured points and was simply looking for any construction that would do so. In the end, none of the manuscript constructions for the volutes in the second volume was used. A simple measure of the spirals as engraved on the published plates shows that their proportions do not conform to the measurements given. The engraver appears, in other words, to have merely labeled the volutes with Stuart's values after constructing them by other means.[40]

Two explanations suggest themselves for this inability to square the data with a more plausible setting out method. One possibility is that the data itself was compromised. Indeed, it is difficult to imagine inaccuracies *not* creeping into such a fine measuring process taking place on a ladder 18 ft above the ground. Another contributing factor may have been that Stuart was expecting an unrealistic level of geometrical perfection in the volutes themselves. For the Greek craftsman, a mathematically precise curve was, of course, impossible, but also unnecessary. All the mason required was a number of points sufficiently close that he could carve something between them that would satisfy the eye. Both Stevens's and Lörtsch's reconstructions suggest approximate spirals of just this sort. The use of models and templates—*paradeigmata*—introduces a further stage in which deviations from the strict mathematical form of a volute might have been introduced: in the copying process. Even if Stuart's measurements were accurate, in other words, they may have included too many variations—introduced between the original setting-out drawing and the process of carving—to allow them to be fitted to a regular geometrical construct. Indeed, Stuart and Revett's own figures suggest that they were not measuring perfect spirals. Four volutes are illustrated in the *Antiquities*, and to check their "accuracy", we can plot the radii of the volutes at successive points on a graph (Fig. 17). A geometrically precise volute would produce a smooth curve, but this does not appear. The graph for each volute dips and rises unevenly.

It is worth noting that Stuart could have easily avoided these difficulties, both for himself and his engraver. Philandrier's method showed how to draw a volute by first determining the radials from the center toward a series of points set out at 45° intervals along the spiral. The system was well-known and had recently been republished by Abraham Swan in a popular practical handbook.[41] Working backward from his own measurements, Stuart could have used Philandrier's method to draw a volute composed of successive 45° arcs. This approach would have no doubt entailed significant drawbacks. The arcs would not lie on a continuous curve, but would have been subtly "broken" from one to the other. More importantly, once the centers of the arcs were found, the method gave no recipe for connecting them. Philandrier's method, in other words, would have been adequate for the engraver, but it gave no way of replicating the volutes at different scales for use in a practical design context. This seems to have been enough to dissuade Stuart.

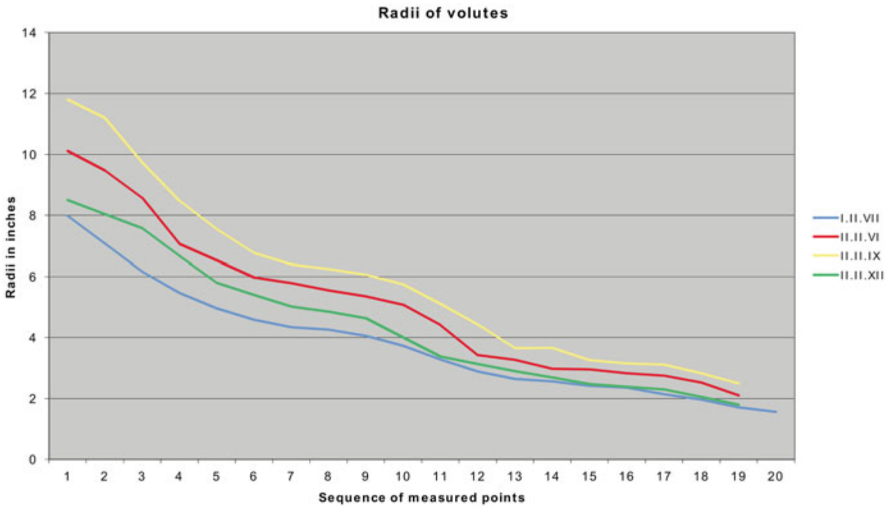


Fig. 17 Graph of the radii of volutes, from Stuart and Revett (1762–1830)

Conclusion

The original survey drawings that survive represent only a small proportion of the measurements that Stuart and Revett made during their sojourn in Greece, but they are enough to give us a good idea of their working method. Whereas the published dimensions are presented as polished, unproblematic, and absolute, we can now see that the reality was somewhat messier. The field notes often show not only minor differences between the recorded measurements and those on the published plates, but also small variations between multiple repeated measurements. These variations suggest that a process of selection and correction took place both in the field and while preparing the published work. It is now also clear that some calculation was involved in obtaining these figures. Indeed, measurements within one thousandth of an inch were usually possible in no other way. The "accuracy" that so impressed the architects of the nineteenth century in effect disguised a process marked by trial-and-error, figures derived from others, and subjective judgment.

Stuart made it clear in his introduction to the first volume of the *Antiquities* that his purpose was simply to record the dimensions of the monuments as accurately as possible and not to impose upon his measurements any preconceived theory of design. He took care to proceed by "purposely forbearing to mention Modules, as they necessarily imply a System." On several occasions, however, he could not avoid making assumptions about the forms of the buildings and the way in which they were set out for construction. Indeed, the large number of Stuart's notebook calculations rather suggests that he made strenuous attempts to check for such proportions. When faced with a structure as ruined as the Theater of Bacchus, for example, Stuart needed to know that the centre of the circle from which the *pulpitum* was set out was not in line with the *versurae*, as a naïve surveyor might have supposed, but in front of them. For this, he had Vitruvius and Perrault to guide him, so that he could immediately make the appropriate measurements and adopt a geometrical method to find this center. It is also clear from his calculations accompanying the sketch of the Temple at Pola, his check on the capital of the Minerva Polias, and numerous other calculations that have not yet been completely explained, that he was making comparisons between his measured dimensions and theories of proportion. For the most part, these remained private experiments, but they were nonetheless essential steps in his understanding of the ruins.

One of the overarching results of this process was a perhaps inevitable lessening of Vitruvius's authority. Few of the Roman author's recommendations appeared to be borne out by their measurements, particularly those for Ionic volutes. Nor were modern methods from Serlio onwards satisfactory either. Worse, they appear to have misled Stuart toward an unrealistic expectation of the kinds of constructions that the Greeks actually used. Did he not see how improbable his own attempts were to find a method that fitted the measured points? Despite the occasional failure, Stuart and Revett's work entailed important insights. Their intimate contact with and their scrupulous measuring of the architecture itself must have convinced them that not only could no modular system be strictly applied, but that architectural practice in ancient Greece was more varied than they and their contemporaries often assumed. This realization is best represented not by the dimensions in their final, published form, but rather by the manuscript field notes, which record how they measured and made sense of them.

Notes

Jason M. Kelly contributed to the section of this paper that deals with the Ionic volute. Frank Salmon wrote the introduction and edited the whole. David Yeomans wrote the remainder of the paper and produced most of the illustrations. We would like to thank Prof. Charles Goldie for his comments on the geometry of the Ionic volute and Anthony Gerbino for his advice and patience.

1. See Wood (1753, (a)*r*): the "principal merit of works of this kind is truth" and James and Revett (1762–1830, vol. 1, vii): "we determined to avoid Haste, and System, those most dangerous enemies to accuracy and fidelity."
2. See Watkin (1996, 641).
3. Penrose (1851, ix).
4. Landy (1956, 255, 258, and 259). For a more recent account of Stuart and Revett that locates the debate about "accuracy" in cultural terms see Kaufman (1989, 74).
5. See Salmon (2006, 107–17).
6. Stuart's Temple of Winds at Mount Stewart, Co. Down, of 1782–85, for example, follows the principal dimensions of the Athenian original very closely.

7. Laing Mss., La.III.581, Edinburgh University Library. There is also a sketchbook in the collection of the Royal Institute of British Architects (SKB/336/2). Joseph Woods, who edited the fourth volume of *The Antiquities of Athens* (1816, ii), recorded that he had been handed 54 of Stuart's manuscript notebooks.
8. Much as we see in the Stuart's drawing of himself studying the Erechtheion in Stuart and Revett, *The Antiquities of Athens,* 2: plate II.
9. Edinburgh notebook, fol. 73v. For further detail on their methods and equipment see Salmon (2006, 131–32).
10. Stuart and Revett (1762–1830, vol. 4 (1816), 29).
11. Stuart and Revett (1762–1830, vol. 1, vii). For a full account, see Salmon (2006).
12. Vitruvius (1999), 58.
13. He began by dividing the total length of the building by 50. Taking the result of that calculation (13.6), he then divided the length of the cella by a figure close (but not exactly equal) to it (13.8), obtaining 27 as the result. Even aside from Stuart's intentional fudging, the arithmetic here is incorrect. The answer should have been 28.1, but neither result would have agreed with Vitruvius's recommendation of 5/8.
14. See Salmon (2006, 124).
15. This is explained in Stuart's published account, Stuart and Revett (1762–1830, vol. 2, 23). The break in the site notes possibly reflects a period of failed negotiations with the Turkish authorities.
16. Edinburgh Notebook, fols.165v and 167r. The editions to which he refers are: Vitruvius (1556) and Vitruvius (1673, 2nd ed. 1684). These pages of the notebook also reproduce the French text of Perrault's Vitruvius, which Stuart translated to obtain the section quoted here.
17. Stuart and Revett (1762–1830, vol. 2, 24).
18. Edinburgh Notebook, fol. 65v. Stuart's dimensions were also recorded in a cross-section of the theater: Additional MSS 21153, fol. 72, British Library.
19. Stuart and Revett (1762–1830, vol. 2, 24).
20. Stuart and Revett (1762–1830, vol. 1, ii, fn. A). Also see Fréart de Chambray (2005, orig. ed. 1650, 91–2) for a similar judgment.
21. Stuart and Revett (1762–1830, vol. 1, ii and 7).
22. Carpenter (1926, 253).
23. Serlio (1537). On this subject, see Losito (1993) and Andrey and Galli (2004, 33–36).
24. See Salviati (1552); Vignola (1572, pl. 20, 1999).
25. Fréart de Chambray (2005, 110) and Perrault (1722, 69–74, pl. IV).
26. First published in Goldmann (1649).
27. Chambers (1791, 53).
28. British Library, Additional Manuscripts 22153, fols. 61–68 and RIBA Drawings Collection, SD 93/4, fols. 1–7.
29. See Andrey and Galli (2004, 37–38).
30. A sheet in the RIBA Drawings Collection, SD 93/4 reproduces this calculation in the form of a small sketch.

31. The latter figure does not appear on the published plates but can be deduced from them by subtracting from the whole capital width (36.834 in.) the distances from the centers to the outer edges of the volutes (7.575 on each side).
32. See Coulton (1977, 53–58); Petronōtēs (1972); and Coulton (1976).
33. See the following articles by Lothar Haselberger (1980, 1983, 1985, 1991).
34. See Haselberger (1994); Kalayan (1971); Koenigs (1983); and Schwandner (1990). For a more extensive bibliography, see Wilson Jones (2000, 249).
35. Loertscher (1989). Also see Haselberger (1997, 89–92).
36. Haselberger (1985).
37. Stevens (1931).
38. Riou (1768, 34–5, pl. 9).
39. RIBA Drawings, SD 93/4/3
40. The carefully drawn volute in Vol. III for the Ionic colonnade near the Lantern of Demosthenes (Ch. XI, Pt. 1) provides a similar case. The diagram, produced by Willey Reveley from Stuart's surviving notes, depicts a logarithmic volute with the centers of the arcs based on diminishing squares. The dimensions given for the volute, however, correspond only fitfully to the illustration, and several values are simply missing. We must conclude that Reveley was presented with poorly recorded field notes that were ultimately impossible to interpret. He appeared to be aware of the discrepancies but decided to let them stand, on the justification that "Mr Stuart has left no memorandum on the subject of these disagreements." Stuart and Revett (1762–1830, vol. 3 [ed. Willey Reveley], vii).
41. Swan ([1745], pl. VIII).

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Faculty of Architecture and History of Art, University of Cambridge: Figs. 3, 6, 16
Cambridge University Library: Fig. 8

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