Reconstructing Building Height:
the Early Hellenistic *Hestiatorion* Propylon at Epidauros

Jari Pakkanen

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Summary

The extensive building at the southern part of the sanctuary of Asklepios at Epidauros is often referred to as a Gymnasium, but it is more likely a Banqueting Hall (*hestiatorion*); partial restoration of its monumental Propylon was finished in 2009. In the restoration proposal the estimate of the building height was based on three factors: the average height of the column drums, the height of the wall blocks and a proposed foot-unit of 0.3018 m. This paper demonstrates that the suggested height of the Doric column of 7.1677 m can be questioned. Using computer-intensive statistical methods for determining the 95% confidence intervals for the column drum and wall block height plus analysing the column shaft profile, it is possible to show that the more likely range for the column height is 7.84–7.92 m and that the shafts were constructed with a slight entasis. It can also be demonstrated that the foot-standard of 0.3018 m identified as the basis of the structure's overall dimensions is statistically insupportable. The proportional height of the column becomes 6.5–6.6, rather than 5.9, lower column diameters, which is more in keeping with other Doric buildings from the Early Hellenistic period.

Introduction

The large, rectangular building (75.36 × 69.53 m) at the southern edge of the excavated area of the Asklepieion at Epidauros was first discovered by P. Kavvadias at the end of the nineteenth century.[1] The main features of the Early Hellenistic building are a monumental propylon in the north-western corner and a large peristyle court surrounded by several large and also smaller backrooms (Figure 1). In the Roman period, an odeion was constructed within the peristyle court. Kavvadias identified the original building complex as a gymnasion, but as R. A. Tomlinson has convincingly argued, the building is more likely a ἑστιατόριον, a banqueting hall.[2] L. Palaiokrassa's recent excavations at the site support this identification, and on the basis of the pottery and coins, the building can be dated to the end of the fourth century BC.[3] K. Danali-Giole's excavations at the Propylon show that the monumental entrance is later than the foundations of the north wall of the Hestiatorion, but this seems to be only a different phase of the same construction programme: archaeological finds and architectural characteristics support that the Propylon should also be dated to the end of the fourth century BC.[4]

[1] Kavvadias 1900, 143–154; see also Kavvadias 1891, 26; 1892, 55; 1899, 105, pls. 5–6; 1901, 49–51; 1904, 61–62, pl. A.
[2] Tomlinson 1969, 106–112.
[3] Palaiokrassa 1988, 22–23, 32.
[4] Danali-Giole 1988, 36–37; Kyriaki 1988, 44.

In connection with the proposal to partly restore the Propylon, V.E.E.S. Kyriaki has carefully studied and published the remaining architectural material.[5] In her reconstruction the main building of the Propylon has six prostyle Doric columns on the northern facade with short flank walls on the east and west (Figure 2). The building is entered via a ramp passing through the central bay of the colonnade which is widened to three metopes instead of two, like at the Propylaia of the Athenian Acropolis. This main porch of the Propylon is separated from a narrower vestibule to the south by two Ionic columns.[6] The recently completed restoration project includes reconstructing two of the exterior Doric columns and part of their entablature (Figure 3).[7]

Even though Kyriaki's reconstruction of the Propylon height is challenged in this paper, I wish to stress that the conclusions presented here would not have been possible without her exemplary fieldwork. Her published numerical data is entirely the basis of this study, and the new building reconstruction is directly generated from that data. This paper will also critically examine some of the methods which have traditionally been used to determine the sizes of various elements of Greek buildings. Again, it is Kyriaki's thorough study and precise data that allows the application of analytical statistical and computer-intensive processes which in this case prove to give a significantly different result than those previously achieved.

Determining the Building Height

Kyriaki's estimate of the building height is based on the average height of the column drums, the height of the wall blocks and Kavvadias' foot-standard of 0.3018 m.[8] In the following arguments the relevance of these three different components are scrutinized in detail and a fourth element, the analysis of the shaft profile, is introduced.

Column Height

At the site there are 16 surviving poros limestone drums which can be used in the column reconstruction. Their dimensions are given in Table 1; the diameter measurements listed are the smaller drum diameters measured between recesses of two opposite flutes.[9] The drums vary in height which gives rise to the main problem of establishing the order height: the variation is significant with the shortest being 0.568 m and the tallest 0.646 m. If the shafts consisted of 11 drums, as Kyriaki proposes,[10] 24% of the original 66 drums have been preserved; if the columns were taller with 12 drums, 22% of the shafts' 72 drums have been located at the site. As we shall see below, the height variation and the limited number of preserved drums makes it impossible to precisely determine the column shaft height.

Instead of trying to calculate the shaft height based on the average drum height, which is the usual approach in studies of Greek architecture, classical statistics could be used to construct a confidence interval, or probable range, for the shaft height. However, there are two conditions which must be met before this may be attempted: the original population must be normally distributed – in other words, the drum height distribution should follow the bell-shaped Gaussian curve – and the sample must be random.[11] Unfortunately, in the case of the Hestiatorion columns neither of these conditions is satisfied. We have no certain indication if the original drum heights were normally distributed, and the group of surviving drums cannot

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5 Kyriaki 1988, 64–158.
6 Kyriaki 1988, 64.
7 Kyriaki 1988, 159–162, 165–169, pls. 102–110.
8 Kyriaki 1988, 121, 150 n. 55.
9 The drums at Epidauros are very fragmentary, so measuring between the recesses of opposing flutes gives more reliable data than attempting to extrapolate the dimensions of the broken arrises of Doric column drums.
10 Kyriaki 1988, 118.
11 See *e.g.* Siegel – Morgan 1996, 322.

be regarded as a random sample because the preservation of column drums at Epidauros or anywhere else is never a random process.[12] There are, however, computer-intensive statistical approaches which can be used in cases of non-normal and non-random data. One of these, the bootstrap-*t* method,[13] is employed in this study to determine the height ranges for different architectural elements.[14] D. Scahill has criticised the use of bootstrap confidence intervals since it produces a wider size range for the studied elements than the traditional means of deriving the height of a building.[15] However, this criticism misses the principal reason why the use of computer-intensive statistical methods should be advocated: their advantage lies in avoiding the false precision which is most often inherently part of the traditional approaches.

The 95% bootstrap confidence interval for the drum mean height can be calculated as 0.596–0.617 m; with the 95% confidence interval we can be 95% sure that the mean drum height is within defined range.[16] The column height range of the shaft with 11 drums is *c.* 7.07–7.30 m and with 12 drums *c.* 7.67–7.92 m.[17] Kyriaki's suggestion for the column height 7.1677 m[18] is expressed in far too many significant digits (it is not possible to reconstruct the height of an ancient column with the precision of even a millimetre), but it is within the first range. However, based on the preserved drums the height of the column cannot with any statistical

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[12] *Cf.* Shennan 1997, 61: 'It is obvious that no archaeological sample can be considered a random sample of what was once present'.

[13] B. Efron, the inventor of the bootstrap method, describes the etymology of the term as follows: 'The use of the term bootstrap derives from the phrase *to pull oneself up by one's bootstrap*, widely thought to be based on one of the eighteenth century Adventures of Baron Munchausen, by Rudolph Erich Raspe. (The Baron had fallen to the bottom of a deep lake. Just when it looked like all was lost, he thought to pick himself up by his own bootstraps.)' The *t* in the name of the bootstrap-*t* method refers to Student's *t* intervals; Efron – Tibshirani 1993, 5, 158–162. The basic principle behind the bootstrap techniques is that the existing samples provide the best guides to the population distributions (here all the original drums and wall blocks of the Propylon); technically, this means taking several random resamples of the samples with replacement in order to approximate, in this case, confidence intervals for the drum and block heights.

[14] Bootstrap methods should be tested before they are used in new applications; on the bootstrap-*t* method, see *e.g.* Efron – Tibshirani 1993, 160 n. 1; on the bootstrap methods in general, see *e.g.* Manly 1997, 58–59. I have used computer simulation to evaluate the performance of bootstrap-*t* intervals in connection with column drum data; see Pakkanen 1998a, 52–56 for a discussion of classical and computer-intensive statistical methods, their applicability to architectural studies, and further references to statistical studies. For a recent overview of the archaeological use of bootstrap, including an evaluation of the Tegea column analysis presented in Pakkanen 1998a, 53–54, see Baxter 2003, 148–153. A reply to Baxter's noted discrepancy of 2 mm at Tegea is in Pakkanen 2013, 64 n. 52.

[15] Scahill 2012, 95, esp. n. 133. Pfaff 2003, 84 discusses the various methods of determining the column height of the Classical temple at Argive Heraion, including bootstrap confidence intervals, and he accepts that the specific height used in the restoration drawings is 'impossible to prove decisively'.

[16] On applying the method, see Pakkanen 1998a, 53–54. The formula used to calculate the *t*-statistic is $T_B = (\bar{x}_B - \bar{x}) / (s_B/\sqrt{n})$, where $\bar{x}_B$ and s_B are calculated from each bootstrap sample; $\bar{x}$ is the sample mean (= 0.6079 m), and n is the sample size (= 16). The minimum of the generated 5,000 t_B values is –4.1897 and the maximum 5.4430; the values limiting 95% of the distribution are $t_{\alpha/2} = 2.4704$ and $t_{1-\alpha/2} = -1.9915$. The confidence interval can thus be calculated as

$$\bar{x} - t_{\alpha/2}\ \left(s/\sqrt{n}\sqrt{(N-n)/N}\right) < \mu < \bar{x} - t_{1-\alpha/2}\ \left(s/\sqrt{n}\sqrt{(N-n)/N}\right),$$

where s is the sample standard deviation (= 0.02154) and N is the population size (= 66). Since the *t*-statistic T_B was calculated without using finite population correction factor, it is justified to introduce it in the confidence interval calculations; on the factor, see Pakkanen 1998a, 52 n. 8. On random numbers used in the generation of the t_B values, see Pakkanen 1998a, 54 n. 15.

[17] The lower limit of the column height with 11 drums can be calculated as $11 \times 0.5964 + 0.511$ (capital height; Kyriaki 1988, 118) ≈ 7.071 m, and the upper as $11 \times 0.6173 + 0.511 \approx 7.301$ m. The drum height range for a column with 12 drums can be calculated using the formulae above (supra n. 16): the slight increase in the population size N from 66 to 72 does not significantly alter the drum height range. $12 \times 0.5962 + 0.511 \approx 7.665$ m; $12 \times 0.6174 + 0.511 \approx 7.920$ m.

[18] Kyriaki 1988, 121.

validity be defined more precisely than the above ranges.

Wall Height

A reconstruction of the building height can also be attempted on the basis of the wall blocks. The entablature carried by the columns turns at the corners to form the top part of the flank walls, and, therefore, the wall height below the architrave is necessarily the same as the column height. The lower part of the wall comprises an orthostate course and a number of ashlar wall block courses. None of the orthostates preserve their full height, but the height can be reasonably well derived from other parts of the Hestiatorion wall as 1.11 m.[19]

Kyriaki gives the height of 47 wall blocks: their height varies between 0.380 m and 0.417 m.[20] Based on the available information, the 95% bootstrap confidence interval for the mean wall block height can be determined as 0.396–0.401 m.[21] The height range of the wall with 15 courses and the orthostate is *c.* 7.05–7.12 m, with 16 courses *c.* 7.45–7.52 m, and with 17 courses *c.* 7.84–7.92 m.

Figure 4 presents a summary of the column and wall height analysis: the confidence intervals determined for the 11-drum column and 15-block wall reconstruction are partially overlapping (7.07–7.12 m), and the height range with 17 wall block courses (7.84–7.92 m) is completely within the confidence interval of the 12-drum column shaft. It is within one of these two ranges that the Propylon column and wall height is most probably situated. It should be noted that the currently proposed restored height of 7.1677 m does not fall within either of these ranges.

Foot-unit

Kyriaki's 'exact' column height of 7.1677 m is based solely on Kavvadias' foot-unit: expressed in terms of the 'constructional podas' of 301.8 mm it is $23\frac{3}{4}$ feet.[22] The critical factor in this calculation is the reliability of Kavvadias' suggestion for the foot-standard, but the length of this unit is accepted as *given* by Kyriaki. It is clearly different both from the traditional 'Ionic foot' of *c.* 294 mm and the 'Doric foot' of *c.* 326 mm. W. B. Dinsmoor argues that only these two were used in Greek architecture,[23] but this should by no means taken as granted. J. J. Coulton's skeptical remark makes the point clear: 'As far as measurement is concerned, the assumption that only two foot-standards were used throughout the Greek world needs to be proved, not just accepted, and the chaotic situation in other branches of Greek metrology suggests that this is unfounded'.[24] Therefore, Kavvadias' proposal should be given more careful consideration.

In his monograph on the sanctuary published in 1900, Kavvadias derives the length of his foot-unit from the length of the stadium dromos which is known to be 600 feet. On two sides he measures it as 181.08 and 181.30 m, and on the basis of four preserved distance markers it can be calculated as 180.95 m. Kavvadias then uses the average of the minimum and maximum values to calculate the foot-length as 301.8 mm[25] (actually, the correct result is closer to 301.9

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[19] Kyriaki 1988, 121–129.
[20] Kyriaki 1988, 156–158. Wall block 4268 with a height of 0.359 m (table 7) is omitted from the calculations because it is clearly an outlier.
[21] The following values can be substituted to the formula above (supra n. 16): $\bar{x}$ = 0.3984 m, n = 47, $t_{\alpha/2}$ = 1.9624, $t_{1-\alpha/2}$ = –2.1181, and s = 0.00825. There were probably alternatively 29 and 30 blocks in each course (the estimate is based on the percentages of preserved wall blocks given in Kyriaki 1988, 125). In the calculations the following values are used for the total number of blocks N: 15 courses N = 442, 16 courses N = 472, and 17 courses N = 501.
[22] Kyriaki 1988, 121.
[23] Dinsmoor 1961, 355–368.
[24] Coulton 1974, 62; 1975, 85–89. For a recent critical evaluation of Greek foot-standards and their use in architectural studies, see Pakkanen 2013, 11–12.
[25] Kavvadias 1900, 108–109.

mm). Kavvadias reports the dimensions of the Hestiatorion (or 'Gymnasium') as 75.57 × 69.53 m. He recognizes its length as 250 stadium feet, because according to his calculations 250 × 0.3018 = 75.58 m, a discrepancy of a mere centimetre.[26] In reality, the discrepancy between the two dimensions is much larger, 0.12 m, due to a multiplication error: the correct product of 250 × 0.3018 m is 75.45 m. In an excavation report published one year later, Kavvadias corrects the building length to 75.36 m but does not comment on the foot-standard.[27] It is obvious that even if Kavvadias has correctly derived the length of the stadium foot-unit,[28] the connection between this unit and the Hestiatorion cannot be established as easily as Kavvadias suggests.

In general, is it possible to establish the length of the foot-standard from the major dimensions of the Hestiatorion? It is completely feasible that the length and width of the building were designed to be round numbers of feet, because there are no immediate factors limiting its size in the sanctuary.[29] The exterior walls of the complex are plain and the design of its major dimensions does not include the intricacies of laying out a surrounding colonnade.[30] However, we should remember that the correct discovery of such a foot-unit is doubly clouded by the possibility of imperfect execution of the original building design[31] together with the inevitability of modern measurement error.[32] Therefore, I have adopted an error estimate of ±25 mm[33] for the measurements which transforms the single figures into ranges (length 75.335–75.385 m, width 69.505–69.555 m).

A single statistical figure, sum of squared discrepancies, can be used for evaluating how well a suggested foot-unit fits to the data. For example, the closest fit for Kavvadias' foot-length of 301.8 mm is given by 250 by 230 feet. However, both of these are clearly off the mark: 250 × 0.3018 = 75.450 m, which is 65 mm more than the upper value of the measurement range of 75.385 m, and 230 × 0.3018 = 69.414 m, which is 91 mm short of the lower limit of 69.505 m. The sum of squared discrepancies can be calculated as $65^2 + (-91)^2 = 12{,}506 \text{ mm}^2$. The usefulness of the approach becomes apparent when the measurement fit is calculated for all the 'foot-unit' lengths within the range 280–360 mm and the result is drawn as a graph (Figure 5). The step used in the calculations is 0.1 mm, so that the first unit is 280.0 mm, the second 280.1 mm, and so on until 360.0 mm is reached.[34]

In Figure 5 the best fitting foot-units are indicated by zero discrepancies, or where the curve actually touches the *x*-axis: the first is just to the left of 290 mm and the last at *c.* 346 mm. Kavvadias' foot-unit with a sum of squared discrepancies of *c.* 12,500 mm^2 is among the poorly fitting units. The best fitting cases with zero discrepancies are presented in Table 2. It is interesting that only a 'foot-unit' of *c.* 290 mm produces a round number for both the length and the width, 260 by 240 feet. However, since we cannot be sure that the architect designed the

[26] Kavvadias 1900, 143, esp. n. 1.
[27] Kavvadias 1901, 49; 75.36 × 69.53 m are also the dimensions given in Palaiokrassa 1988, 21.
[28] Rather than giving a single figure for the stadium foot-unit, it would be more correct to give a range based on the minimum and maximum lengths of the stadium: the length of the unit can thus be defined as 301.6–302.2 mm (180.95 / 600 ≈ 0.3016 m; 181.30 / 600 ≈ 0.3022 m).
[29] See Tomlinson 1983, fig. 4 for a general plan of the sanctuary with the most prominent geographical features.
[30] *Cf.* Dinsmoor 1961, 356.
[31] Coulton 1975, 89–98.
[32] Kavvadias' two values for the Hestiatorion length differ by 0.21 m over the length of *c.* 75.5 m; the variation is *c.* 1/360, where good modern surveying should reduce the measurement error to less than ±5 mm (*c.* 1/7500).
[33] ±25 mm (*c.* 1/1500) is still moderately good traditional surveying.
[34] Even though a step of 0.1 mm is used in determining the possibly fitting foot-standards, I do not suggest that the unit could be determined that accurately: rather, minimizing the length of the step makes certain that no possibly fitting units are omitted from the analysis. I implemented the program used in the foot-unit analysis on top of statistical program Survo 98. I have recently advocated the use of cosine quantogram analysis in the study of archaeological metrological patterns and proportions (see Pakkanen 2011 and 2013 for case studies and references to earlier publications). However, using the sum of squared discrepancies is also a perfectly valid method of evaluating the question at hand.

building plan using round numbers, the question of the Hestiatorion foot-unit remains open. What is certain is that Kavvadias' stadium foot-standard of 301.8 mm cannot be used to establish the exact height of the column.

Shaft Profile

As we have seen above, based on the column drum and wall block heights, there are two possible ranges for the column height (7.07–7.12 m and 7.84–7.92 m; see also Figure 4). In this section the column shaft profile is analyzed in order to see whether one of the height ranges should be preferred over the other. Whether the column shafts had entasis or not is certainly among the most important factors involved in reconstructing a Doric column.[35] As background it should be noted that entasis is a regular feature of fourth-century Doric architecture in the Peloponnese and Delphi: in fact, the columns of all buildings which are preserved well enough for the matter to be evaluated have entasis. There is also a tendency to place the maximum projection of the entasis in the middle of the shaft.[36]

Figure 6 presents on the left the shaft profile based on Kyriaki's suggested reconstruction:[37] the height of the shaft is modified so that the total height of the column is within the range determined for the 11-drum and 15-wall-block reconstruction (7.07–7.12 m; the shaft height of 6.58 m in Figure 6 corresponds to a 7.095 m high column with the capital). The *x* and *y* axes are drawn at different scales in order to make the profile more discernible: the scale for *x* axis is ten times greater than for *y* axis. The five missing drums are indicated by dotted lines in the drawing, and their average height, 0.595 m, is approximated by dividing by five the gap left by the preserved drums.[38] The shaft profile is slightly s-shaped, which is due to the method of reconstructing the two missing bottom drums: the tendency of the top nine drums is quite clearly curving, but the bottom drums force the curve back to almost a straight line.

The unlikelihood of the 11-drum shaft profile is easily corrected by adding one drum to the bottom of the shaft. Kyriaki uses the drum 4508 with an upper diameter of 1.144 m for her second shaft reconstruction,[39] but there is a no reason why it could not be from the first. The lower diameter of this drum cannot be measured, so Kyriaki's estimate is based on the average drum diminution of 22 mm.[40] If the shafts had entasis, however, the diminution is not constant: the taper is slight in the lowest drums and gradually increases towards the top of the column. In fact, it is not necessary to make any assumption about the amount of diminution, since enough information is provided by the preserved drum dimensions to establish, in the first place, that the shaft profile was curving, and in the second, the mathematical formula of the best-fitting curve to the data; for the latter, a method called non-linear regression can be used. The measured drum dimensions used in the estimation of the curve formula are plotted as circles in Figure 6; the 12-drum shaft height of 7.37 m on the right of the figure corresponds to the mid-point of the column height range 7.84–7.92 m with the capital height (0.511 m) subtracted,

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[35] Kyriaki does not introduce entasis to the taper of her straight 'ideal column', so the curving profile of the shaft is not taken into account in the reconstruction proposal, perhaps for simplicity's sake; Kyriaki 1988, 118, 155 table 3.

[36] The fourth-century Tholos at Delphi, the fourth-century temple of Athena at Delphi, the Tholos at Epidauros, the temple of Athena Alea at Tegea, the temple of Apollo at Delphi, the treasury of Kyrene at Delphi and the temple of Zeus at Nemea; see Pakkanen 1997, 323–344. Scahill (2012, 99–105) shows that the columns of the South Stoa at Corinth were also constructed with entasis, even though the fragmentarily preserved drums do not allow for a precise evaluation of its characteristics.

[37] Kyriaki 1988, 155 table 3, 165.

[38] [6.58 – 0.568 (drum 4451) – 0.602 (drum 4338) – 0.582 (drum 4249) – 0.646 (drum 4307) – 0.591 (drum 4147) – 0.614 (drum 4146)] / 5 = 0.5954 m.

[39] Kyriaki's second column reconstruction is not discussed in detail in this paper, since there hardly is enough evidence for a reliable reconstruction: from the middle of the shaft five out of six drums are missing; Kyriaki 1988, 155 table 3, 165.

[40] Kyriaki 1988, 118.

and the average height of the missing drums is estimated as *c.* 0.627 m.[41] When a parabola is fitted to the data,[42] the lower diameter of the bottom drum can be calculated as 1.160 m,[43] a dimension 6 mm less than Kyriaki's suggestion. The 12-drum reconstruction of the shaft produces a smoothly curving profile with an entirely plausible maximum entasis of *c.* 9 mm in the middle of the shaft.[44]

Comparison of the 11- and 12-drum shaft profiles strongly suggests that the taller reconstruction should be preferred over the shorter one. The s-curve of the 11-drum alternative (on the left in Figure 6) could be corrected by reconstructing two more slender lower drums, but this leaves no place for drum 4508 in the scheme. The possibility that the drum would belong to a thickened angle column is quite likely excluded by the preservation of a corner capital which has the same diameter as the four top drums.[45] With the 12-drum column and 17-course wall favoured, the height of the Hestiatorion Propylon column and the wall below the architrave can be established as 7.84–7.92 m, which is the overlapping range of the 95% bootstrap confidence intervals of these two elements. This is 0.67–0.75 m higher than the previously proposed reconstruction of 7.1677 m.[46] Figure 7 presents the elevation of the building facade restored with these 12-drum columns. The new height also changes significantly the proportions of the building.

Column Proportions

Column dimensions and proportions of some fourth and third-century Doric buildings are listed in Table 3. The lower diameter of the Propylon column at the arrises can be estimated as *c.* 1.20 m (if the depth of the fluting is correctly reconstructed as 20 mm,[47] the lower diameter can be estimated as $1.16 + 2 \times 0.02 = 1.20$ m).[48] The new proportional height of 6.5 to 6.6 lower

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[41] Average height of the missing drums: [7.37 – 0.568 (drum 4451) – 0.602 (drum 4338) – 0.582 (drum 4249) – 0.646 (drum 4307) – 0.591 (drum 4147) – 0.614 (drum 4146) – 0.634 (drum 4508)] / 5 = 0.6266 m. The average height is slightly greater than in the 11-drum reconstruction (0.595 m).

[42] In the regression I have used the estimate-operation of the statistical software Survo 98: ordinary least squares approximation is used in the estimation process and the Davidon–Fletcher–Powell variable metric method in the minimization of the residual sum of squares; see Mustonen 1992, 178–196.

[43] The data points used in the non-linear regression can be presented as coordinate pairs; the x coordinate is the drum diameter and the y coordinate is the approximated shaft height. The pairs are as follows: (1.144, 0.634); (1.113, 1.888); (1.093, 2.502); (1.075, 3.129); (1.056, 3.720); (1.034, 4.366); (1.013, 4.948); (0.967, 6.202); (0.942, 6.804); (0.920, 7.372). The estimated model is parabola $(y - y_0)^2 = a \times (x - x_0)$, and the estimated parameters are $x_0 = 1.2626$ (standard error 0.0112), $y_0 = -8.9193$ (0.6732), and $a = -772.84$ (39.68). The bottom diameter x can be calculated as 1.160 m by solving the above model equation with respect to x and giving $y = 0$; correspondingly, the missing drum diameters can be estimated as 1.129 m (top diameter of the second drum, $y = 1.261$) and 0.991 m (ninth drum, $y = 5.575$). The bottom diameter of the shaft is not notably dependent of the estimated conic section. I have tested this by fitting an arc of a circle to the data: the fit is poorer, but the result is different only by a millimetre (1.161 mm).

[44] The amount and position of maximum entasis is calculated by fitting a curve to the shaft profile points and locating its greatest distance from the line connecting the bottom and top of the shaft; on the method, see Pakkanen 1997, 323–336; 1998a, 62–67.

[45] Kyriaki 1988, 118, 149 ns. 40–41, 155 table 3. Drum 4508 was actually excluded from the finished anastylosis of the two corner columns (see Figure 3).

[46] In light of the conclusions of this paper, some questions regarding the executed restoration of the two Propylon columns and entablature can be raised: the first is whether the eight centimetre range for the column height would have been precise enough for restoration purposes and the second is whether there was enough original material for restoring the columns. The new 12 drum-reconstruction also diminishes the proportion of surviving material. These issues were brought to the attention of the restoration team in 2000. The physical restoration finished in 2009 at Epidauros uses 11 drums in the column shaft and 15 wall blocks between the orthostates and the architrave level.

[47] Kyriaki 1988, 118.

[48] This could perhaps leave space for an additional 13th drum at the bottom of the shaft, since the width of the top of the stylobate is 1.265 m (Kyriaki 1988, 149 n. 42) and the maximum lower diameter of the hypothetical drum can be calculated as 1.200 + 0.016 (taper of the lowest drum in the 12-drum reconstruction) = 1.216 m. The

diameters is significantly different from Kyriaki's suggestion of 5.94 lower diameters,[49] but it is perfectly normal in fourth and third-century Doric contexts (see col. *G* in Table 3).[50] Also the taper and entasis proportions of the Hestiatorion Propylon columns fit well to comparative material from other Doric buildings (see cols. *H–J*).

Conclusions

Using statistical analysis of the preserved architectural block dimensions together with mathematical modelling of the column shaft curve, it has been demonstrated that the column of the Hestiatorion Propylon at Epidauros should be restored with 12 rather than the executed anastylosis with 11 drums. Due to the small number of preserved blocks, the height of the column and the wall below the architrave cannot be defined more precisely than as being within the range 7.84–7.92 m. The previously restored *exact* height of the column of 7.1677 m is determined solely on the basis of a predefined foot-standard of 0.3018 m: it can be shown that Kavvadias' argument connecting this unit to the Hestiatorion is invalid and, therefore, it cannot be used in the column height reconstruction. Furthermore, in the age of highly advanced digital technologies for three-dimensional reconstructions it can be questioned whether physical anastylosis programmes of ancient architecture should proceed in cases where the material is as fragmentary as at Epidauros.

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The first drafts of this paper were written as long ago as in 1999–2000. I gave the manuscript to the Committee for the Preservation of the Epidauros Monuments and after discussions with V.E.E.S Kyriaki and VasilisbLambrinoudakis I agreed that before proceeding with the publication I will give them time to finalise the studies on the Propylon and publish the final restoration proposal. Only details of the paper have been changed in the final editing and some references added.

I wish to thank Richard Anderson for thoroughly reading and discussing the first manuscript of this paper. Also, the comments I received in 2000 from Richard Tomlinson, Manolis Korres and Michael Djordjevitch were very valuable.

possibility is not considered further in this paper because no traces of a larger drum have been discovered at the site.

[49] Kyriaki 1988, 120; due to the new lower column diameter of 1.20 m, Kyriaki's suggestion should be modified to 5.97 lower diameters.

[50] When I wrote this footnote in 2000, it read as follows: 'It is rather the unusually robust columns of the South Stoa at Corinth which require explanation, suggesting that further fieldwork is perhaps required to determine whether the columns of the building have been correctly reconstructed.' Broneer's (1954, 30–32) column height is only 5.71 m, but as Scahill's (2012, 85–99) recently published work on the Stoa demonstrates, the height should be restored most likely as *c.* 6.4 m (and in any case as more than 6.0 m).

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Table 1. Column drum dimensions.
Based on Kyriaki 1988, 155, table 3.

No.	UD	LD	H
4099	0.920	0.935	0.574
4451	0.920	0.940	0.568 (0.566–0.569)
4261	0.92	0.95	0.612
4340	0.93	0.96	0.616
4569	0.940	0.966	0.629
4338	0.943	0.968	0.602 (0.600–0.604)
4060	0.96	0.994	0.609
4084	0.972	1.000	0.625
4249	1.013	1.035	0.582 (0.580–0.583)
4144	–	1.055	0.616
4307	1.034	1.056	0.646
4098	1.049	1.066	0.613 (0.610–0.615)
4147	1.056	1.075	0.591 (0.590–0.592)
4146	1.093	1.113	0.614
17017	1.121	1.141	0.596
4508	1.144	–[51]	0.634

Table 2. Best fitting foot-units and
Hestiatorion main dimensions.

foot-unit (mm)	dimensions in feet
289.8	260 × 240
290.9	259 × 239
291.0	259 × 239
292.1	258 × 238
293.3	257 × 237
305.0	247 × 228
306.3	246 × 227
306.4	246 × 227
307.6	245 × 226
322.0	234 × 216
323.4	233 × 215
323.5	233 × 215
324.8	232 × 214
324.9	232 × 214
340.9	221 × 204
342.5	220 × 203
342.6	220 × 203
344.1	219 × 202
344.2	219 × 202
345.8	218 × 201

[51] Even though 1.166 m is given as the lower diameter in the table, it is clear from Kyriaki 1988, 118 that the dimension could not be measured, it is only estimated on the basis of average drum diminution – a method which is only valid if the shaft did *not* have entasis.

Table 3. Column dimensions and proportions of mid-fourth to early third century B.C. Doric architecture. Dimensions in cols. *A*–*F* are given in meters.

	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*
Epidauros, Tholos (11/12 drums)[52]	6.9 / 7.5	6.5 / 7.1	0.998	0.772 / 0.750	0.01	3.4 / 3.4	6.9 / 7.5	3.5 / 3.5	0.15 / 0.14	0.48–52
Tegea, t. of Athena Alea[53]	9.544–80	8.952–77	1.55	1.21	0.011	4.3–4.7	6.16–18	3.79–80	0.12	0.48–53
Delphi, treasury of Kyrene[54]	3.86	3.64	0.556	0.458	0.008	2.0	6.94	2.69	0.22	0.56
Nemea, t. of Zeus[55]	10.33 (9.55)	9.70 (9.00)	1.63 (1.404)	1.307 (1.112)	(0.013)	(4.6)	6.342	3.33	(0.14)	(0.51)
Pergamon, t. of Athena Polias[56]	5.25	4.95	0.754	0.605	0.008	2.6	6.96	3.01	0.16	0.53
Epidauros, Hestiatorion Propylon	7.84–92	7.33–41	*c.* 1.20	*c.* 0.955	0.009	3.6	6.5–6	3.3	0.12	0.49
Corinth, South Stoa[57]	*c.* 6.4	*c.* 6.0	0.96	0.794	*exists*		6.7	2.8		
Lindos, t. of Athena Lindia[58]	5.60	5.24	0.87	0.685			6.4	3.5		
Delos, Dodekatheon[59]	4.62	4.37	0.69	0.566	0.005	2.2	6.7	2.8	0.11	0.51
Thasos, NW Stoa[60]	5.16	4.85	0.742	0.595			7.0	3.03		

A. Column height
B. Column shaft height
C. Lower diameter of the shaft at the arrises
D. Upper diameter of the shaft at the arrises
E. Maximum entasis
F. Height of maximum entasis
G. Proportional height of the column: *A* / *C*
H. Taper of column shaft (%): 100 × (*C* – *D*) / *B*
I. Proportional emphasis of maximum entasis (%): 100 × *E* / *B*
J. Proportional position of maximum entasis in the shaft: *F* / *B*

[52] Pakkanen 1997, 327–329.
[53] Pakkanen 1998, 73, app. D.
[54] For dimensions in cols. *A*–*D*, see Bousquet 1952, 46–48; for entasis, see Pakkanen 1997, 332–334.
[55] Pronaos column dimensions used to calculate the entasis proportions are given in parentheses. For dimensions in cols. *A*–*D*, see Hill – Williams 1966, 9–10, 22; for entasis of the pronaos column, see Pakkanen 1997, 334–336.
[56] For dimensions in cols. *A*–*D*, see Bohn 1885, 11; for entasis, see Pakkanen 1998b, 155–156. Radt 1988, 22, 179 dates the building to *c.* 330–320 B.C. on historical reasons, but traditionally it has been dated to early 3rd century; see e.g. Gruben 2001, 464.
[57] Broneer 1954, 30–32; Scahill 2012, 86–99. For the date of *c.* 300 B.C., see Williams – Fischer 1972, 171; Scahill 2012, 286–289.
[58] Dyggve 1960, 87, 110.
[59] On the column reconstruction, see Pakkanen 2000.
[60] Martin 1959, 14–17, 47.

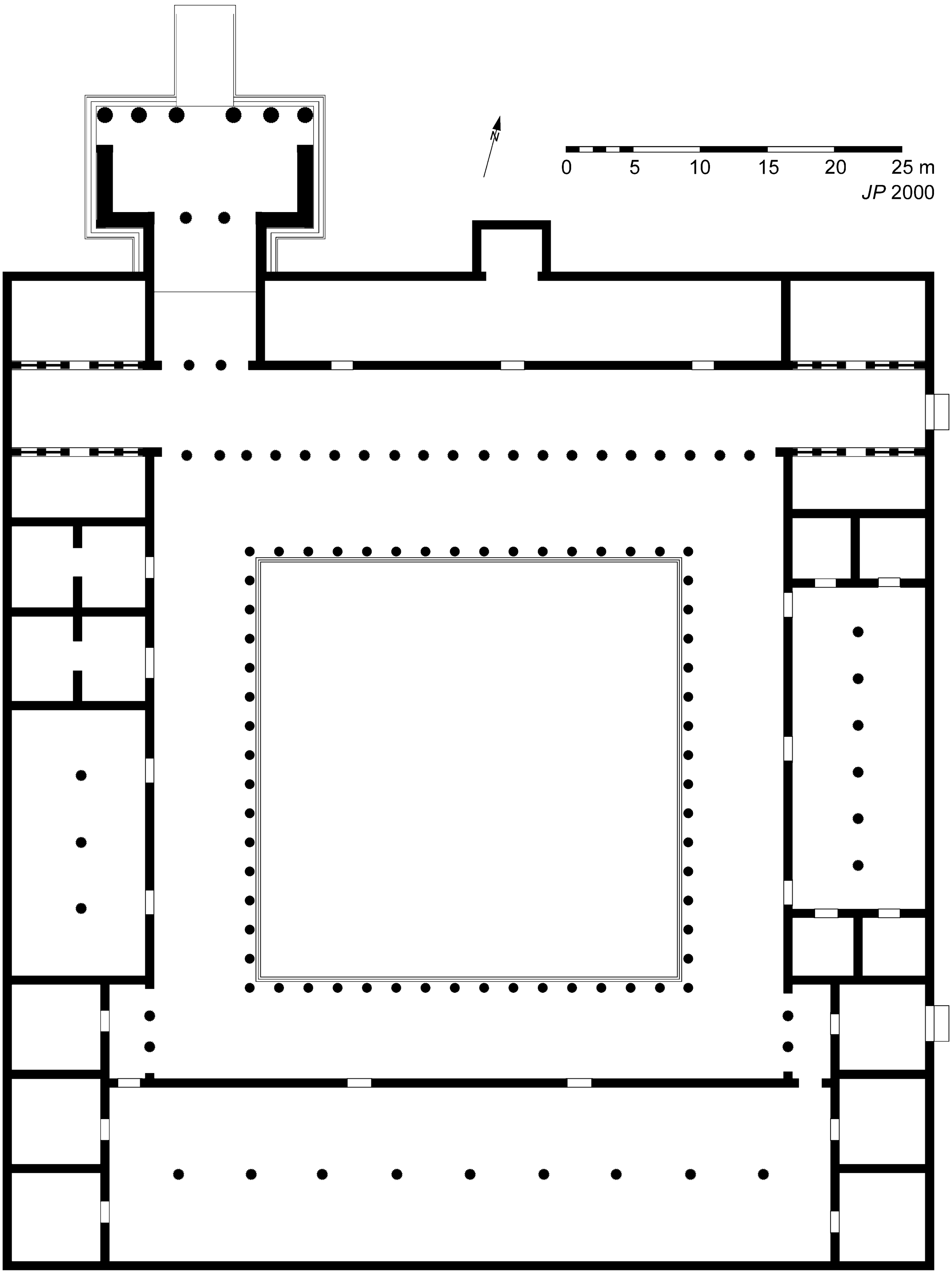

Fig. 1. Hestiatorion, Epidauros. Restored plan (J.P. based on Committee 1988, pl. 8; Kyriaki 1988, pls. 73, 90).

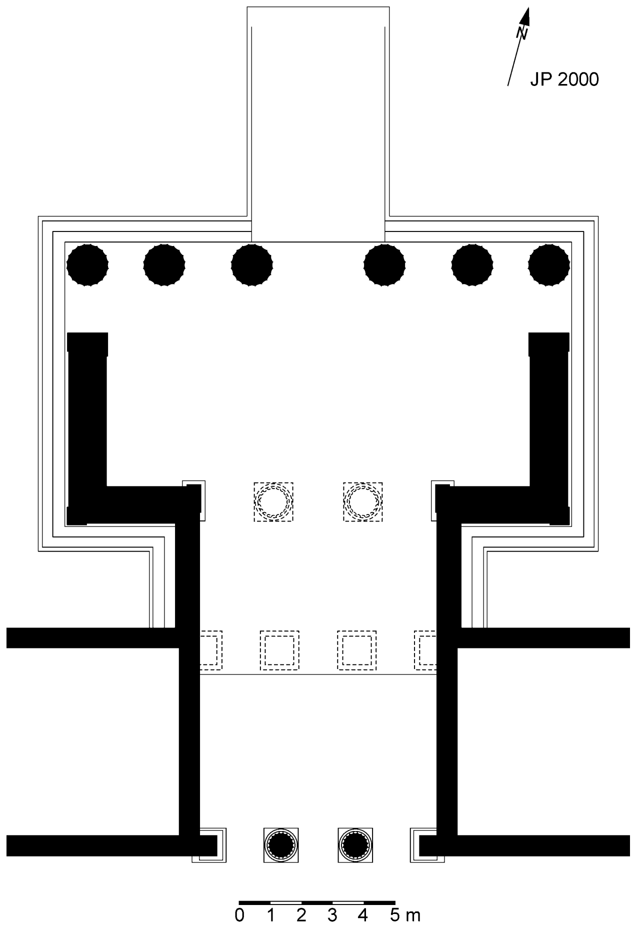

Fig. 2. Hestiatorion, Epidauros. Restored plan of the Propylon (J.P. based on Kyriaki, pl. 90).

Fig. 3. Hestiatorion, Epidauros. Photograph from north-west of the Propylon after restoration (J.P. 2011).

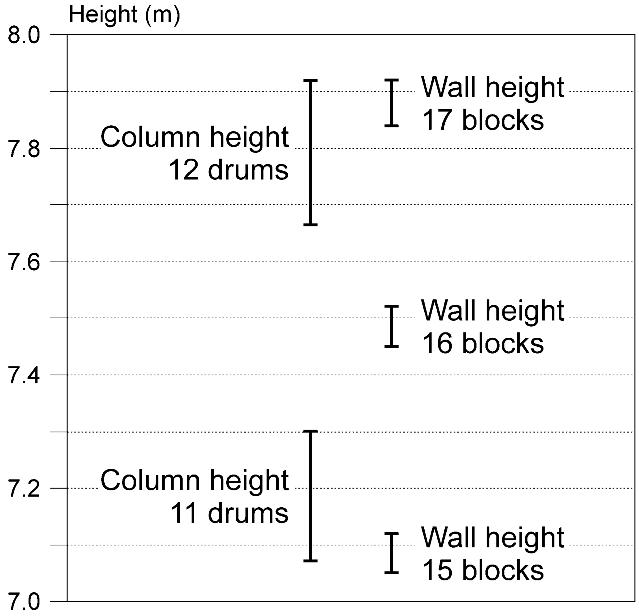

Fig. 4. Hestiatorion, Epidauros. Propylon column and wall height ranges (J.P.).

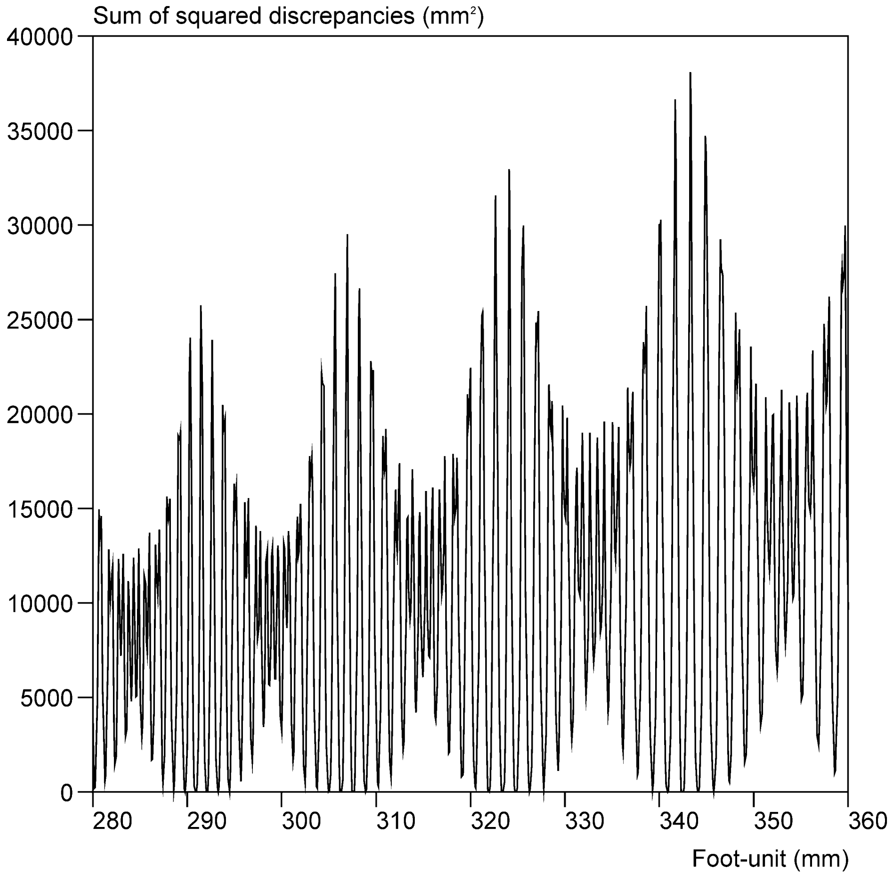

Fig. 5. Hestiatorion, Epidauros. ‘Foot-unit’ fit calculated on the basis of length and width. Full feet, measurement error margin ±25 mm (J.P.).

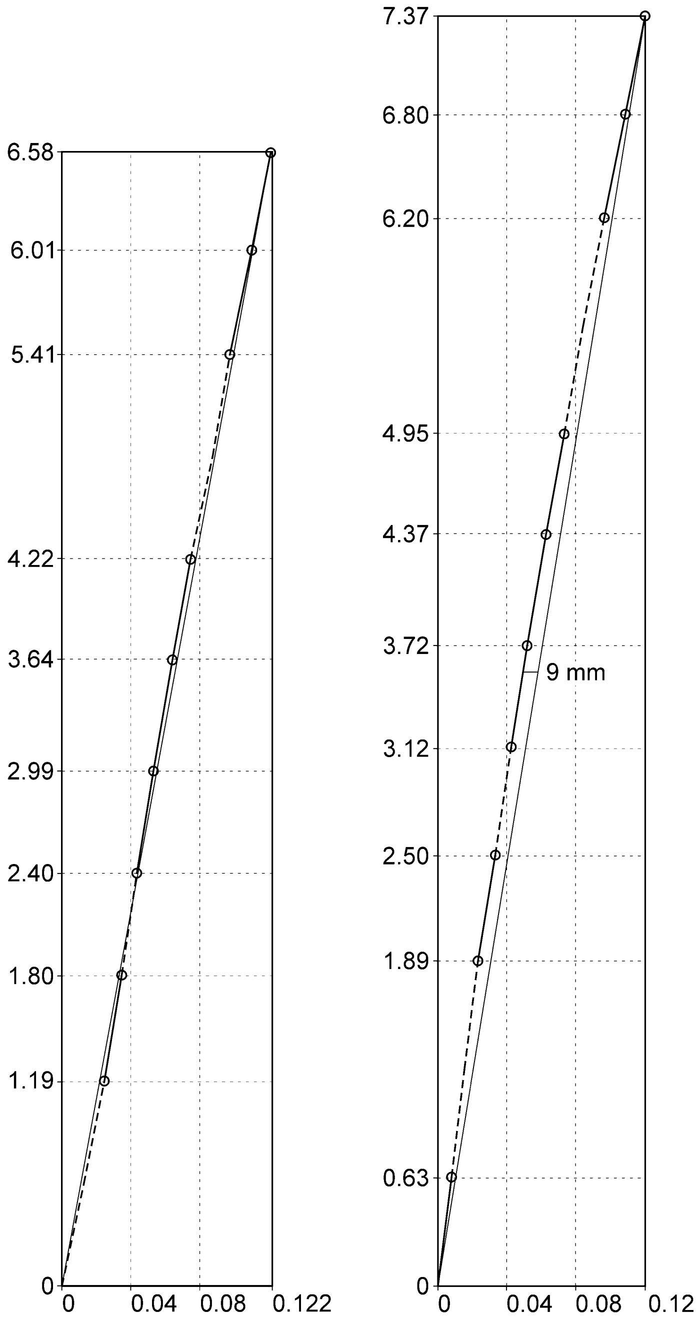

Fig. 6. Hestiatorion, Epidauros. 11-drum (left) and 12-drum (right) reconstructions of the shaft profile (J.P.).

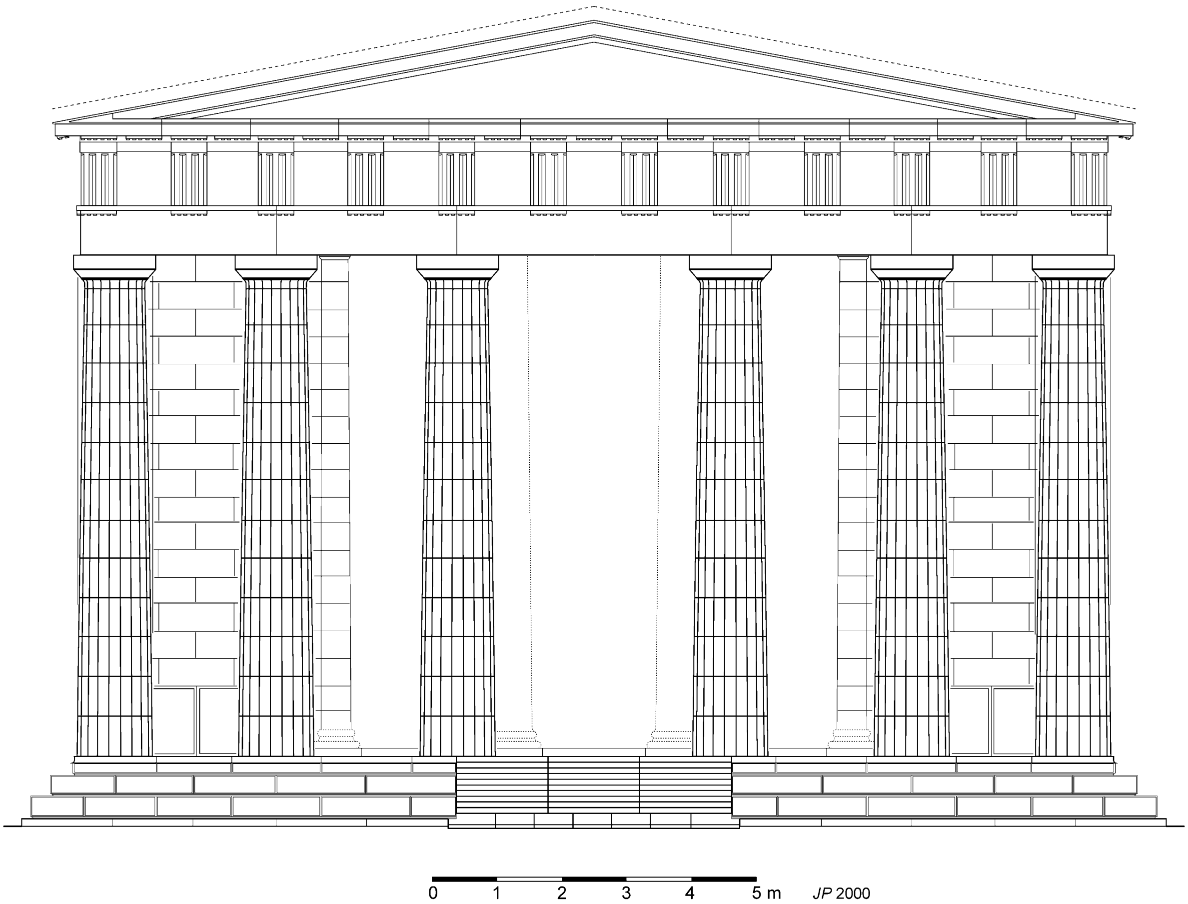

Fig. 7. Hestiatorion, Epidauros. Reconstruction of the Propylon facade with 12-drum columns (J.P.).