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GREEK TEMPLE DESIGN RECONSIDERED: THE TEMPLE OF ATHENA AT PAESTUM AND ITS MONUMENTAL STEPPED ALTAR

With a digression on methodology in Greek metrology

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Abstract

The dimensions of the outlying altar of the temple of Athena at Paestum show that the Greek architect used his imagination to create a safe building – *i.e.* protected from evil spirits – by means of 'applied magic'. It follows that aesthetic matters seem to be of secondary importance. The work as a whole was fully designed before construction began (*ca.* 510 BC). The altar provides the clue to a full understanding of the cella dimensions. Although the cella is not well preserved, an analysis of its metric dimensions gives striking results. The plan's features lean on a fixed foot-standard of Athenian origin. The characteristic measure of hundred feet was composed of the lowest number of three successive Pythagorean number triples beginning with a prime number. These number triples emerge in the series immediately after the well-known 3/4/5 triple. Our analysis shows once more the existence of standardized Greek measures of length.

Introduction

There is at present consensus of opinion among investigators that the construction of an aesthetically satisfying building was the major intention of a Greek temple architect. There are several things conflicting with this opinion. First, the structure of a Greek temple was simple and conventional. Normally a temple was a freestanding building set on a level site. The strict adherence to convention both in general arrangement and in detail suggests that any aesthetic aspect of temple architecture was already settled in the archaic period. That may explain why architects of the classical period felt no need for a drastic change of the over-all form[1]. Second, many temples were left unfinished for centuries. Thus, the original architects had passed away long before the project came to an end. It follows that many an archi-

[1] The form of the Erechtheion at Athens is a unique exception.

tect never saw the realization of his plan. Third, Coulton (Coulton 1974, 65) observed that the flank intercolumniations are consistently smaller than the front ones in mainland Greece, but consistently larger or equal to those on front in Sicily and south Italy. He concluded that it is hard to believe that mainland architects found slightly smaller flank intercolumniations aesthetically desirable while those in the West should have thought the exact opposite. In dealing with the younger temple of Apollo at Didyma (soon after 334 BC?), Haselberger (Haselberger 1985, 131) remained perplex (Fig. 1): "The naiskos was built approximately 2.8 meters narrower than the plans (drawn on a wall of the adyton on a scale of 1:1) indicate, and its relative proportions were thereby drastically altered. A liberty of this magnitude is hard to explain, even in the light of all we now know about Greek architecture." Such facts do not support, I think, the idea that Greek architects considered aesthetic matters of primary importance in designing a temple. Clearly, they strongly wanted something else, to be realised in an early stage of the construction.

If we want to understand Greek temple design, we must be willing to enter into the labyrinth of archaic thought. I venture on a few remarks. If the community decided to build a temple for a God, we cannot expect that worship was postponed until the temple was finished. In my opinion the architect's major concern was the protection of the sacrificial ground from evil spirits. He intended to keep the demons out of the temple by producing a parallelism of the dimensions of the cella and the dimensions of the altar. Laying off some main dimensions may be already sufficient to start the sacrificial rites. A measure of 100 feet as a means of protection was also thought to be very effective. Thus the problem is to establish the character of laid out securing dimensions if we find them. In fact, the plan of the younger temple of Apollo at Didyma is all we need to analyse and so settle the question. The original architects, Daphnis and Paionios (Vitruvius VII praef. 16), designed this temple on the Ionic foot of 29.86 cm (de Zwarte 1994, 117-124; Haselberger 1996, 164-168). With the drastic change of the width of the inner temple (naiskos) with regard to the original plan, the leading architect at the time of the drawings on the adyton wall (*ca*. 250 BC) could add a new feature to the original design, that is *two* measures of 100 feet (Fig. 1). As these measures do not represent the side of a rectangle – as in the Parthenon in Athens (de Zwarte 2002, 14) – they cannot be explained away as an aesthetic feature. The alternative explanation is that the addition of measures of hundred feet is to be seen in relation to ancient Greek belief in the magic power of numbers. There is, indeed, sufficient proof that Greek architects could find different protective solutions that met all the requirements. The position of the measure(s) of hundred feet in the younger Apollo temple at Didyma and the Hera temple I and the Athena temple at Paestum is however quite different.
However, the question arises why a measure of hundred feet could be suitable for the purpose of screening from evil spirits. My starting-point is the

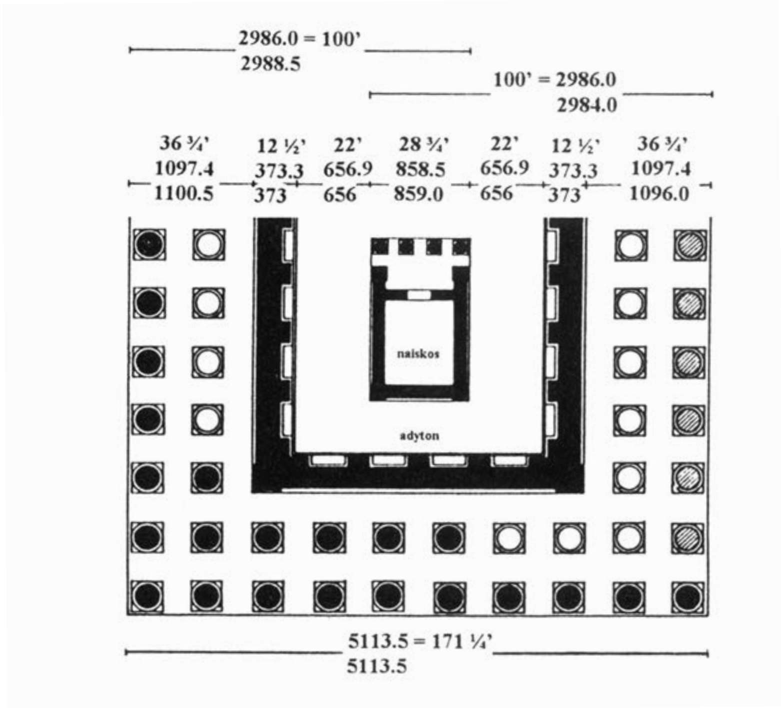

Fig. 1. The younger temple of Apollo at Didyma viewed from west. Naiskos as built to incorporate two measures of 100 feet in plan (measurement after Knackfuss 1941, drawing 146).

Pythagorean ontology of numbers. Here are a few sayings of the Pythagoreans according to Aristotle's report (*Metaphysica* A 5): Everything is number (A5, 985b 6), ten is a perfect number (A5, 986a 8-9), number is the substance of all things (A5, 987a 18). The reason Aristotle discusses the Pythagorean number philosophy is that he is concerned with the nature of existence and wishes to consider the views of others. In considering the question why all men count up to ten, Aristotle (*Problemata*, XV 3) says once again that ten is a perfect number. Philolaos, who lived about 400 BC, called the number ten "great, all-powerful and all-producing, the beginning and the guide of the divine and of the terrestrial life"[2]. The Pythagoreans, as we have seen, held ten to be perfect. This ten, conceived as the sum of the first four

[2] Diels/Kranz 1956, I 411 (Philolaos, Frg. B 11).

natural numbers, was called the Tetractys. An oath of theirs runs: "Yes, I swear by him who has given our soul the Tetractys, source of ever-flowing nature"[3]. Unfortunately, I found no ancient Greek written source dealing with the number hundred. It might be that archaic Pythagorean architects simply created the most 'powerful' number hundred by squaring the perfect number ten or that Pythagorean mathematicians held that the number hundred possessed 'power' because it is the sum of the odd numbers 1 up to including 19. Anyhow, the architect of the temple of Athena at Paestum realized the number hundred, starting from three successive Pythagorean number triples (below table 7). Such a procedure is easily explained as 'magic' but not at any time as aesthetic. As in Didyma, the measure has been used twice and its use does not make sense in the perception of the beautiful.

If numerological protection of a temple overrules aesthetic matters, many temples need to be studied afresh, and consequently, investigators have to base their work on an intensive study of a single building rather than on a whole series of buildings. Such studies are also in the interest of architectural history. In working out such a number-based method of analysis, the question arises what degree of accuracy we are to expect in the execution. The architect has to take into account the discriminative qualities of man and spirits. We may guess that he is fully prepared to make use of the fallible judgement of the human eye. For example, axial intercolumniations planned to be of equal length are not always equal because it is aesthetically more satisfying to erect a column in such a way that its axis coincides with the joint of two stylobate blocks[4]. However, it is unwise to cheat the spirits. Measures intended for the protection of the sanctuary have to be executed as accurate as possible, as faulty dimensions could attract attention of evil spirits with serious consequences for the building and the priests.

My speculations upon archaic thought may be wrong in detail, but the results of my inquiry into the building principles of the temple of Athena at Paestum overwhelmingly bear out the idea of Greek architects being at work to realize 'magic' number protection rather than an aesthetic appearance of the building. From this discovery follows an entire new starting point for an analysis in order to get grip on the real basis of sacrosanct Greek architecture.

The temple of Athena at Paestum (*ca.* 510 BC): Introductory observations

In previous studies of the temple of Athena ('Ceres') at Paestum the remote altar was neglected. As a result, the architect's true intentions could not be

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[3] Delatte 1915, 253. The oath is verse 47 of the golden verses. On the Tetractys see also Naredi-Rainer 1982, 34-36 and 160.

[4] The axial spacings of the temple of Athena at Paestum, which are equal to the length of one stylobate block, average 262.6 cm, minimum 258.3 cm and maximum 265.5 cm (Krauss 1959, 17 and drawing 11).

ascertained as the altar is an essential part of a sanctuary. Nevertheless, an analysis of previous studies of this temple is of use, notably to correct the unfounded fancy that Greek architects had a preference for whole numbers of feet in the design of buildings.
The late Friedrich Krauss, who published an account of the temple of Athena in monograph form, had a longstanding interest – see the bibliography – in this temple. Certainly, he made sense of the measures he established. It strikes me, however, that in the course of time he proposed three standards of length which might have been used by the architect of the temple (35.2 cm in 1931, 32.88 cm in 1941 – which he calculated from the 32.88 m length of the stylobate thought to be identical with hundred feet – and finally 32.8 cm, sticking to a stylobate of 100 feet long, in 1959) but never published a ground-plan with dimensions expressed in feet. Surely, Krauss realized that none of them could be proved on the strength of his measurements, as the greater part of the discrepancies between theoretical and actual measurements must be ascribed to error in execution. Nevertheless, a foot of 32.8 cm was widely accepted by architectural historians. Indeed, a foot-standard of 32.8 cm was useful in defining the axial intercolumniation (average 262.6 cm, 8 x 32.8 = 262.4 cm). However, Krauss' reserve in publishing plans expressed in feet has to be admired, not criticised. Anyone who wishes to deal with this temple and uses a foot of 32.8 cm, has to neglect the lack of accuracy in execution, so much the more if one also endorses the hypothesis of Greek design in whole numbers of feet. Perhaps, such a design scheme might be seen as a preliminary design that has to be modified to satisfy the requirements of practical use. Of course, the surmised identification of a series of whole numbers of feet in a south Italian temple is very attractive as it forms a point of departure for an inquiry into Pythagorean thinking on numbers or harmonics or into a non-Pythagorean geometrical scheme of design[5]. In my opinion, such a whole number mental template cannot be affixed to Greek architecture in general. However, it cannot be excluded that a singular architect stuck to a design based on whole numbers: the architect of the temple of Athena?

In his very useful book *'Architektur und Harmonie'* Naredi-Rainer (Naredi-Rainer 1982, 151-158) made the temple of Athena at Paestum an example in support of his theory of Greek temple design in whole numbers of feet (Fig. 2). I defend a different position, but it goes without saying that the aim of this paper is not to lower Naredi-Rainers standards, but to beat him at his own game by introducing evidence he has overlooked. Naredi-Rainer says: "Bei

[5] See Naredi-Rainer's comment (1982, 155-157) upon the studies of Ross-Holloway 1966 (Pythagorean number philosophy), Kayser 1958 (Pythagorean harmonics) and Wedepohl 1967 (geometrical construction) in relation to the temple of Athena.

der Planung ging man wohl von der Cella aus und leitete aus ihrer Breite als deren Drittel die Jochweite ab. Daher musste für die Cellabreite eine durch 3 teilbare Masszahl gewählt werden: sie beträgt 24 dorisch-pheidonische[6] Fuss à 32.8 cm"; I compare his statement with the measurement as given by Krauss (Krauss 1959, 17 and drawing 11); (table 1).

Table 1. Design in whole numbers of feet (after Naredi-Rainer).

Factual (cm) after Krauss		Theoretical (cm)	Difference (cm)
Cella over-all width	778.5	24 x 32.8 = 787.2	- 8.7
Intercolumniation	262.6	778.5 : 3 = 259.5	+ 3.1
		8 x 32.8 = 262.4	+ 0.2
Front stylobate	1452/1454	44 x 32.8 = 1443.2	+ 8.8/10.8
Flank stylobate	3288/3288.5	100 x 32.8 = 3280.0	+ 8.0/8.5

The accuracy with which the measures predicted by the proposed design agree with those actually measured in the temple is disappointing, but that does not detract from my position, and I am sure that many a scholar will object to it. The same theoretical design in feet has been published by de Waele (de Waele 1980, fig. 10). De Waele fixed the metric value of the foot at 32.75 cm. However, both investigators held different theories concerning the way in which Greek temples were planned. According to de Waele Greek architects used an additive system in planning the dimensions of the stylobate. In particular, the axial distance of two columns should be a standard element in the architect's design. It is important to note that building inscriptions show a preference for whole numbers of feet in orders to be placed with the quarries, which especially refers to the length of stone blocks. In the temple of Athena, the axial intercolumniation is equal to the length of a single stone, but these stones are not rigidly standardized in length. We cannot therefore simply assume that the average of the interaxials is the equivalent of a whole number of feet. Moreover, whatever the method of metrological analysis of the dimensions of the structures of this temple, there is no logical way to choose for just one of the proposed metric values of the foot-standard (de Waele 1995, 506); this disproves the assumed design in whole numbers of feet.

To summarize: Divided as we are, a new judgment of the evidence is needed to find a solution that may appeal to all of us.

[6] The name Doric-Pheidonic is confusing. The foot-standard of 29.86 cm may be termed Pheidonic-Ionic and the standard of 32.66 cm Solonic-Attic.

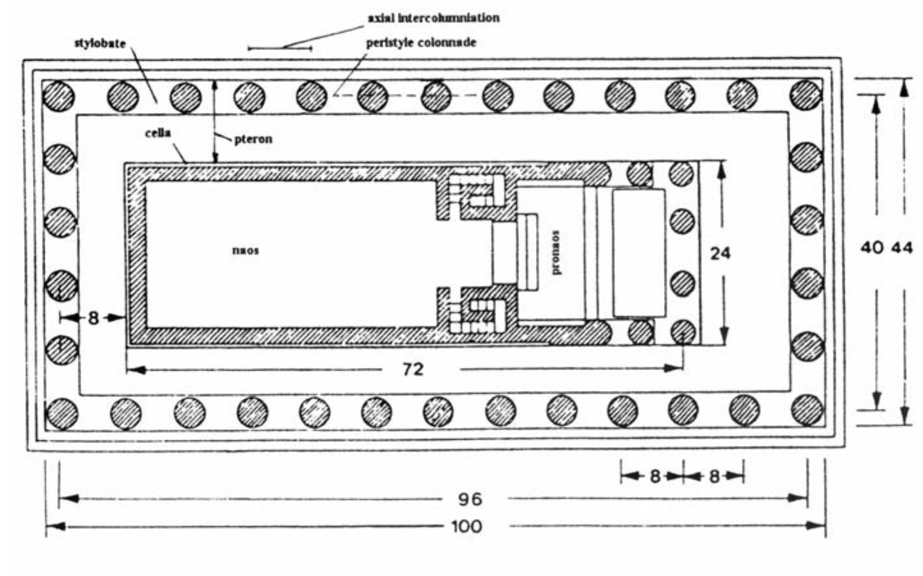

Fig. 2. The design of the temple of Athena at Paestum (after Naredi-Rainer 1982). The width of the cella and 3 axial intercolumniations on the front and the back are both 24 feet (1 foot = 32.8 cm).

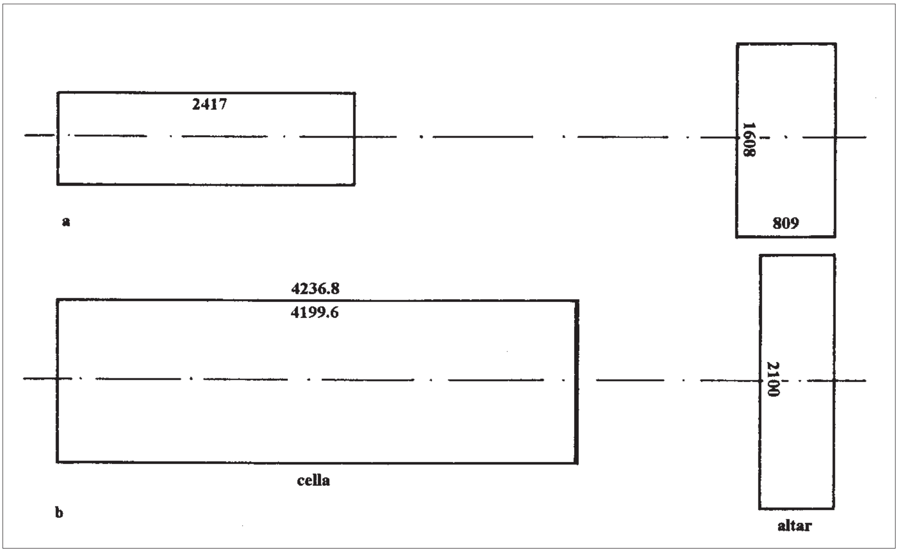

Fig. 3. The relation of the altar platform dimensions to the cella dimensions (cms): (a) temple of Athena (809+1608 = 2417) and (b) Hera temple I (2x2100 = 4200).

Surprisingly perhaps, the length of the foot-standard is not necessarily the first problem that has to be solved as Krauss' measurements give us already a clue to get grip on the architect's intentions. When we compare the dimensions (Krauss 1959, drawings 2 and 3) of altar and cella, we see an equality of measures which is both logical and accurate, but it does not appeal to me aesthetically. However, in my view, it is easy to see that this quality was intended to create 'magic' protection (Fig. 3a): altar platform length + altar platform width = cella socle length; 1608 + 809 = 2417 cm.
Higher up in the building (Fig. 4) another protective measure became effective when the construction had come on the top of the frieze: altar platform width = height of Doric order. Krauss (Krauss 1959, 2-3) gives the exact dimensions: column height (612.2 cm) + architrave height (103.6 cm) + frieze height (92.0 cm) = 807.8 cm. It is difficult to understand the identity of these dimensions as an *aesthetic* feature as it cannot be appreciated by a visitor whatever his position on the temple-ground. It may be convenient at this point to summarize the dimensions of those parts of altar and temple which support the idea of magic protection (table 2)[7].

Table 2. Non-aesthetic equalities of the temple of Athena.

Fig.	Altar (cm)		Remarks	Temple (cm)		Fig.
3, 11	Platform width	809	=	Doric order height	807.8	4
3, 7	Platform length	1608	809 + 1608 =	Cella-socle length	2417	3, 8
7	Stand length	1208	x 2 =		2416	
7	Table length	1436	=	Inner naos length (reconstr.)		8
11	Table width	296.5	293.9 x 2 = 587.9	Inner naos width (reconstr.)		10

It is evident that we shall start to use in our analysis only those units of measure which are already known from archaeological or documentary sources. Of course, the Ionic foot (29.86 cm), recently attested for the Hera temple I ('Basilica') at Paestum as the only foot-standard based in Pythagoras'

[7] Krauss 1959, drawings 2, 3 and 16; Krauss 1976, 36, fig. 3 for the correct (!) inner naos width (587.3 cm) as reconstructed in 1941. In 1941, the reconstruction of the cella still misses the staircase halls. The reconstruction in 1959 is based on the recovery of two fragments of step stones between 1941 and 1959 (Mertens in Krauss 1976, 68). For a metrological study it is of no importance whether the staircase halls are part of the origi-

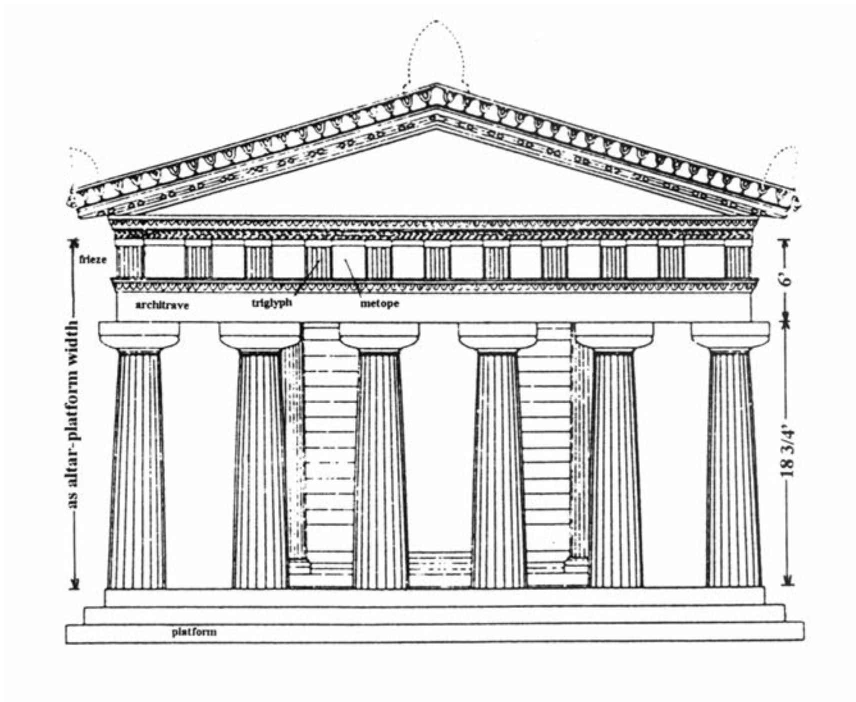

Fig. 4. The temple of Athena at Paestum. Altar platform width = height of Doric order.

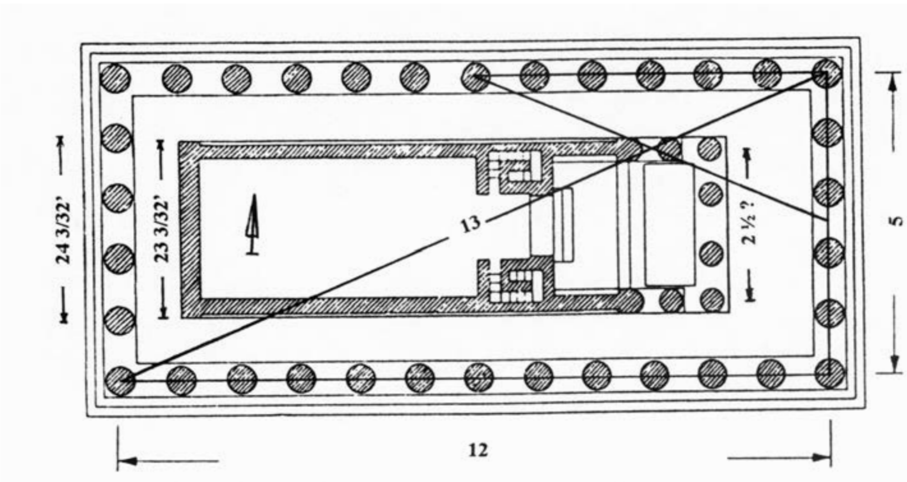

Fig. 5. The Pythagorean triple 5/12/13 in the temple of Athena at Paestum. The width of the cella and 3 axial intercolumniations differ 1 foot (1 foot =32.66 cm).

number theories[8], is the first candidate for an analysis of the Athena temple. However, a thorough study of the measurements converted into Ionic foot failed to reveal the basic numerological starting-point of the architect. Surprisingly, the well-known derivative of the Ionic foot, the Attic foot (32.66 cm, that is $1^1/_2$ Ionic dactyls longer than the Ionic foot) performed much better from the beginning. As we shall see, it is plausible that two foot-standards were in use at Paestum. Moreover, the metric value of these standards is exactly the same as in Athens[9]. It seems reasonable to suggest that there were only a limited number of standards of length in use in the Greek world (Wesenberg 2002, 370).

Let us now return to Fig. 3a to see the result of the actual measurements when expressed in Attic feet: 74 AF (2416.8 cm) = $49^1/_4$ AF (1608.5 cm) + $24^3/_4$ AF (808.3 cm). The fact that the dimensions accurately can be converted into whole or in quarter feet is promising but in itself no proof that the architect indeed used the Attic foot. In this temple we find abundant evidence of dimensions expressed in dactyls and half-dactyls, e.g., the upper column diameter of the colonnade (2 9/16 AF = 83.7; measured 84.1 cm) is two-thirds of the lower column diameter (3 27/32 AF = 125.5; measured 126.2 cm; Krauss 1959, 2). However, this result does not consolidate the use of the Attic foot as a calculation in Ionic feet also gives satisfaction (126.0 cm = 4 7/32 IF x 2/3 = 2 13/16 IF = 84.0 cm). Anyhow, the use of the half-dactyl cannot be neglected. I neglect the slightly more accurate results in IF and stick to the Attic foot because the *features* of the design can only be illuminated when analysing dimensions, converted into AF. Fortunately, the measures which form part of the height of Doric order give certainty that the architect's foot-standard was indeed the Attic foot (table 3 and Fig. 4).

Table 3. Height of Doric order.

height of	measured cm	Interpretation (1' = 32.66 cm)
Frieze	92.0	91.9 = 2 13/16
Architrave	103.6	104.1 = 3 3/16
Column	612.2	612.4 = 18 3/4
Total	807.8	808.3 = 24 3/4

[8] De Zwarte 2004 (Among other things, the square root of two in whole numbers and the telling numbers 618 and 1000 for the golden isosceles triangle).

[9] De Zwarte 1996 (Hephaisteion: 1 AF = 32.66 cm) and 2002 (Parthenon: 1 IF = 29.86

In Vitruvius' rules for Ionic temples (III 5.1-15) each element was derived from the one defined previously and that is what we find here in a temple of mixed forms. The height of the Doric frieze[10] was derived directly from the architrave height: the frieze height is 15/17 of the architrave height. Given the dimensions as measured, the ratio 15:17 cannot be expressed in Ionic feet with a reasonable degree of accuracy. Measuring in Attic feet, we find the sum of architrave height and frieze height as a whole number of feet, and a curious ratio. However, in Pythagorean south Italy such a ratio is not surprising, as the numbers 15 and 17 belong to the triple 8/15/17. About 510 BC triples seem to become in vogue (Fig. 5). The axial intercolumniations on the front (5) are as wide as those on the flank (12). Consequently, the ratio 5:12 in the axial distances of the colonnade is evident indeed, that is, aesthetically of no importance. But the numbers 5 and 12 are the interesting part of the case as the architect once more made use of the last word in 'applied magic', that is again a Pythagorean triple, this time 5/12/13[11]. Indeed, a practical way to protect a whole area from evil spirits. To compare with Naredi-Rainer's design (Fig. 2), I indicate in Fig. 5 the true connection between the cella and three innermost axial intercolumniations on front and back. The exterior of the back wall, which differs from Krauss' and Naredi-Rainer's reconstruction, will be discussed below.
The conclusion of the introductory part of our inquiry into the temple of Athena has been mainly devoted to the question which of the two rigidly standardized foot-standards is most likely to have been used by the architect. Unfortunately, the stubbornly defended, but ill-founded current opinion still is that the authorities of the various Greek cities did not attach great importance to the precise adjustment of common length standards. It is easy to show that the architect of Athena's temple used a foot of 32.66 cm, but opponents of the idea of standardized Greek foot-standards may put it down to mere coincidence. Thus it is necessary to dwell at length on methodology in metrology (see the digression). Before pursuing the subject, a concise account of two other temples at Paestum may be of use as it provides us with additional information for assessing the probability of any suggested system of design in south Italy.

The Hera temple I (*ca.* 530 BC)

We must allow the ancient architect his own way to deal with protective measures. The architect of the first temple of Hera ('Basilica') did it in his

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[10] Above the frieze the form of the temple is no longer Doric (Krauss 1959,1; 1976, 39).

[11] Recently I noticed that Upchurch first pointed out the existence of such a triangle. His observation has been developed by Nabers and Ford Wiltshire (1980, 211, fig. 1) on a foot length of 32.8 cm. A second triangle in the elevation (1980, 212, fig. 2) has to be dismissed, as this triangle leans on the *reconstruction* (Krauss 1959, drawing 16) of the largely missing sloping sima.

way: Cella length (the width of the pronaos step excluded) = two times altar platform length (Fig. 3b). Using the factual evidence[12], the analysis of the measures results in the design as outlined above: cella length 4235.0/4238.5 cm (north/south), mean 4236.75 cm; (4236.75 – 37.2) : 2 = 2099.775 cm. The measured length of the altar platform is 2100.0 cm. The calculation in Ionic feet runs (141 7/8'- 1 1/4') : 2 = 70 5/16'. The altar platform width is 70 5/16'- 50' = 20 5/16' = 606.5 cm (measured 607.0 cm). Surprisingly, we find most likely the length of the architect's foot-standard from the dimensions of the altar platform: (2100 – 607) : 50 = 29.86 cm, the exact metric equivalent of the Ionic foot. Indeed, in principle, it is possible to extract the foot used by the architect from the dimensions of buildings without the aid of contemporary texts.

The Hera temple II (*ca*. 460 BC)

A glance at the second temple of Hera ('Poseidon') at Paestum, which was built about half a century later than the temple of Athena, might give us a clue to the workings of a building committee in classical Paestum, when one had to decide to build a new temple. Is it reasonable to suggest that the architect had been instructed to design the front stylobate of the colonnade as long as the cella over-all length of the temple of Athena? These are the facts[13]: Hera temple II 2429.6/2431.6 cm (west/east); temple of Athena 2428.5/2432.1 cm (south/north).

The temple of Athena at Paestum: Reconstruction of its plan

The reader may not expect to find here a reconstruction of the missing roof nor art-criticism as to Krauss' reconstruction of the missing top of the altar table. First of all, I am interested in the original layout of the walls of the cella which requires reconstruction from the surviving indications. So, let us first see what Krauss has done about it. The difficulties confronting such an exercise are not to be underestimated if the foot-standard is unknown. How is one to show that the reconstructed wall thickness is correct? If Krauss' reconstruction of the walls is plausible in the context of what experts know of Greek architecture, his ideas must be accepted; the readers of his book have no criteria to reach a better solution. I suppose that Krauss worked on the basis of a knowledge of the constructions normal to Greek architecture irrespectively of the modifications to be found in individual buildings. However, what is normal and what is exceptional? Anyhow, in 1941, Krauss fixed the wall thickness on flanks and back of the naos up 79.5 cm but in 1959 up 65.6 cm (Krauss 1976, 36, fig. 3 and 1959, drawing 11). I found that Krauss' reconstruction of 1941 was correct as for the internal width of the

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[12] Mertens 1993, 3, fig. 3 (altar) and drawing 2 (ground-plan).
[13] Krauss 1976, 46, fig. 4 (Hera II) and 1959, drawing 11 (Athena).

naos (587.3 cm; 18 AF = 587.9 cm) but incorrect in 1959 when he widened the internal width to have the wall thickness up to 2 feet (2 x 32.8 = 65.6 cm)[14]. It is clear that Krauss' efforts brought on results which could not produce an understandable clear plan because he was ignorant of the architect's foot-standard. For the same reason manifold attempts after 1959 all failed to disclose the way the temple was designed.

There is every chance that the considerations of the architect can be ascertained if the right unit of measurement (32.66 cm) is used in the analysis. We must look out for round or whole large numbers of feet in obvious places and symmetry in the use of small numbers of feet, guided by the dimensions of the altar[15]. It all starts with the correct interpretation of the surviving indications that permit the reconstruction of the layout of the original wall constructions (Fig. 6a). At the back of the naos only the two socle courses are still extant. The north flank is better preserved than the south flank. Here two orthostate[16] blocks are still *in situ* on the topmost socle course and a trace on top of one of these blocks, situated about 3 cm off the outer edge of the orthostate, is the only evidence for the position of the first normal course of blocks which are all robbed. Krauss used the evidence on the flank to reconstruct an identical wall on the back (Fig. 6b). My reconstruction (Fig. 6c) reveals that at the back of the naos the second socle course, the orthostate course and higher up the normal courses were vertically aligned on the outside. But on the flanks, apart from the protrusive back wall, the orthostate course receded and a second recess is represented by the normal courses. The protrusive back wall is set-off against a refinement visible more eastward in Naredi Rainer's drawing (Fig. 2) but not in Krauss' reconstruction. However, a minor aesthetical detail, I push the point of recession to a more satisfying place further to the east (Fig. 5). Lengthwise the reconstruction is justified by finding the external length of the naos as a round number of feet: 1538.5 + 97.2 – 3.8 cm = 1631.9 cm; 1633.0 cm = 50 feet (Fig. 8).

Is 50 a holy number as it is in later days? In *de Vita Contemplativa*, a work commonly attributed to Philo (*c*. 20 BC-50 AD) the worshippers are represented as holding their great feast on the fiftieth day. Using numbers, a Pythagorean concept is also suitable: $3^2+4^2+5^2 = 50$.

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[14] The imprint left by a stone block on the top of an orthostate block on north side of the naos, which reduces the wall thickness on the outside by about 3 cm, had previously escaped detection. See Krauss 1959, drawing 11.

[15] The reader who has still his doubts about my proposition to use only fixed Greek measures of length is requested to verify significant numbers for the accuracy of fit by using at choice, but consistently, a slight variation of the proposed standard of 32.66 cm.

[16] The orthostate is the bottom course of the walls of the cella of a Greek temple, generally twice or three times the height of the upper courses. In this case (see fig. 6a) the height of these blocks is 161.5 – 64.9 = 96.6 cm. Certainly the blocks were delivered from the quarry at 3 feet height (98.0 cm).

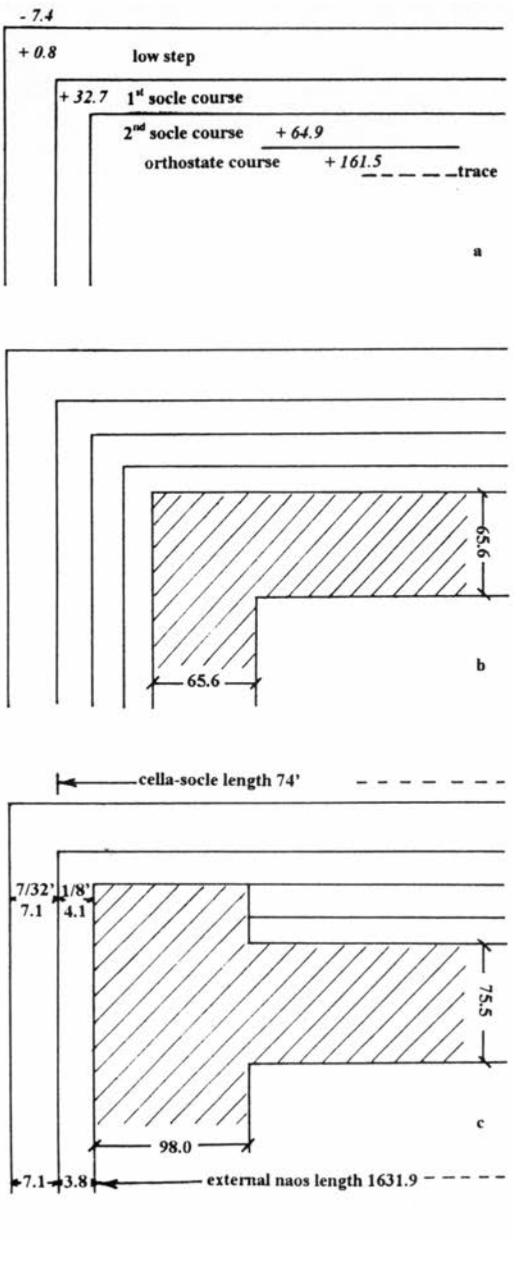

Fig. 6. The temple of Athena at Paestum. North-west corner of the cella (not to scale). Factual evidence after Krauss 1959, drawing 11 (a), reconstruction of the walls by Krauss, 1959, drawing 3 (b) and reconstruction by author (c).

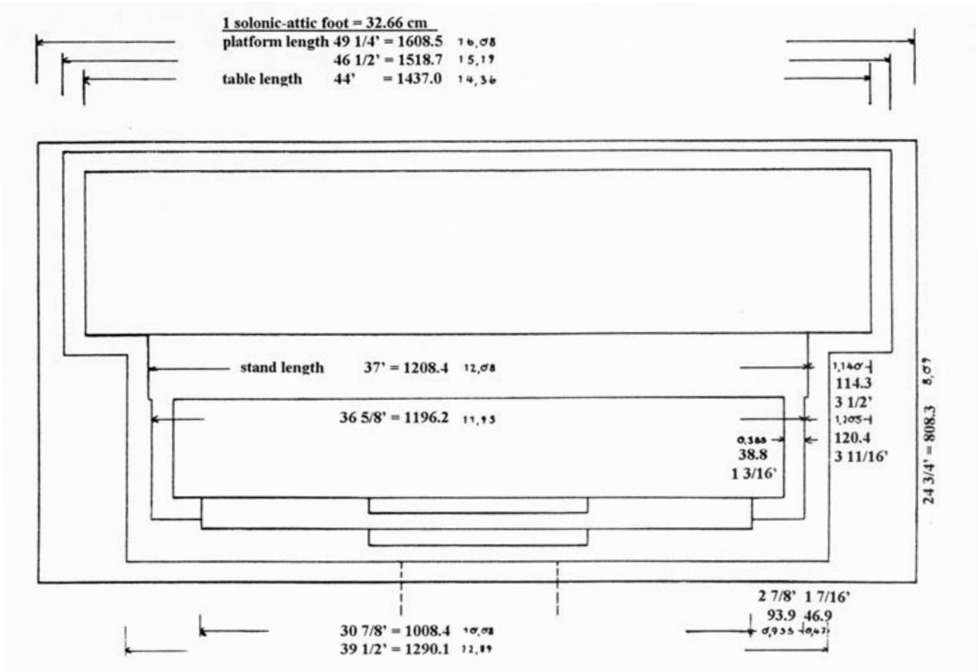

Fig. 7. The altar of the temple of Athena at Paestum viewed from west (after Krauss 1959, drawing 2).

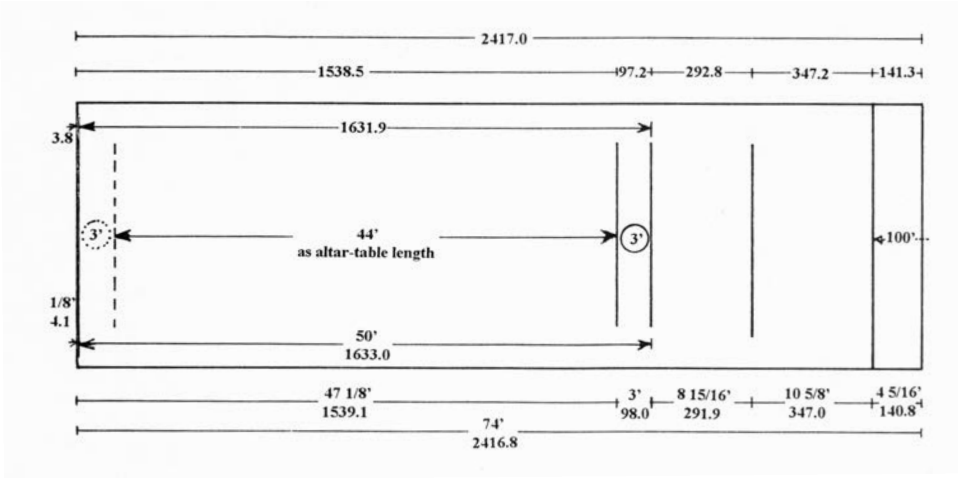

Fig. 8. The cella of the temple of Athena at Paestum (after Krauss 1959, drawing 11).

Let us now look at the monumental stepped altar (Fig. 7)[17]. Krauss gives no opinion about the usage of the altar. Mertens (Mertens 1993, 1 and 94), in discussing the similar altar of the first temple of Hera at Paestum, distinctly states that it is a burnt-offering altar. As far as I know, little attention has been paid to the question of why these altars of the Western Greeks are so large, as this is in contrast with altars in mainland Greece. It is striking that the entrance to the altar tables is on west side[18]. People of all times think that a God dwells in the temple. Thus it is not in their way of thinking if god, *i.e.* the cult statue, is in the temple but the priests of the god sacrifice animals on the outlying altar while standing with their backs to the temple. The outlying altar was the place of public sacrifice and I take it for granted that the rites were solemnized in the presence of the god. It is possible that several shapes[19] of the god or goddess were showed to the people which were assembled on the sacrificial ground in front of the altar. It is clear from Fig. 7 that the length of the altar table is 44 feet but the stand for the priests only 37 feet, so there is room for two portable cult statues in the corners of the table. An acrolith is a portable cult statue whose extremities alone were of stone but for the rest consists of wood and other light materials. This explanation solves the question, at least to my satisfaction, of the large altars.

The external naos length of 50 feet is a cause for satisfaction. Equally satisfactory is the symmetry in the design if we assign to the back wall – see Fig. 6c: 98.0 cm - 3 feet thickness (Fig. 8). That this is intended is suggested by the fact that the resulting internal naos length and the altar-table length are of both 44 feet. The end point of a protective measure of 100 feet is indicated in Fig. 8 on the east side.

By using a foot-standard of 32.66 cm instead of 32.8 cm it was possible to illuminate some characteristics of the design, and the execution coincides almost exactly with that design. However, the change in foot length brings in the introduction of fractional measures as I do not wish to moderate my demands as to the accuracy of fit for other dimensions. Thus the axial intercolumniation (average 262.6 cm), formerly interpreted as 8 x 32.8 = 262.4 cm, becomes 8 1/32 x 32.66 = 262.3 cm, not 8 x 32.66 = 261.3 cm as the latter fixation should reduce the axial distance on front by 5 cm and on flank by 12 cm. There is no written evidence for the use of any fraction of a dactyl less than a half in an architectural context. However, as we shall see, the quarter-dactyl was used in designing some parts of the frieze and for a small measure in the naos (below). Really surprising is the occurrence of the half-

[17] Fig. 7 is a reproduction of Krauss' drawing 2, but I have removed all lines having to do with the reconstruction of the superstructure of the altar table.

[18] Krauss 1959, 1; Mertens 1993, xv and drawing 1b (on page 1 the entrance is erroneously on the east side).

[19] At Paestum at least four shapes of Hera are known (Mertens 1993, 91).

dactyl in long measurements, e.g., in the design of the stepped platform, which carry the columns of the colonnade (table 4).

Table 4. The dimensions of the stepped platform of the temple of Athena at Paestum.

length of	measured (cm) sum of blocks	direct	Interpretation (1' = 32.66 cm)
Front, 1st step (w/e)	1615.0/1616.0		1615.6 = 49 15/32
, 2nd step (w/e)	1533.5/1534.0		1534.0 = 46 31/32
, stylobate	(w/e)	1452.9/1454.11452.0/1454.0	1452.3 =
44 15/32			
Flank, 1st step	(n/s)	3453.0/3452.0	3451.8 =
105 11/16			

Clearly, as to the dimensions of the stylobate (see table 1), this interpretation of the evidence is not near to Naredi-Rainer's suggestion. It might be objected that the dimensions on front are open to other interpretation if some allowance is made for a slight error in execution, thus giving a more satisfying interpretation in feet ($49^{1}/_{2}$' = 1616.7; 47' = 1535.0; $44^{1}/_{2}$' = 1453.4 cm). I admit that this possibility cannot be ruled out with absolute certainty on the basis of Krauss' measurement, but I stick to the interpretation as given in table 4, first, because the figures prove a uniform tread width of the steps of $1^{1}/_{4}$ feet and, second, by making an appeal to Krauss' professional skill, what refers in this case to his calculations of the width of the missing normal metopes and corner metopes (Krauss 1959, 3). The basis for such calculations is the belief that ancient architects calculated the sizes of the individual parts of their buildings. This idea is not generally accepted by students of Greek architecture, as it excludes other possibilities such as designing by eye or geometrical design schemes. In considering the matter from all angles, I keep on the safe side by saying that artists and visionary architects do not like to follow the beaten track. However, the frequent use of the half-dactyl in the design of the temple of Athena proves that the architect of this temple had calculated his design beforehand.

As the temple of Athena has uniform front and flank intercolumniations, the addition of an equal number of feet to the frieze lengths on front and flank will give the correct size of the stylobates, provided that the columns are planned to be vertical and not inclined inward[20]. Only one triglyph is still *in situ* on the east front. The triglyph width (T), measured 55.0 cm, is in the pro-

[20] Coulton 1974, 63; Krauss 1959, 3: "Die Säulen stehen senkrecht, der Tempel hat keine Kurvatur."

portion 3:5 to the height of the frieze (already mentioned in table 3): 2 13/16' x 3/5 = 1 11/16' = 55.1 cm. In the ratio 3:5 we recognize the well-known Pythagorean number triple 3/4/5. The axial intercolumniation (I; 8 1/32') is equal to the width of two triglyphs + two metopes (Fig. 4). Thus the width of one metope (M) = $^1/_2$ (I – 2T) = 2 21/64' (76.0 cm). The architrave width (A; measured 99.6 cm) is 3 1/16' (100.0 cm). The formula[21] for the calculation of the width of the corner metope (Mc) is $^1/_2$ (A – T) + M, which gives Mc = 3 1/64' (98.5 cm).
The calculations of the frieze lengths run as follows. For the front (see Fig. 4) 11T + 8M + 2 Mc = 43 7/32' and for the flank (7 interaxials added) 25T + 22M + 2Mc = 99 7/16'. An addition of $1^1/_4$ feet to the flank frieze gives the length of the stylobate 100 11/16' and the addition of the same length to the front frieze gives the length of the stylobate 44 15/32', as indicated in table 4. This result is again an example of a well-considered design as the frieze is exactly one tread width shorter than the stylobate. In summary, it appears from the evidence that ancient architects indeed used quarter and half dactyls in designing a temple.

The next problem that has to be solved is the manner in which the cella was placed within the stylobate rectangle. Table 4 shows that variations of about 0.5-2 cm were found between identical measures[22]. As the half-dactyl is approximately 1 cm, the analysis of the dimensions of the platform alone, and especially those on front of course, tends to fail as the analyst likes to have dimensions expressible in feet and simple fractions of feet. Fortunately, the analysis of the frieze elucidated the matter. As a result we have the correct point of departure (see Krauss 1959, drawing 11) for analysis of the tripartite division (table 5) of the total length and width, that is, the dimension of the cella and the distances from the stylobate edge to the cella (ptera).

Calculations show that neither mutual relationship of the ptera exists nor a relationship between a pteron and the cella. Clearly, the architect arranged the fixing of five out of six measures accurate to half a dactyl for other reasons. Broadways a satisfactory over-all result had been achieved by the position of the second socle course on flanks which was placed exactly half a foot

[21] Krauss 1976, 28, fig. 2. The missing corner triglyph could have had, theoretically at least, a width slightly different from the normal triglyph width. This possibility does not effect the length of the frieze as the sum of corner triglyph width and corner metope width is invariable.

[22] Normally, the analyst has simply to accept the figures as found in the publication. In many cases it is impossible to find the cause of the variations. It might either be an error in execution or it is the result of deformation in later times. Perhaps, it is an error in modern measurement or a false reading of faded writing when preparing the publication or a printer's error.

Table 5. The position of the cella within the stylobate rectangle (see Fig. 2).		
W pteron + cella + E pteron (n)	336.4 + 2432.1 + 521.1	= 3289.6 cm
(s)	336.4 + 2428.5 + 522.6	= 3287.5 cm
Interpretation	335.8 + 2431.1 + 521.5	= 3288.5 cm
	10 9/32' + 74 7/16' + 15 31/32'	= 100 11/16'
S pteron + cella + N pteron (e)	338.7 + 778.5 + 338.5	= 1455.7 cm
Measurement across cella (w) cm	338.1 + (6.7)[23] + 762.4 + 8.2 + 338.0	= 1453.4
Interpretation	337.8 + 776.7 + 337.8	= 1452.3 cm

off the axial sight lines of the second and fifth column on both fronts of the colonnade (Fig. 5). A second right-angled triangle drawn in Fig. 5 – and before that experimental in Krauss' drawing 11 – suggests another feature, but it cannot be proved as measurement in detail at the intersection of the hypotenuses is missing. Lengthwise, the fixation of the east pteron up 15 31/32 feet reminds us of the second step on front of the platform (table 4: 46 31/32'). The evidence, 521.1 and 522.6 cm, gives an indication of the margin of error but no proof for the interpretation chosen. If the interpretation is correct, we may conclude that measurement in half-dactyls could precisely be made if required. But it will give the modern investigator much trouble as the burden of proof lies with him. Again a devious way is needed for the final proof. Generally, an analysis of closed series of measures precedes the final interpretation of individual measures. Of course, such an exercise is impossible if we are ignorant of the foot-standard. I may add that investigators of Greek architecture may consider themselves lucky that the ancient Greeks used fixed measures of length. In passing I mentioned above a protective measure of hundred feet (Fig. 8). The measure had been attached by the architect to the inner edge of the pronaos stylobate, which carried once four columns (Krauss 1959, drawing 11). But any evidence for the middle columns (dowel holes) is not extant (Fig. 9). The series of measures which give together 100 feet include the width of the east pteron. The starting-point of the protective measure is on the west side of the altar platform (table 6)[24].

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[23] Brackets put by Krauss in drawing 11. He gives no information about the meaning of these brackets (1959, 34).

[24] Krauss 1959, 1, 14-15, drawing 3 (tread width of steps on the east front) and drawing 11.

Table 6. From altar platform to inner edge of pronaos stylobate: 100 feet.			
	measured (cm)	Interpretation (1' = 32.66 cm)	
From west side of platform to 1st step	2513.8		2514.8 = 77
First step: tread width	40.9	40.8 = 1 1/4	
Second step: tread width	40.7	40.8 = 1 1/4	
East pteron width (n/s)	521.1/522.6	521.5 = 15 31/32	
Cella step: tread width (n/s)	7.2/ 8.5	7.1 = 7/32	
Pronaos stylobate width (n/s)	141.3/141.6	140.8 = 4 5/16	
First step to w. side of stylobate (n/s)	751.2/754.3		751.2 = 23

We have seen that small fractions of a dactyl were measured, but it appears from tables 5 and 6 that their laying out had been done more accurately on the north side of the cella than on the south side. Unfortunately, the inaccuracy on the south side brought an error in the construction of the superstructure of the altar. I shall return to this point later. The side of the altar platform which faces the temple seems to be preferred for the start of the measure of 100 feet. The architect of the Hera temple I at Paestum selected the same place but the end was planned differently (de Zwarte 2002, 14, fig. 5).
Let us return to the naos (Fig. 10). The internal naos width fits in with the original measurement of Krauss in 1941[25]. The evidence of the wall thickness cannot be very exact as it is the result of only one measurement (80.0 – 3.0 = 77.0 cm) between traces on levels, about 50 cm different in height (Krauss 1959, drawing 11, on north side). For the rest the metric equivalences are in agreement with the measurement, but the final recess has been expressed in quarter dactyls. This cannot be simplified by changing the wall thickness, for a wall of 2 11/32' (76.5 cm) goes with a recess of 5/64' (2.6 cm) and one of 2 3/8' (77.6 cm) with 3/64' (1.5 cm). Though it is now impossible to ascertain the precise thickness of the wall, I suggest that for the designer of the plan 7/64' was visually most attractive as it is half the step width of 7/32'.
Krauss' measurement laid the basis for the internal naos width of 18 feet, but it remains to be proved that the width of the altar-table reflects the architect's intentions in a similar way, as the altar-table length is the same as the internal naos length. Thus let us now return to the altar (Fig. 11). Analysing in feet, it is immediately clear that the architect succeeded in killing two birds with one stone: 14' + 9' = 23'. The table width is half the internal naos width and the distance from the edge of the platform on west to back of the table is so managed that a sum total of 100 feet is realized (Fig. 12). Unfortunately, there was an error in laying out the desired number of 23 feet from the platform edge (Fig. 11). As the distance from platform edge to front of the table

[25] Krauss 1976, fig.3: 587.3 cm.

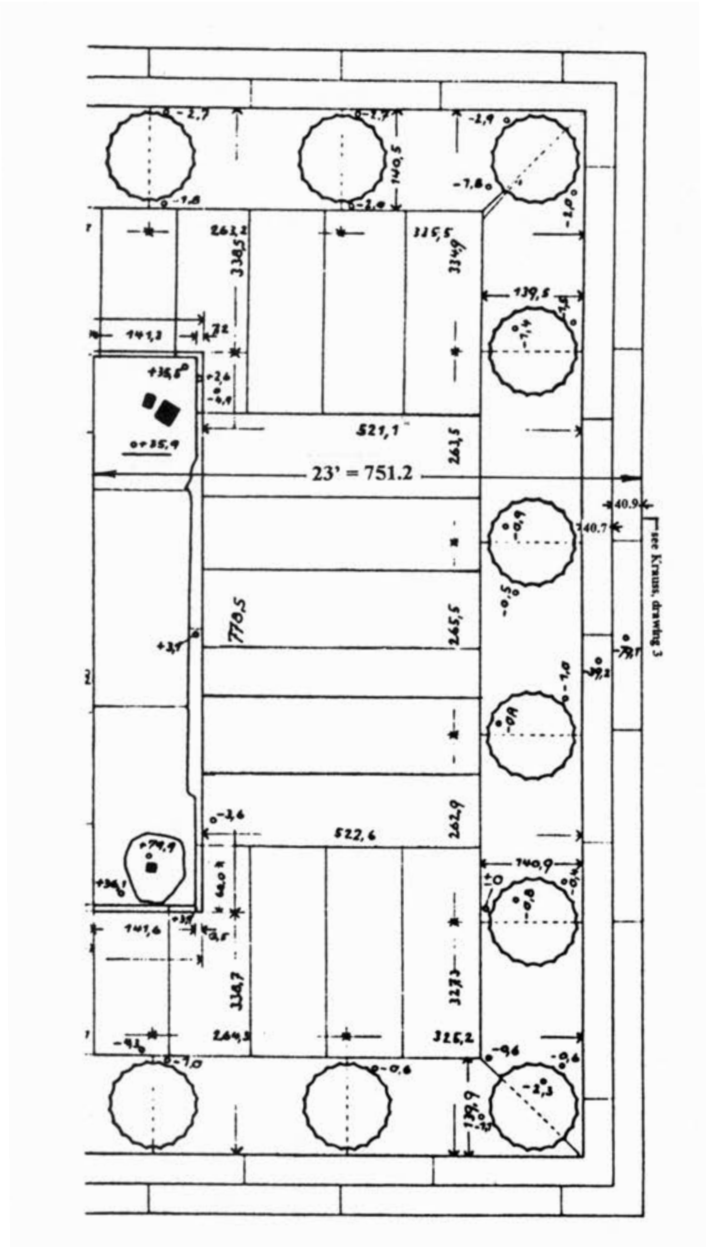

Fig. 9. The temple of Athena at Paestum (after Krauss 1959, drawing 11). From west side of pronaos stylobate to edge of first step on east: 23 feet.

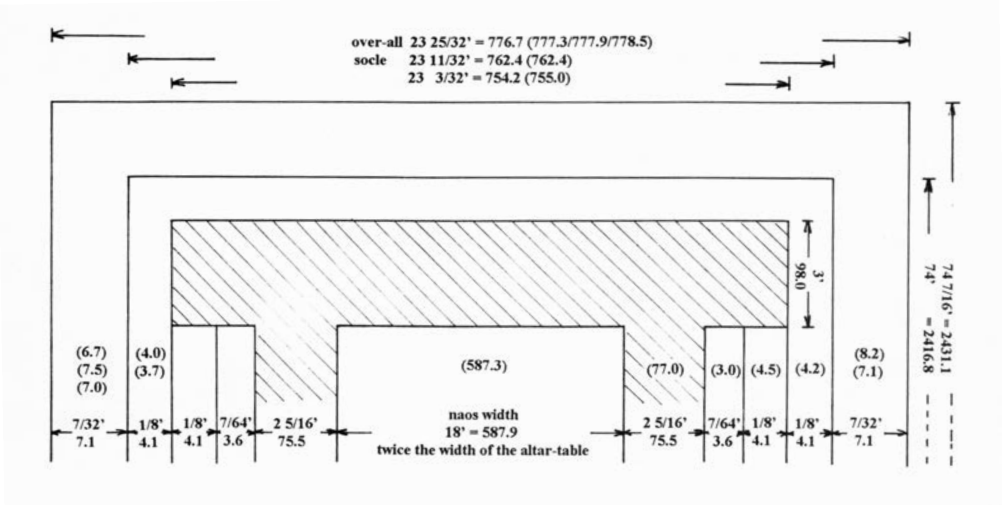

Fig. 10. The temple of Athena at Paestum (not to scale). The reconstruction of the internal naos width (factual evidence between brackets).

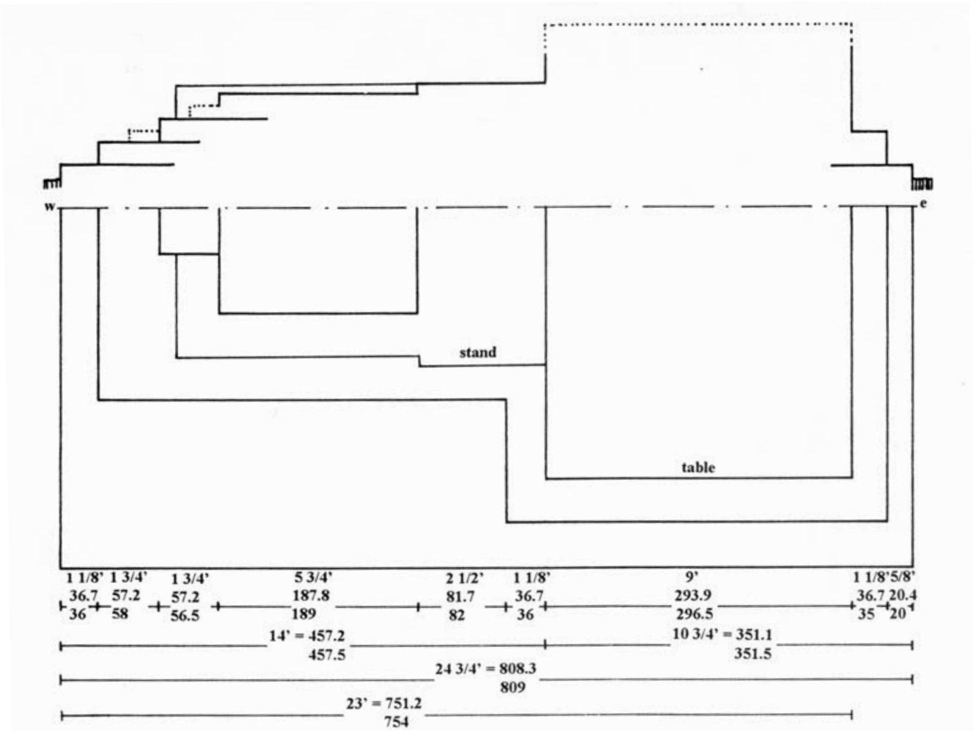

Fig. 11. The altar of the temple of Athena at Paestum viewed from south and section w-e.

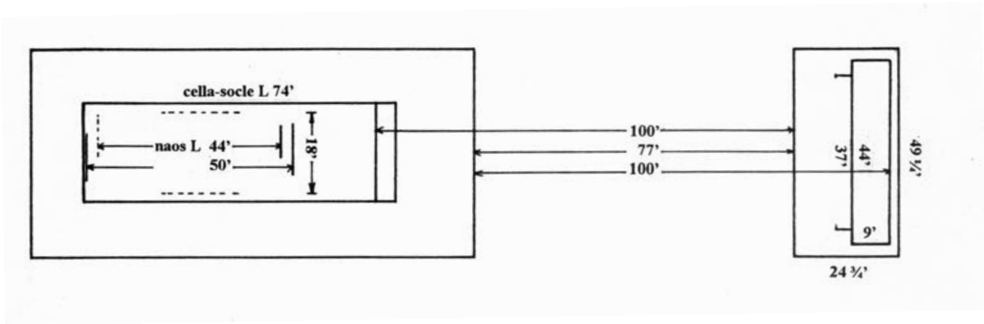

Fig. 12. The temple of Athena at Paestum. The relation of the altar dimensions to the cella dimensions (feet).

is indeed 14 feet, the error took effect to the width of the table. Apart from the measure of 23 feet, there are no discrepancies between plan and reality (Figs. 7 and 11). Using a measuring-cord or a number of rod-lengths, accurately setting out 23 feet is equally easy as 10 or 24¾ feet. It follows that the instruction was given in a different way. The foreman had evidently been instructed by the architect to repeat the distance already set out in the temple. However, the execution of this distance on south side (table 6: 754.3 cm) did not coincide exactly with the design. Certainly the foreman did not make a mistake by choosing the south side for the repetition. The point is that he did not know that the measure had to be exactly 23 feet. It is striking that the inaccuracy of a basic dimension passed unnoticed. One solution might be to posit lack of supervision by the architect, another to assume that the original architect passed away and that his successor was not acquainted with the precise nature of the design. Whatever the precise answer to this question, it is clear that the basis of the temple had been completed before the altar-table was finished.

The presence of the 'holy' measure of 100 feet has convincingly been demonstrated, but the details of its composition still require explanation. Inevitably, the question arises: was the division into 23 (= 5+7+11) and 77 (= 7x11) feet simply caused by lack of space on the site, as there is no apparent relationship between them, or were these numbers based on a mathematical theory? Surprisingly perhaps, it is the second alternative which indeed might explain these numbers. This is confirmed by the fact that important dimensions of the naos (Fig. 12) can be explained in line with our suggestion. There is every appearance that the architect made use of the supposed magic power of three successive Pythagorean triples beginning with a prime number (table 7).

Table 7. Design based on triples.	
Triples	Use of lowest number
5/12/13 7/24/25 11/60/61	5 + 7 + 11 + (7 x 11) = 100 11^2 – (7 x 11) = 44 7 + 11 = 18 $5^2 + 7^2$ = 74 7 – 5/5/7 = 257

For the Greeks number was, by definition, what we would call positive whole number. Number 257 (table 7) refers to the axial intercolumniation (8 1/32') expressed in half-dactyls.
The currency of magic protection can be stressed from evidence gathered elsewhere at Paestum. In the first temple of Hera ('Basilica') a square and a golden isosceles triangle are invisibly extant in a horizontal plane about two metres above floor level (de Zwarte 2004). The square represents a very accurate expression for the square root of 2 in whole numbers and the triangle is the essential part of the pentagram. In 2004, I took it to be a demonstration of mathematical knowledge. This is still correct, but further examination showed that it was not the great point for the architect.

I conclude with a brief discussion of the significance of this system. It is immediately apparent that the Hera temple I at Paestum furnishes concrete evidence of geometrical constructions, but it remains to be clarified for what purpose these constructions have been laid out. From level + 190.5 cm one can visu-

Fig. 13. Geographical positions of islands and cities mentioned in this study.

alize triangle and square by stretching strings horizontally between five points. However, three points got inaccessible long before completion of the temple and so the final result was a hidden treasure of mathematical knowledge which was inaccessible for the Pythagoreans themselves. It is true, these constructions are continuing to exist, but they are invisible for human beings. However, the ancient Greeks gave credence to demons. The only explanation that fits in with the evidence is that the magic power of the invisible constructions screened the priests from evil demons.

A digression on methodology in Greek metrology

Methodology is an ugly word, but it serves to remind us that inquiries into the validity of accepted conclusions should often be directed not at the conclusions themselves but at the means by which they are obtained. It is well known that Greek metrology has had its successes and failures. Not surprisingly, linear measures have acquired a reputation for being a treacherous quicksand of speculation and controversy.

The first successful contribution to Greek linear metrology was Dörpfeld's derivation of an approximate value of the foot (32.6-32.8 cm) by comparison of some dimensions specified in feet in the official building accounts (408/7 BC) of the Erechtheion in Athens with values in meter found in the temple as executed (Dörpfeld 1890, 168-171; Bankel 1983, 65-67, 94-99).

Unfortunately, Dörpfeld was impressed with the idea that large dimensions were planned in whole numbers of feet, so he believed that the foot length could be ascertained by his interpretation of only two measures in the Parthenon. In retrospect we may now decide that this was a failure. The use of fractional measures in planning large dimensions cannot be excluded. For example, length and width of the stylobate rectangle of the Parthenon may be measured either in Attic feet as 212 5/8' x 4/9 = $94^{1}/_{2}$' or in Ionic feet as 232 7/8' x 4/9 = $103^{1}/_{2}$' and, in fact, the foot used by the architect of the Parthenon was the Ionic foot, not the Erechtheion (Attic) foot. If the ratio 4:9 of stylobate width and length is accepted, it can be substantiated irrespective of the Attic or the Ionic foot. The only direct way to find the architect's standard will be by working out the results for both standards and comparing them with the values found in the building as executed: actual (after Penrose in English feet) 6953.9 x 3089.2 cm; theoretical value converted into cm 6944.3 x 3086.4 (basis: 1 Attic foot = 32.66 cm) or 6953.6 x 3090.5 (basis: 1 Ionic foot = 29.86 cm). The accuracy of fit is an important indicator to decide which foot-standard probably will satisfy best when the investigator will go on with his study. However, it might be objected that my preference for the interpretation of the stylobate dimensions in Ionic feet is solely based on the firm belief in Greek measures of standardized length, as a slight change of the Attic foot (for example: 32.70 instead of 32.66 cm) only seems to result in an acceptable accuracy of fit. I may rejoin, then, that this study merely is initiated by interpreting the stylobate dimensions and has to be followed by a more profound study to make the architect's intentions more transparant[26].

I think Greek measures of length were standardized[27]. It may be helpful to offer more evidence. Very first, however, I shall discuss the opposite view. The failures of Greek metrology are probably attributable to the fact that what is a historical subject appears to be a scientific one. Any hypothetical case collapses if there are great differences between factual and theoretical dimensions, granted that the Greeks have used foot rule and measuring rod in laying out their buildings. First of all it may be noted that, strictly speaking, no theory can ever be proved. It can only be falsified. Certainly, it is not sufficient to collect as many dimensions as possible of a given building and then subject them to an intense statistical bombardment. This technique suffers from the grave disadvantage of always supplying an answer. The result, for example, is 31.1 cm. What does it mean? One Drusian foot or 1 1/8 Roman foot? But if the building dates from the fifth century BC: perhaps a variation of the Attic foot?
The variation in standard of length in premetric Europe was seen by many scholars as similar to the state of affairs in the various Greek cities. It was argued that one or other large measure within the range of 3250-3290 cm was a consciously chosen length of 100 feet which should prove that the Attic foot varied in length accordingly. For example, the Hephaisteion in Athens: length of step on flank below stylobate 32.51 m. However, a less fragile solution is preferable: stylobate on front 1372 cm; 42 feet, at 32.66 cm a foot, is 1371.7 cm. As to the number 42, recorded by Vitruvius (IV 3.3) in this connection, is it reasonable to suggest that he was inspired from hearsay as to the Hephaisteion, which is a hexastyle temple? I may add that, in my opinion, a modular design was used by the architect (de Zwarte 1996). The inquiries into the design of the temple of Athena at Paestum had suffered from the same approach based on the length of the stylobate on the flank (32.88 m). However, as we have already seen above, the Attic foot of 32.66 cm fits in with the evidence. It may be noted that these derivations of the foot length have been achieved after Dörpfeld's discovery of the Erechtheion foot. Scholars publishing earlier had more free a field for uncontrolled speculations. However, the method is essentially the same. So Hultsch calculated a foot of 30.83 cm from the 30.83 m length of the front stylobate of the

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[26] De Zwarte 2002, 14-16 (The last paragraph of this paper has to be dismissed for its erroneous representation as the Attic foot was already instituted by Solon. The older Ionic foot was either endured by Solon or revived in a later period).

[27] De Zwarte 1994. Theoretical values of the foot-standards: 29.85984 cm (Ionic; 16 dactyls), 32.6592 cm (Attic; $17^1/_2$ Ionic dactyls), 29.39328 cm (late Attic?/Roman; $15^3/_4$ Ionic dactyls). Practical values 29.86, 32.66 and 29.394 cm. The mathematical evidence for the value of the Ionic foot cannot be disproved: de Zwarte 2004.

Parthenon[28]. Recently the same method was still applied to large measures between 5200-5300 cm to suggest the use of an Egyptian-Ionic cubit of varying length. From being a conjecture, it became a fundamental principle.

I wish to make clear that I am concerned with pitfalls in metrological method. Resuming an old problem and by presenting more factual evidence as well as an acceptable conversion into a foot of standardized length (either of 32.66 cm or of 29.86 cm), I hope to tip the balance in my favour.

In the late nineteenth century archaeologists and architects had good hopes to deduce the length of the Greek foot from the stadium, as Herodotus (II 149) reported that the stadium was equal to 600 feet. Unfortunately, the lengths of the excavated Greek athletic stadia varied so much that every stadium produced a different foot length in this way. Accepting the foot-standard of 32.66 cm, there must be a reason for cutting short these courses at Olympia and in Athens[29]. Otherwise I cannot understand why the course at Olympia was exactly 15 feet longer than the course at Athens. According to Koenigs (Koenigs 2003, 143) the length of the course at Olympia is 192.28 m ($588\frac{3}{4}$ x 0.3266 = 192.286 m) and Dörpfeld[30] calculated a length of 187.39 m at Athens ($573\frac{3}{4}$ x 0.3266 = 187.387 m). It might be objected that the observation could be right but the point of departure debatable. If we take the foot at 0.327 m the result is more attractive for its whole numbers of feet (588 x 0.327 = 192.276 m; 573 x 0.327 = 187.371 m). However, is it reasonable to suggest that the Attic foot, a derivative of the Ionic foot, was standardized at 32.66 cm ($17\frac{1}{2}$ Ionic dactyls) because the Ionic foot was standardized at 29.86 cm? Recent measurement of many Sicilian temples by Mertens (Mertens 1984, 82, 105) may elucidate this point. I give two nice examples (1'= 29.86 cm).

The stylobate dimensions of temple A at Selinous are 1613.3 cm (1612.4 cm = 54') and 4031.0 cm (4031.1 cm = 135'); ratio 2:5. The stylobate of the temple of Juno Lacinia at Akragas measures 1695 cm (1694.6 cm = $56\frac{3}{4}$') and 3813.0 cm (3812.7 cm = 127 11/16'); ratio 4:9. The accuracy of fit is excellent in both cases. Nevertheless, I declare myself in favour of the Ionic foot on the evidence of only two measures. So, the proposed foot length needs rigorous testing on these temples before it can be accepted with full confidence.

If a design cannot be unravelled, the metrological starting-point might be wrong. Fortunately, I have a clear example at hand to illustrate this. Mertens (Mertens 1993, 97, note 251) says, in discussing the curious archaic aesthet-

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[28] Hultsch 1882, 67; six years later – on basis of better measurement but the same idea – Penrose 1888, 9: 30.89 cm.

[29] Pausanias (V 16.2), who lived about 165 AD, mentions an occasional reduction of the course by 1/6 at Olympia.

[30] Dörpfeld 1882, 300-301. I neglect his assumptions to the effect of further reduction.

ical appearance of a temple at Kallion from the late fourth century BC, "Gesamtverhältnisse in Kallion: B:L = 12.55:28.22 = 4:9 (!)," which refers to the dimensions of the stylobate. In this case the accuracy of fit is of no use for finding the architect's foot-standard as both standards meet our requirements. However, one standard is less easy to detect, certainly in this case as we are all familiar with arithmetical ratios. If Mertens' observation is right, the Ionic foot was used: 42' (1254.1 cm) x 9/4 = 94 1/2' (2821.8 cm). However, it is possible that in the course of further inquiry based upon the Ionic foot doubts arise because extremely complicated fractional measurements emerge which are hard to accept[31]. Then we must re-build our metrological argument from its very basics.
I defend the position that the Attic foot was used if the differential system of proportioning in the temple at Kallion was the same as in the Hera temple I at Paestum (above: length minus width is a whole number of feet): 86 7/16' (2823.0 cm) – 38 7/16' (1255.4 cm) = 48'.

As demonstrated above, it is impossible only to use the dimensions of a rectangle as a means for deriving the foot-standard, even if the outcome is a well known standard. If the assumed standard is not known from elsewhere, much more additional evidence is needed before it can be accepted as factually established. This is of course particularly true when only a few dimensions can be measured precisely. For this reason it was needed to study afresh the huge portal of the temple of Delian Apollo on Naxos on which Gruben had postulated a Cycladic foot-standard of 29.48 cm (Gruben 1972, 322). Putting it to further trial on Naxos, Paros and Delos, Gruben found that the foot length varied between 29.3 and 29.55 cm. He started with the assumption that the external dimensions have been planned in the proportion of 7 to 9. However, the occurrence of a proportional relationship in the metric system may be misleading.
For metrological purposes the portal may simply be visualized as a rectangle centred horizontally within another rectangle[32]. As evidence from neighbouring Delos will be used, I give Gruben's result and a conversion into Attic feet (table 8).

It may be noted that the accuracy of fit is better for the horizontal dimensions if using a foot length of 29.48 cm and the opposite for the vertical dimensions.
Some additional evidence supports the Attic foot-standard. Coulton (Coulton 1975, 86, note 137) mentions an inscription on the central wall of the south

[31] I did not investigate whether the Ionic foot may be maintained or not in the temple at Kallion.
[32] For a photo of the impressive portal see *Antike Welt* 33 (2002), 394, fig. 12.

Table 8. Portal of the temple of Delian Apollo on Naxos (*ca.* 530 BC).			
	measured (cm) (Gruben 1972)	Interpretation (1' = 29.48 cm)	Interpretation (1' = 32.66 cm)
External width	619.2	619.1 = 21	620.5 = 19
Internal width	376.0	375.9 = 12 3/4	375.6 = 11 1/2
Pier width	121.6	121.6 = 4 1/8	122.5 = 3 3/4
External height	796.0	796.0 = 27	796.1 = 24 3/8
Internal height	584.2	585.9 = 19 7/8	583.8 = 17 7/8
Lintel height	130.0	129.0 = 4 3/8	130.6 = 4
Threshold height	81.8	81.1 = 2 3/4	81.7 = 2 1/2

stoa at Delos which states a length as *orguiai* (fathoms) MZ. I accept Coulton's assumption that the inscription refers to the over-all length of the building (72.47 m). Herodotus (II 149) tells us that the *orguia* (the length of the outstretched arms) was equal to six feet[33]. It is striking that Coulton based his calculation on MZ = 47, which results in a foot length of only 0.257 m[34]. The sign Z meant 7 at Didyma (*ca.* 250 BC) but, as far as I know, the sign M to mean 40 is only attested for the Byzantine era[35]. The problem is solved if we read M as 30 on Hellenistic Delos: 222 feet at 32.66 cm gives 7250.5 cm and 222 divided by 6 = 37.

It can hardly be a surprise that the same unit was used to build the great temple of Apollo on Delos (*ca.* 460 BC). It is important to note that the colonnade of this temple is exactly alike to the colonnade of the temple of Athena at Paestum, apart from its dimensions. The information presented in the quotation (Nabers/Ford Wiltshire 1980, note 27) provides for the starting-point to conclude the foot-standard and a glimpse of the architect's intentions:

"Even the peripteral temple of Apollo on Delos, which also has uniform interaxials all the way around its 6 by 13 peristyle, fails to achieve a Pythagorean triangle. Since the interaxials are uniform, there does exist a triangle (measured from corner column axis to corner column axis again) in the plan which has the *proportions* of the 5, 12, 13 Pythagorean triangle, but the sides of the triangle are not expressed in terms of even feet. The Pythagoreans considered only whole numbers to be numbers. The excavators determined that a foot of 0.297 m. was used in the construction, with 7 11/16

[33] Herodotus (II, 149) explains the *Attic* system on behalf of his readers in Ionia, where the fathom was equivalent to seven feet (de Zwarte 1994, 124-125: metrological relief at Oxford).

[34] Coulton's value of 0.2501 m is the result of an error in calculator reading.

[35] On copper coins of AD 498 and later the largest denomination bore the mark M (= 40 nummi).

feet to each interaxial: Fernand Courby, *Les temples d'Apollon* (*Délos* 12, Paris 1931) 93-95."
Nabers and Ford Wiltshire correctly observe that the Pythagoreans considered only (positive) whole numbers to be numbers, but nowhere is stated, if measures of length are involved, that it is on the level of the foot. Thus a measurement of 7 11/16 feet is no problem, as it corresponds to 123 dactyls. The real problem is that the architect of this temple did not use a foot length of 29.7 cm. We have to convert the axial intercolumniation of Courby into Attic feet: 7 11/16 x 29.7 (about 228.32 cm) : 32.66 = 6.9907.. feet; 7 Attic feet = 228.6 cm.
Indeed, the architect's feature is a 5/12/13 triangle, enlarged by a factor of seven. This yields an axial distance on the front of the colonnade of 5x7or 35 feet and on the flank of 12x7 or 84 feet. The hypotenuse of such a triangle, 13x7 or 91 feet, is of interest as it may represent the 13 columns on the flank of the colonnade in defining the long side of a rectangle, provided that the evidence for the shorter side is in line with our observation.

The state of preservation of the great temple of Apollo is a disappointment: most of the foundations, small parts of the euthynteria and the platform, and fragments of the superstructure are still extant. It follows, that the various rectangles which incorporate the individual parts of the substructure, need to be reconstructed from the available evidence. According to Courby's reconstruction, the dimensions of the euthynteria – the special top course of a foundation used as a levelling course – appear to correspond to the number of columns at the front and along the flank of the temple. Courby reconstructed 1372 cm for the width (1371.7 cm = 42 or 6x7 feet) and 2978 cm for the length (2972.1 cm = 91 or 13x7 feet). The width has been excellently reconstructed, but the length slightly too long. Fortunately, the hypotenuse of the triangle supports the theoretical length of the euthynteria. Certainly, we may conclude that Cycladic foot-standards of 29.48 cm and 29.7 cm have to be dismissed.

In spite of my inquiries into Parthenon and Hephaisteion it is not generally accepted that in Athens two foot-standards were used. The opposite view – only one standard was used – is based on the fact that in the Athenian building accounts simply the word 'foot' is used without specifying the name of the foot. Consequently, Dörpfeld (Dörpfeld 1890, 168) rejected his earlier study on the Greek foot (1882) on the *assumption* that the Athenians had only one foot-standard, the Erechtheion foot. However, recently Korres (Korres 1994, 63) was of the opinion that a foot of 29.37 cm was more acceptable than a foot of 32.7 cm on the evidence that the smaller foot satisfies much better at the small dimensions of the Parthenon. It is precisely this method that Dörpfeld had used in his inquiry into the temple of Athena Nike in

Athens[36]. He concluded that 1 dactyl was equal to 18-19 mm, 1½ dactyls to 28 mm and 2 dactyls to 36-37 mm. The corresponding values for the standardized Ionic foot of 29.86 cm are 18.7, 28.0 and 37.3 mm. Clearly, this method is very useful for establishing an approximate value of the foot-standard used by the architect. Naturally, the conjecture – based on the building accounts of the Erechtheion – that the Athenians used only one foot-standard, has to be dismissed in the light of the design of the Parthenon that leans on the shorter foot-standard, unless it can be demonstrated that the proposed design cannot be maintained.

In his essay on methodology in Greek architecture, Wesenberg (Wesenberg 1995, 220) inferred from the regrettable state of affairs about ancient metrology quite another cause, namely a competency problem. Nowadays mainly professional architects and classical archaeologists are engaged in the study of ancient Greek architecture. According to Wesenberg, the problem may be solved if alone highly specialized investigators are willing to acquire adequate knowledge of (1) Greek architecture and (2) the historical presuppositions. As to (1) it would seem to me that sufficient knowledge of the technical side of architecture will do to work in any specific field of architecture. As to (2) I fully disagree. In fact, a presupposition is a previous supposition and a supposition is a position laid down without proof. Thus, presuppositions are at best nothing more than generally accepted opinions and so capable of improvement.

By bringing up Greek measures of length for discussion, I hope to stimulate the study of Greek architecture, but it also has a wider aim. I try to make clear that modern misinterpretation of ancient factual evidence clouds the issue of our view on the abilities of ancient societies. Surprisingly perhaps, but standards of mass led me to find the designs of the first and second temple of Hera at Paestum.

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[36] Dörpfeld 1882, 293-295. According to Dörpfeld the large dimensions are unreliable as a consequence of destruction and modern restoration. In 1686, the Turks dismantled the temple to obtain material for the construction of a rampart. But on the destruction of this rampart in 1835 the pieces were recovered and the temple was rebuilt (1836-1843). The temple has been rebuilt for the second time from the foundations in the years 1936-1941 but not quite satisfactorily (Dinsmoor 1950, 186, note 1). A splendid photo of the temple is published in *Antike Welt* 33 (2002), 406, fig. 32. In my opinion, the re-buildings of the temple of Athena Nike give a unique opportunity to make it the subject of a congress as it all has been done without knowledge of the foot-standard. Wesenberg (2005, 54) pointed out that the foot length is decisive in the discussion on the design of the Ionic columns of the temple of Athena Nike and the temple of Dionysos at Teos (The axial intercolumniation on front of the temple of Dionysos is 326.5 cm, that is either 10 15/16' at

As with standards of length, the study of ancient standards of mass was hampered by misinterpreting the available evidence. I discovered that ancient weight-sets in many countries around the Mediterranean give only accurate results on this condition: Weights must be placed in both pans of an equal-armed balance; the difference in mass stands for commodities to be weighed (de Zwarte 1995 and 2000). It occurred to me that this principle might be capable of extension to measures of length. If one accepts the difference in a weighing procedure, then, for what reason such a principle could not be used by architects in linking length to width of a rectangle? Indeed, the method was used by the architect of the first temple of Hera at Paestum (de Zwarte 2002, 14) in defining the dimensions of the outlying altar (Mertens 1993, 3, fig. 2): length minus width = 2100 – 607 = 1493 cm = 50 Ionic feet at 29.86 cm. If the method can be demonstrated once more, it will provide a strong argument for revising existing theories. Fortunately, this is easily done. Recently I found within a stone's throw of the Hera I temple at Paestum decisive evidence for the use of both this proportional system and the existence of standardized Greek foot lengths. Moreover, the second temple of Hera ('Poseidon'), which was built about 70 years later than the first one, was designed in Attic feet, not Ionic feet, which permits the conclusion that different foot lengths were used in one and the same city. This way the actual dimensions of the cella were calculated by the architect: length minus width = 100 feet. The measurement by Krauss (Krauss 1976, 46, fig. 4) mentions the length of the north side, 4617.3 cm – the length on the south side is not stated – which gives minus the east side (1349.4 cm) or the west side (1348.6 cm) a difference of 3267.9 or 3268.7 cm. Interpretation (1'= 32.66 cm): 141 5/16' (4615.3) – 41 5/16' (1349.3) = 100'. The north side is 1/16' too long, the west side is less than 1/32' too short and the east side was correctly executed[37].

The Attic foot standard ($17^1/_2$ Ionic dactyls) is later in origin ('Solonic': Ath.

[37] Maarten de Weerd, who kindly read the draft critically, pointed out that a geometrical proportion might be used. The only literary evidence for the use of such ratios by architects is the occurrence twice of the ratio 1 : √2 in Vitruvius' *De Architectura* (IV.1.11: Corinthian capital and VI.3.3: Roman atrium). Geertman (1984, 48-49) holds that Pompeian architects used geometrical proportions in house-planning not directly, but by means of arithmetical approximations. Indeed, such a design principle puts irrational values into the normal division of the foot standard into 16 dactyls by means of expression in whole numbers. This method was already familiar to architects of the archaic period. The architect of the Hera temple I at Paestum designed a square by using the numbers 309 (side) and 437 (diagonal), which gives indeed a very accurate approximation of √2 (de Zwarte 2004, 44). The long side of a rectangle, easily constructed from the diagonal of a square with a side of 100 feet (1600 dactyls), becomes 141.421..', which is close to 141.4375 = 141 7/16' (2263 dactyls = 4619.3 cm) and the difference between diagonal and side is 41.421..' , which approximates 41 7/16' (663 dactyls = 1353.3 cm). However, the factual evidence as established by Krauss does not support this method, if we accept that ancient architects may make mistakes in the laying out occasionally but not continuously.

I hope to discuss the design of the colonnade of the Hera II temple at Paestum – *with*

Pol. 10) than the Ionic standard ('Pheidonic': Herodotus VI 127). Values of 32.66 cm and 29.86 cm are fit for everyday use by investigators of Greek architecture.

The comparative metrologist prefers the theoretical values as comparative metrology is based on the theory of unbroken continuity. If a new measure was needed, the appropriate action was to adapt what was already at hand, not make a fresh start. The Egyptian cubit of 52.25472 cm (28 dactyls) was equal in length to the Samian cubit (Herodotus II 168); the Samians preferred the foot (16/28 x 52.25472 = 29.85984 cm) for mathematics (Pythagoras for instance) and the erection of buildings (Hera temple on Samos: de Zwarte 1994, 125-127); the Attic foot is $17^1/_2$ /16 x 29.85984 = 32.6592 cm (Athens: Erechtheion and Hephaisteion) but the Ionic foot revived after the time of Solon (Athens: Parthenon and the temple of Athena Nike); the Roman foot is 63/64 x 29.85984 or 9/10 x 32.6592 = 29.39328 cm; the Anglo-Saxon foot is 29.39328 x 8/9 = 26.12736 cm (a natural foot of 10 2/7 English inches); the English foot is 7/6 x 26.12736 = 30.48192 cm, but the practical and legal value is 30.48 cm. It follows, that the estimate of the Roman foot at 29.6 cm is a failure (Hultsch 1882, 88-98). However, the comparative metrology is of use to dismiss this estimate[38].

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[38] The outcome of a controversy (1907-1916) did not bring an end to the application of comparative metrology but stimulated younger scholars to adopt the statistical approach to clear up problems (de Zwarte 1995, 103-112). Nowadays, the value of comparative metrology is underestimated. However, the treatment of written evidence which is not stated in the metric system gives no result if one uses practical values, the more so if the practical value is based on a assumption which cannot be proved, e.g., a Roman foot of 29.6 cm (Grierson 1972, 29, note 137). I give a clear example, starting from the theoretical value of the Roman mile: 5000 x 0.2939328 = 1469.664 m. Grierson says (1972, 5): "Metrologists may be divided into two classes. Those who are historians by training are disposed to stick closely to the texts, and to material evidence where it exists, and interpret these fairly strictly in their historical and social contexts. ... In contrast to historical metrologists are others who base their conclusions upon what I can only term mathematical romanticism and diffusionism run mad... Ancient measures are translated into modern units with a quite unwarranted degree of precision; ..." Generally speaking, the reader is well advised to preserve the happy mean between extremes. However, it is certainly useful to pursue the point. If there are conflicting documents, you can have your choice, but be sure to choose the right one, otherwise meaningless results will be produced. In any case, state the contents of the documents you put aside as a reader might have better ideas to solve the problem. Working in the field, a practical value is sufficient to get result, e.g., fix the Roman mile at 1470 m. If you are a theorist involved in complicated calculations, then use the theoretical figures at hand, otherwise you will miss the most interesting results. Rounding off is only the finishing touch, if you wish to do so.

Grierson says (1972, 29): "... a passage in the Old English version of Orosius ..." (*ca.* AD 900) "This is a passage giving the length of the walls of Babylon as 70 1/7 miles, where the Latin text has 480 stadia, i.e. 60 miles." Grierson concluded that the Anglo-Saxon mile would have been 4154 modern English feet. However, his result is not convincing. First, this figure has no apparent relation to the modern English mile of 5280 feet as might be expected and second, the figure 70 1/7 remains obscure and third, The ratio 63/64 between the Roman foot and the Ionic foot is decisive evidence to conclude that Vitruvius converted designs on the Ionic foot into theoretical design on the Roman foot, as Wesenberg discovered that a module of 63/64 is needed to restore the original design (Wesenberg 1983, 164). The ratio 9/10 hints at the origin of Roman standards of mass and capacity, which are related to the Attic foot (de Zwarte 1994, 128).

Let us return to Athens. Penrose measured the Parthenon in English feet, but the architect's standard was the Ionic foot. The modern investigator of the Parthenon might prefer to avoid the intermediate stage, *i.e.* the metric system: 48 English feet are equal to 49 Ionic feet. As in former days many investigators published their measurements in English feet, I remark that direct conversion into Attic feet or Roman feet is equally accurate:15 English feet equal 14 Attic feet and 27 English feet equal 28 Roman feet. I use in these calculations the theoretical value of the English foot: 30.48192 cm. This is acceptable as the difference between 100 theoretical feet and 100 legal feet is only 0.192 cm.
Though I only discuss the basic standards of length in architectural use, I certainly do not deny the existence of other standards. For example, the date of introduction of the Roman foot (practical value 29.394 cm; de Zwarte 1994, 115 and 128-131) is still unknown. Perhaps more important is the question

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stadia at 625 feet each. However, more probably the translator used the information given by Polybios and Julian of Ascalon, who reckon the mile at 8 1/3 stadia at 600 feet each (All sources are of easy access in Radke 1973, 1447-1448, but the metric estimates based on a 'Roman' foot of 0.2963 m have to be dismissed).

The calculations run as follows: 480 : 8 1/3 = 57.6; 57.6 x 1469.664 (Roman mile) divided by 1207.084032 (Anglo-Saxon mile = 3960 English feet) gives 70 10/77; rounded off 70 1/7. The relation Roman mile to Anglo-Saxon mile = 375 : 308. If I interpret the passage rightly, the translator possessed a document informing him that 308 Roman miles are equal to 375 Anglo-Saxon miles: 57.6 x 375/308 = 70 10/77. The fixation of the Anglo-Saxon mile at 3960 English feet seems acceptable because this is $^{3}/_{4}$ of the modern English statute mile of 5280 English feet (Elizabeth I, act of parliament, 1593). Of course, for the sake of completeness, I give the rival calculation: 60 x 1469.664 divided by 70 10/77 results into 1257.3792 m or 4125 English feet. In this case 77 Roman miles equal 90 Anglo-Saxon miles. However, this variant of the Anglo-Saxon mile is 25/32 of the English statute mile, which is less probable than $^{3}/_{4}$. Finally, this variant was dropped because it was impossible to find an acceptable subdivision. Summary: The practical length of the Anglo-Saxon mile in the metric system is 1207 m; the theoretical length is 3960 English feet = 4620 Anglo-Saxon feet; its hypothetical subdivision is 7x40x16$^{1}/_{2}$, which I suggest on the analogy of the subdivision 8x40x16$^{1}/_{2}$ of the statute mile. Finally, it is easy to see that such an inquiry is fruitless if one uses practical values. How is one to show that 70 1/7 is a rounding of 70 10/77 and how to choose objectively between the alternatives? In 1994, with much more evidence than presented here, I tried already to get the so-called Roman foot of 29.6 cm out of the way (de Zwarte 1994, 126-128, 142). On p. 142 of that study I dealt with the connection of the French *pied de roi* why this foot-standard was brought into being. Such a small reduction of the Ionic foot seems futile, but it cannot be ignored[39].

To summarize: It is a notorious fault of many architectural studies – that is, the metrological part of it on which the study is founded – to treat probabilities as facts. It is urgently necessary that we proceed to study Greek architecture, without being hampered by false axioms. In this study I have collected a large quantity of evidence that permits the conclusion that Greek architects mainly used two standardized measures of length, the Ionic foot of 29.86 cm and the Attic foot of 32.66 cm. Certainly, in Athens and at Paestum both the Ionic and the Attic standard were in use.

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[39] One square Roman foot = $(29.394 \text{ cm})^2$ = 864.007.. cm^2 (de Zwarte 1994, 127). I cannot resist making it exactly 864 cm^2 as Roman landsurveyors working in Campania used the formula 8640 square Roman feet = 1 vorsus = 10000 square Campanian feet. See Hultsch 1882, 671 (after Hyginus, *de condic. agr.* 121, 25 and additional information after Varro, *de re rustica* I 10 and Frontinus, *de limit.* 30). A calculation gives the approximate length of the Campanian foot-standard: about 27.32 cm. Another bit of evidence – see Dörpfeld 1885, 291, also after Hyginus (*de condic. agr.* 340) – might furnish the clue to the exact length of the Campanian foot. In some parts of Italy the Roman surveyors found a limitation with pickets placed at distances of 94, 375 and 470 Roman feet. Dörpfeld, following Nissen, concluded that the result of the survey stood for 100, 400 and 500 Italian feet. The irregularity is puzzling: 5 x 94 = 470 but 4 x 94 = 376, not 375. If we exclude the possibility of error in copying the original text, a possible explanation is that 375 is exact due to chance. If so, the older foot = 375/400 x 29.394 = 27.56 cm or exactly 15 Roman dactyls. Unfortunately, if it is indeed an accidental result, it cannot be used for dating purposes with regard to the Roman foot. The remain of a limitation at Metapontion in Lucania presents good evidence for a foot length slightly over 27 cm, but the limitation dates from the middle of the sixth century BC (Heimberg 1985, 279-281). For that reason I stick to the metric length of 27.56 cm but explain it as $13^1/_2$ dactyls on the Attic standard at 32.66 cm. Again by chance the length of my own foot is about 27.5 cm, so the Italian foot may be termed a natural foot, which is especially of use in agrarian communities. Mainly in studies of houses at Pompeii and Herculaneum, architectural historians use the designation Oscan foot, which refers to Frontinus (Hultsch, 1882, 671) who says that a square with side of 100 feet was called vorsus with the Oscans and

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