**DOCUMENTING ARCHITECTURAL REPAIRS WITH PHOTOGRAMMETRY: COLUMN DRUMS OF THE TEMPLE OF ATHENA ALEA AT TEGEA***

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**Abstract**
The Temple of Athena Alea at Tegea is one of the most important temples constructed in the fourth century BCE in mainland Greece. The architecture of the fourth-century marble temple was studied in detail by the author in the 1990s and the current project at the site aims to test whether new three-dimensional documentation methods can be used to settle the open issues in the design and construction of the temple. In 2016, aerial photography, reflectorless total stations and photogrammetry were used to document the archaeological site and produce a detailed georeferenced three-dimensional model of the temple. In 2019, the column drum repairs of the temple were modelled with photogrammetry to compare the documentation and reconstruction drawings made in the 1990s with the new digital models. The advantages of current three-dimensional methods are speed of documentation and very high accuracy in capturing the dimensions, geometry, toolmarks and textures of the architectural repairs.

**Keywords:**
Greek architecture; temple of Athena Alea at Tegea; column drum repairs; photogrammetry; three-dimensional documentation

## 1 Introduction

Pausanias visited the temple of Athena Alea in the second century CE and he was highly impressed: he describes the building as "far superior to all other temples in the Peloponnese"; its

* The documentation of the column drum repairs at the temple of Athena Alea at Tegea was carried out in February 2019 with the permission of the Ephorate of Antiquities of Arkadia. Special thanks are due to its director, Dr Anna Vasiliki Karapanagiotou, and the staff of the Tegea Museum. I am grateful to Jean vanden Broeck-Parant for organising the workshop *Ancient Architectural Repairs in the Greek World* held at Oxford 28 February 2019: it provided the incentive to travel to Tegea in early February 2019 and carry out fieldwork for photogrammetry on the Athena Alea column drum repairs; the feedback from the workshop was highly valuable.

architect was one of the best-known sculptors of the period, Skopas of Paros.[1] With the exception of the conglomerate foundations, it was completely constructed of local Dolianà marble in the fourth century BCE.[2] The foundations and a few blocks of the temple euthynteria on the S side are the only parts of the temple still in situ but a great number of marble blocks from the building lie scattered all around the archaeological site (fig. 1).[3] Column drums are one of the best preserved types of blocks of the temple. Most of the smaller rectangular blocks such as the ones from the cella walls ended up being recycled after the destruction of the temple.[4] First test trenches at the temple site were dug in 1879 and the French School at Athens carried out full-scale excavations in 1900–1902; the final private property in the SW corner of the temple was pulled down and excavated in 1909 by the Archaeological Society of Athens.[5] The Norwegian Institute at Athens carried out excavations inside the cella of the Classical temple and to the N of the foundations in 1990–1994 and 2004.[6]

The publication of architecture has traditionally been based on hand-drawn two-dimensional line-drawings and photographs. Only recently, this approach has been challenged by new types of illustrations based on three-dimensional digital documentation.[7] Photogrammetry has quickly established itself as the preferred new method in archaeological contexts due to low cost of required hard- and software. It can provide accurate, detailed and efficient recording of architectural features in the field. This paper explores its use for documenting the dimensions, geometry, toolmarks and textures of column drum repair pieces and cuttings at Tegea.

Considering the long lifespan of Greek monumental buildings, repairs have been a surprisingly neglected topic in architectural scholarship. They are most often only noted briefly in the publications or illustrated in the drawings without further detailed discussions. The 2019 Oxford workshop *Ancient Architectural Repairs in the Greek World* and its publication is a clear step forward in this field. This paper concentrates on the column drum repairs of the Late Classical temple of Athena Alea.

## 2 Documentation

The new field documentation campaign at the temple of Athena Alea at Tegea was initiated in 2016 to settle the open questions in the dimensions of the building and the architectural design of the temple.[8] It was designed to take advantage of new 3D documentation methods combining intensive reflectorless total station drawing and photogrammetry.[9] The campaign included an aerial survey of the archaeological site using a drone. The georeferenced orthorectified mosaic image of

[1] Paus. 8.45.4–5.
[2] Pakkanen 1998, 8–9. On the date of the temple as 350–325 BCE, see Østby 2014c, 341–346.
[3] Dugas et al. 1924 is still the main publication of the temple architecture. For a recent discussion of subsequent studies on the temple, see Pakkanen 2014a; the temple design is further analysed in Pakkanen 2013, 94–109, and Østby 2014c (the two studies are written independently of each other and the first one presents several new temple dimensions based on the fieldwork conducted in the 1990s); for a preliminary catalogue of building blocks at the site, see Pakkanen 2014b.
[4] On the column drums and different categories of blocks, see Pakkanen 1998; Pakkanen 2014b. On the destruction of the temple, see Østby 2014c, 348–350.
[5] Pakkanen 1998, 6.
[6] Østby 2014a; Østby 2014b.
[7] See, e.g., Pakkanen 2009; Sapirstein 2016; Pakkanen 2018.
[8] Cf. Pakkanen 2013, 94–109, and Østby 2014c, 317–326, 334–340.
[9] Pakkanen 2018; Pakkanen et al. 2020.

the temple and its surrounding area is presented in fig. 1[10] and a second, more detailed one, of the temple foundations was also made. Photography for photogrammetry of the drum repairs was carried out in one morning in February 2019. Flooding of the site severely inconvenienced the documentation of one of the drums (Block 809 in fig. 2); also, nearly continuous rain made taking the sets of photos more challenging, though the cloud cover also provided consistent illumination for the photos.[11] I took photographs both of the whole drums and more detailed ones of the architectural repairs.

A carefully placed carpenter's square can be used to orientate the block so that the features of the drum under scrutiny are automatically planar in PhotoScan. The square with coded targets 6a, 9 and 11 was positioned so that it rested on the flute (fig. 3). Because of the taper of the drum, the shorter arm of the square is not parallel with the bottom surface. Since the main target of 3D documentation was the repair on the side of the drum, I considered this to be less important. An alternative would have been to place the square similarly as the smaller square at the top (with targets 1 and 2), but damage to the block and the large size of the square did not allow such a placement. In the central pane of the PhotoScan model (lower part of fig. 3), the thumbnail photos show the locations where the photographs were taken from.

For Block 809, three scales with coded photogrammetry targets were used to dimension the 3D model of the drum and the fourth scale can, therefore, be used as an independent check of the accuracy of the model. The scales were placed around the column drum repair (fig. 3). After modelling, the referenced orthomosaic was exported from PhotoScan to ArcMap for more reliable planar measurements[12] and the length of the 50-cm control scale was measured as 500.1 mm (fig. 4).

I took second sets of photos of the drums with no scale bars for final publication illustrations of the complete drums. Using these sets, it is possible to produce documentation where the scale bars on the drums are not visible.[13] However, since the focus here is on the arris repairs,[14] these sets were not utilised for this paper. The camera used in the documentation was Sony α7R with a 36-megapixel full frame sensor; the focal length of the standard zoom lens FE 28–70mm F3.5–5.6 OSS was set at 28 mm. I have carried out extensive tests using different combinations of camera

[10] The drone used was a DJI Phantom 4 with a 12-megapixel sensor. The orthomosaic has been produced using PhotoScan and exported to ArcMap for the georeferenced plan in fig. 1. It is composed of 103 aerial images taken at an altitude of c. 20 m from the temple foundations; ten Ground Control Points (GCPs) were used in positioning the photographs and scaling the model. The initial georeferencing is based on the drone GPS; GCPs were subsequently resurveyed with a total station reducing the local errors in the grid to millimetres. The resurveyed GCP coordinates have been used in all successive post-processing: e.g., the GCP on the temple S flank euthynteria (F13) gives the height of the ancient ground level of the sanctuary near the temple and it was calibrated as 617.33 metres above the sea level. For a more precise spot height, it should still be checked with a Differential GPS. It is based on several unobstructed drone GPS measurements, but it should for now be regarded as only approximately correct in absolute terms. However, the discrepancies between the 'true' height and the recalibrated site height do not affect the internal consistency of the 3D model because of the systematic use of GCPs.

[11] Planned subsequent fieldwork at the site was not possible due to Covid-19 travel restrictions in 2020.

[12] The ruler tool in PhotoScan can be used for approximate measurements in 3D, but the tools in ArcMap are better suited for precise two-dimensional measurements.

[13] My standard method for dimensioning architectural elements for photogrammetry in the field is to measure small marker dots on the blocks with a reflectorless total station; on combining photogrammetry and total station documentation, see Pakkanen 2018; Pakkanen et al. 2020. In case the target is difficult to reach, such as in the case of the bottom of the reservoir at Pleuron, it is possible to keep the laser pointer of the total station on and take the photogrammetry photographs so that the pointer is visible; Pakkanen 2018, figs. 6.9, 6.10.

[14] 'Arris' is the technical term for the sharp edge between the flutes of a Doric column.

bodies and lenses including drone and mobile phone cameras and good 3D models are surprisingly easy to produce when the lighting and weather are good: the most important factors in photogrammetry documentation are to have sufficient overlap between the photographs, keep the target in focus, retain the same zoom setting throughout the set of photos and have a sufficient number of precisely measured control targets or scales. If the zoom ring in a lens has a tendency to drift, it is advisable to use a piece of tape to fix the ring in place. When the conditions are challenging, such as at Tegea in February 2019 with rain and flooding, good-quality equipment is necessary.[15]

## 3 Column drums with repairs

Structurally, the peristyle columns in Greek temples are very important: they carry the load of the exterior order entablature and together with the cella walls that of the roof. Therefore, integrity of the stone used in the columns was essential for the long-term stability of the buildings. At Tegea, the large cut on one of the drums could have been made for inspecting how serious the crack on the block is.[16] Repair cuttings on columns are documented in architectural publications, but they are often not discussed in detail.[17]

The drum repairs of the temple of Athena Alea fall under Type C in Tommaso Ismaelli's typology of architectural restorations: the damaged parts of the blocks are repaired with replacements without metal attachments.[18] At Tegea, there is no evidence of using binders and the shape of the repairs and excellent workmanship were the keys to holding the pieces in place. The following comparative examples are from the Greek mainland and Delos. Column repairs in Asia Minor have been quite extensively covered by Ismaelli.[19]

Tapering arris repairs have been recorded in the drums of the sixth-century temple in the sanctuary of Athena Pronaia at Delphi and the late fifth-century temple of the Athenians on Delos. At Delphi, the repair extends over two drums[20] and it is unlikely that there would have been similar cracks on two superimposed drums. Therefore, the damage to the column was most likely caused during construction of the temple, either when lifting heavy blocks above the column or, more likely, when the stonecutters were removing the extra protective mantle of stone and carving the fluting at the very end of the building project. On Delos, a triangular repair piece was placed at the lower part of a column drum and it is attached to the block with a small metal clamp.[21]

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[15] However, a standard DLSR camera and a zoom lens are usually enough even in these cases: for a photogrammetry cross section of a Classical-period well at Naxos in Sicily, see Lentini, Pakkanen, Sarris 2021, pl. 1.2; Pakkanen, Lentini forthcoming, fig. 4. The depth of the well is over 6 metres and there was hardly any light or space at the bottom of the well: I took the photographs in 2016 using a Nikon D7200 with a standard zoom lens AF-S DX Nikkor 18–105mm set at 18 mm.
[16] R.R.R. Smith made this suggestion at the Oxford *Ancient Architectural Repairs* workshop.
[17] See, e.g., Dinsmoor, Dinsmoor 2004, fig. 10.3 of the E façade of the Propylaia: the first column from the S has a rectangular cut on the eighth drum from the bottom; the location of the repair at the bottom of the drum could suggest that it is part of the Classical construction phase and not the Frankish alterations. For general discussions of repairs in the Greek world, see Martin 1965, 302–304; Hellmann 2002, 95–98; Ismaelli 2013.
[18] Ismaelli 2013, 280–287, figs. 9–15.
[19] Ismaelli 2013, 283, esp. n. 59.
[20] Demangel 1923, 21, fig. 28.
[21] Courby 1931, 198; Vallois 1978, 507 n. 2. In Ismaelli's repair typology, this is an example of Type D using metal attachments; Ismaelli 2013, 287–293.

One of the top drums of the peristyle columns of the Classical temple of Hera at the Argive Heraion has a very large part repaired. The section extends over six flutes and partially over two further ones; vertically, the patch covers most of the top half of the drum. It was held in place by at least one H-clamp.[22] A quite similar large repair is documented in the Hellenistic temple of Asklepios at Messene, though if the new piece was attached to the rest of the block with clamps, the cuttings have broken away. It is almost half the height of the drum and extends nearly right across the block with a maximum depth of nearly 0.20 m from the side of the drum.[23] Because of plastering the exposed surfaces of the limestone blocks, these repairs would have been invisible when the buildings were finished.[24]

Drum repairs in antiquity were not limited to the Greek and Roman worlds: for example, a column of the fifth-century Throne Hall at Persepolis has a repair piece with a complex shape set in lead.[25] However, the focus of this paper is on the temple of Athena Alea and a full comparative study is beyond the scope of this study. I have briefly discussed the architectural repairs of the Tegea drums in two previous publications.[26]

### 3.1 Block 809. Column drum with two arris repairs

Block 809 was discovered in the Norwegian excavations carried out in 1990–1994.[27] The column drum is located to the N of the temple foundations (figs. 1–2) and it is from the middle of the column shaft.[28] The arrises of Block 809 have been repaired in two places. The smaller one has most of the repair pieces still in place and it is clearly visible on the side of the drum currently facing upwards (figs. 3–4). The second larger repair is in the present NE corner of the drum close to the ground (figs. 5–6).[29] The dimensions of the three repair pieces and the cutting were measured using a referenced orthomosaic exported from PhotoScan to ArcMap. Comparison with the documentation carried out in the 1990s using traditional methods reveals discrepancies of a millimetre as can be expected.

The process of repairing the arris can be reconstructed on the basis of the preserved pieces (fig. 6). A rectangular area of 387 mm × 35 mm and depth of 43 mm from the tip of the arris was cut to receive the marble repair pieces. The top piece is now largely missing revealing a small ledge cut into the drum. The resting surface of the rectangular cut has traces of triangular toolmarks of c. 5 mm × 3 mm which were left when an iron point was used to finalise the cut. These are now largely filled with organic material so they are not discernible in the solid 3D model (fig. 4a) but their size can readily be measured on the orthomosaic (fig. 4b). The two larger pieces were held in place by the third tapering piece. The visible unevenness of the surface of the flutes in

[22] The cutting for the second H-clamp has most likely broken off; Pfaff 2003, 92, 235.
[23] Pakkanen 2011, 50, fig. 12. For similar, though much smaller, repairs on a drum of the third-century BCE temple of Athena at Pergamon, see Bohn 1885, 12–13.
[24] At Messene, the thickness of the stucco layer can be measured as 5 mm; Pakkanen 2011, 49–50, fig. 11.
[25] Tilia 1968, 87, fig. 110.
[26] Pakkanen 1998, 28–30; Pakkanen 2014a, 364–365.
[27] Pakkanen 1998, 22; Pakkanen 2014a, 353, 365. On the drum and its dimensions, see Pakkanen 1998, 28–29, A41 in App. A, figs. 9–10 (the latter is also reproduced in Hellmann 2002, fig. 114); Pakkanen 2014a, 365, figs. 14–16; Pakkanen 2014b, 413.
[28] All shafts at Tegea had six drums; Dugas et al. 1924, 131–133; Pakkanen 1998, 20. Block 809 is a third drum counting from the lower end of the shaft; Pakkanen 1998, A41 in App. A.
[29] The 3D model is based on 72 photographs.

the 3D model (fig. 4a) is due to lichen which has started grow on the marble after its exposure in the 1990s (fig. 4b).[30]

There is no certain indication of the date of the smaller repair, but the high level of workmanship is similar to the rest of the temple, so it is very probable that it was part of finishing the temple in the fourth century. There is no sign of a crack close to the patch, so the damage to the stone was most likely discovered or caused during final fluting of the columns. It is possible that the final repair piece is held in place by a small dowel, but it is not possible to check this without damaging the pieces still in situ. No traces of lead potentially fixing the pieces to the rectangular cut was discovered in the excavations. It is also possible that the very slight expansion and shifting of the marble crystals after cutting would have been enough to hold the three pieces in their place. The quality of craftsmanship at Tegea is witnessed by the fact that the pieces are still in their original positions even though the top part is largely missing.

The second larger repair cutting in the current NE corner of the block is mostly broken away when the edge of the top surface was damaged (figs. 5–6). When the photogrammetry documentation was carried out, it was not possible to take photographs next to the drum on the N side due to flooding: the closest ones are highlighted in the bottom right corner of fig. 5.[31] The only new measurement of the repair cut based on the 3D model is its maximum distance from the top surface of c. 310 mm. Its width was recorded in the 1990s as 77 mm and depth from the tip of the arris as 67 mm. More detailed 3D documentation conducted under better conditions would make possible observations on the toolmarks and probably indicate whether the shape of the repair was tapering, as on Block 7, or rectangular.

### 3.2 Block 7. Column drum with a tapering repair

Block 7 is one of the column drums excavated at the beginning of the 20th century and documented by Mogens Clemmensen.[32] The column drum is located on the N flank of the temple foundations (figs. 1–2) and it is from the middle of the column shaft.[33] Early photographs show that the drum was in this place already in the early 20th century,[34] though a stone was placed under the block at some point after the original photographs were taken, probably to facilitate drawing of the state plan of the temple foundations.[35] Block 7 has a large tapering cut on the current SE side of the drum.

Two scales were placed at the top of the drum and two at the bottom for photogrammetry documentation of Block 7 (fig. 7).[36] All four scales were used for dimensioning the 3D model, so in this case no control scale was employed. The drum is tilted because of a stone placed under it and I chose to use the additional scale in modelling to ensure that both the vertical and horizontal dimensions of the model would be as accurate as possible.[37]

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[30] For photographs of the repair and the block during the excavations, see Pakkanen 1998, 29, A41 in App. A.

[31] I did not see the repair cut when taking the photographs and I thought it was underwater, so I was quite surprised when its shape emerged in the post-processing of the 3D model in photogrammetry.

[32] In his table, the D-drum number is 17; Dugas et al. 1924, 132; Pakkanen 1998, 20, 28–29, A4 and A11 in App. A.

[33] Block 7 is a fourth drum counting from the lower end of the shaft; Pakkanen 1998, A11 in App. A.

[34] Dugas et al. 1924, pls. 82–83.

[35] Dugas et al. 1924, pls. 3–4.

[36] The 3D model is based on 93 photographs.

[37] The scale bar errors in the model are minimal: the panels in the left column of fig. 7 give the discrepancies between the stated lengths of the scale bars and their modelled sizes.

It is in many cases easier to discern surface details and geometry of the block on the basis of the solid photogrammetry model (on the left in fig. 8) than on the textured model (on the right in fig. 8). The lichen growing on the marble surfaces is a distraction in the latter case. The second set of photographs without the scale bars could have been used to produce fig. 8, but my choice was to use the initial set so that the metal scales provide a colour and texture contrast to the marble block. Dimensions such as diameters, height and flute widths can be measured directly from the exported two-dimensional views of the model with millimetre accuracy. The dowel holes and the empolion cutting in the middle are slightly fuzzy because of the conditions during documentation: rain water was collecting in the depressions resulting in reflections in the photographs.

The shape of the tapering cut is quite complex (fig. 9). On the left side, its distance from the top surface is exactly 600 mm and on the right 610 mm. At the bottom, the cut is deeper on the left side (124 mm) than on the right (104 mm).[38] The maximum width is 179 mm and this tapers quickly towards the top of the drum, but its shape at the top is not known because of the breakage of the drum. The vertical crack, the cause of the repair, is visible both on the solid and textured model. It is possible that the tapering cut was made to inspect the crack whether it was structural or not.[39] The circular toolmarks on the vertical surface are better discernible on the solid model. They were made with an iron point and they have mostly a diameter of c. 6 mm.

At the lower end of the drum, the width of the flute with the crack can be measured on the 3D photogrammetry model as 218 mm and the two neighbouring flutes have the same width. The split has not widened since the construction of the temple and fluting of the columns. Therefore, the assessment of the Classical builders was correct and the crack was not structurally significant enough for discarding the whole block.

## 4 Conclusions

Carrying out architectural repairs during the construction process of a monumental building was always a question of economy, no matter whether the repair was large or small: discarding sizeable blocks such as column drums could have slowed down the building process, especially if the resting surface of the block had already been matched with the drum below.[40] A new block had to be ordered from the quarry and transported to the site. Once the column drum was in place and the entablature placed on top of it, the only economically viable option would have been to repair as best as possible. Dismantling the entablature would have been risky, potentially resulting in damage to the architrave or frieze blocks. On marble buildings, such as at Tegea, the repairs would have required excellent craftsmanship to render them as inconspicuous as possible; on lime- and sandstone structures the repair pieces would have been stuccoed over and, therefore, invisible. In cases where the drum was not yet matched with the one below, it could be rotated so that the damaged side was facing the interior of the monument. Since the columns had a protective

[38] The depth of 114 mm as shown in Section AB of fig. 9 is in the middle of the cut.
[39] The marble column A4 of the porch of the Augustan Prytaneion at Ephesos has a rectangular repair cut at the bottom of the third drum which in the documentation is connected with a diagonal crack (Steskal 2010, pl. 57.2) and could have a similar function as the cut at Tegea. The repair is classified as Type C1 in Ismaelli 2013, 283.
[40] On the complex and time-consuming procedure of adjusting the horizontal joint between two drums to fit together, see Korres 1994, 107–109. On the cost of quarrying, transport and construction of columns, see Pakkanen forthcoming.

mantle of stone left in place until the very end of the construction process, small irregularities in the matrix of the stone could have been discovered only during the final fluting.

Photogrammetry is ideally suited to documenting architectural repairs: taking the photographs and post-processing of the 3D models can be done quickly which should leave more time to study the architecture on site rather than using all the available time on measuring and drawing. The resulting models and orthomosaic images are highly accurate when it comes to the dimensions and geometry of the repair pieces and cuttings. Complex shapes on partially broken drums, such as on Block 7 at Tegea, are extremely difficult to measure and draw using traditional means. Studying toolmarks is possible based on both solid and textured 3D models. The only improvement to the method presented in this paper would have been supplementing photogrammetry modelling with total station 3D line-drawings to further emphasise the salient features of the repairs.[41] Images which highlight the boundaries with lines are easier to interpret than photogrammetry models and orthomosaics which often display subtle differences in colour and texture. However, as has been demonstrated in this paper, using solid and textured 3D models as the starting point of the final publication illustrations can emphasise the different types of features in the column drums repairs at Tegea.

[41] This would have required a second fieldwork campaign in 2020 which could not be carried out because of the coronavirus pandemic. On combining 3D line-drawing with photogrammetry, see Pakkanen 2018; Pakkanen et al. 2020.

## Figures


Fig. 1. Georeferenced orthomosaic of the archaeological site and foundations of the temple of Athena Alea at Tegea (plan by the author)


Fig. 2. The archaeological site in February 2019 from the north indicating the column drums with arris repairs (photograph by the author)

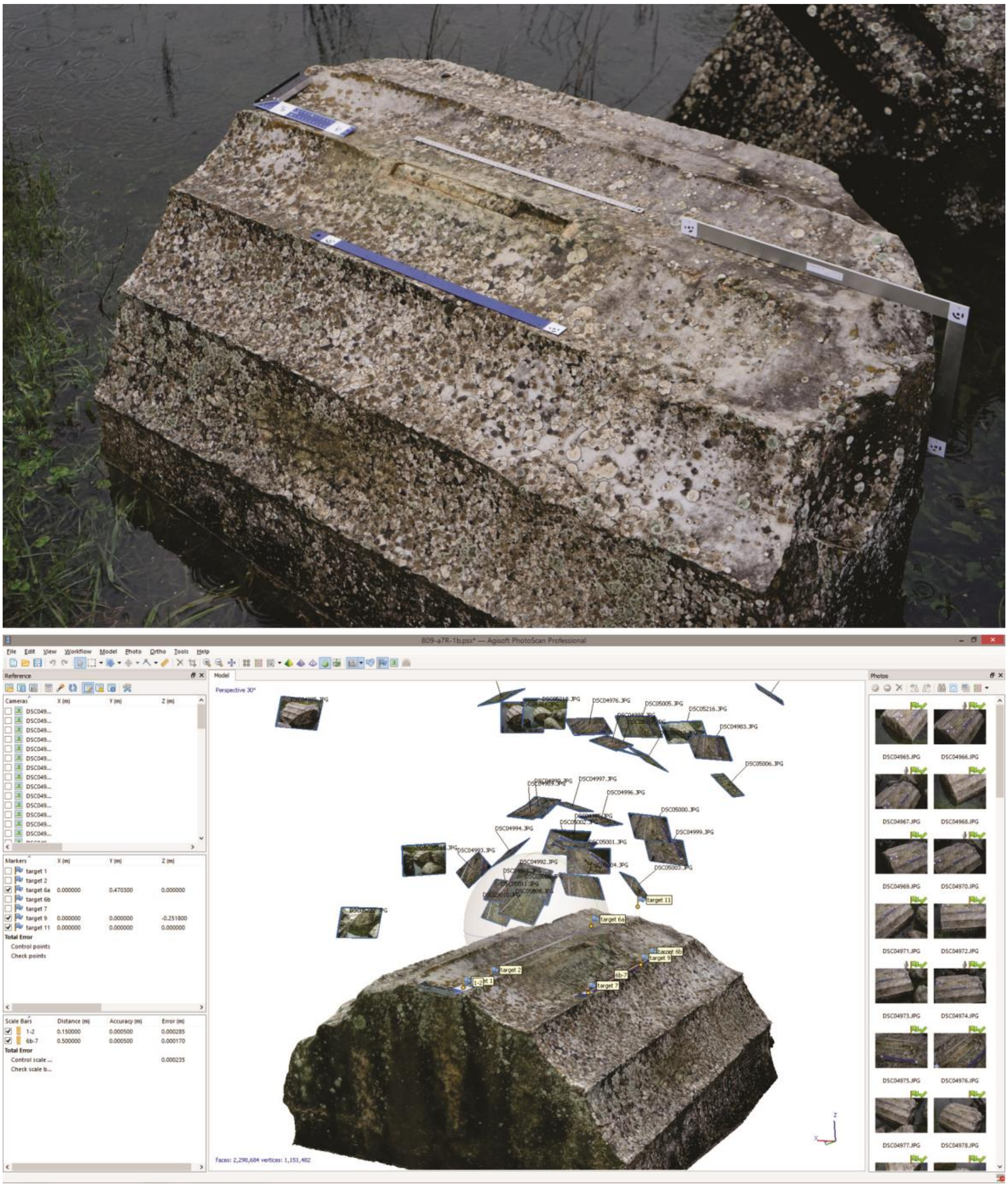

Fig. 3. Photograph of Block 809 with scales for dimensioning of the drum and 3D textured photogrammetry model (both by the author)

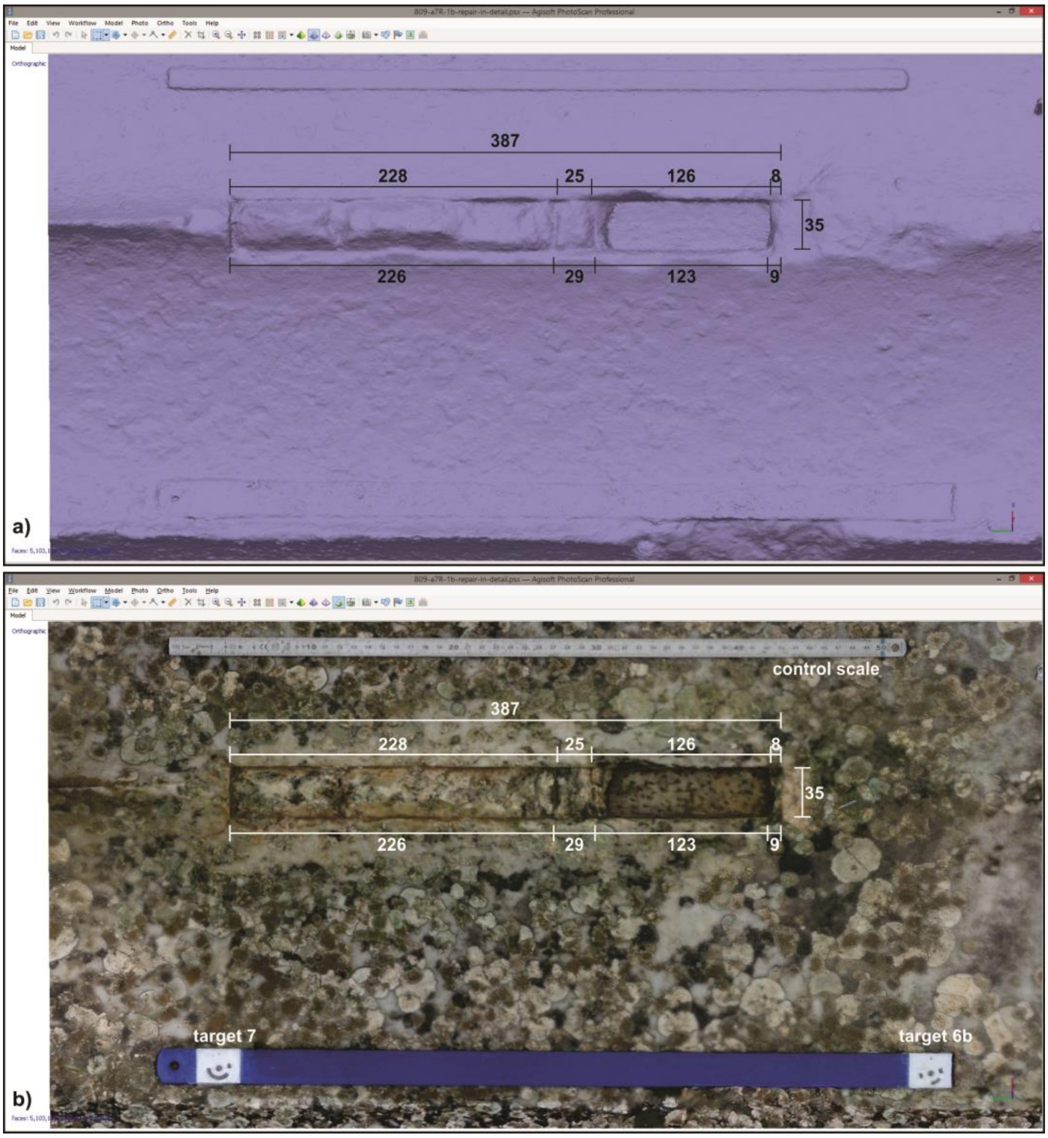


Fig. 4. a) Solid 3D model of the arris repair on Block 809 with in situ marble pieces; b) textured 3D model showing scales for dimensioning and control (both by the author)

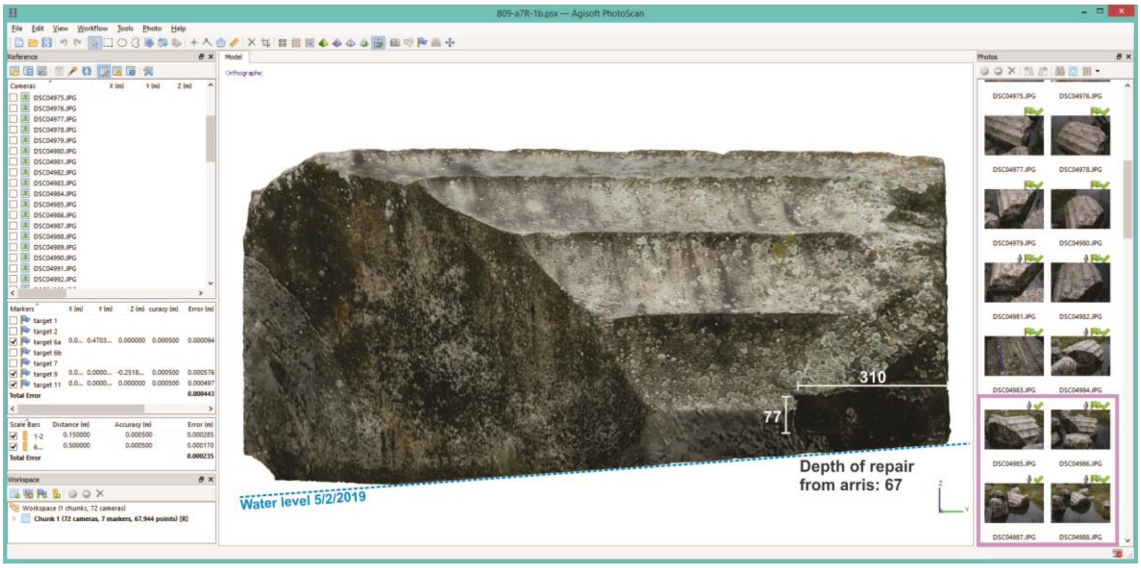


Fig. 5. Side view of Block 809 with second arris repair (model by the author)

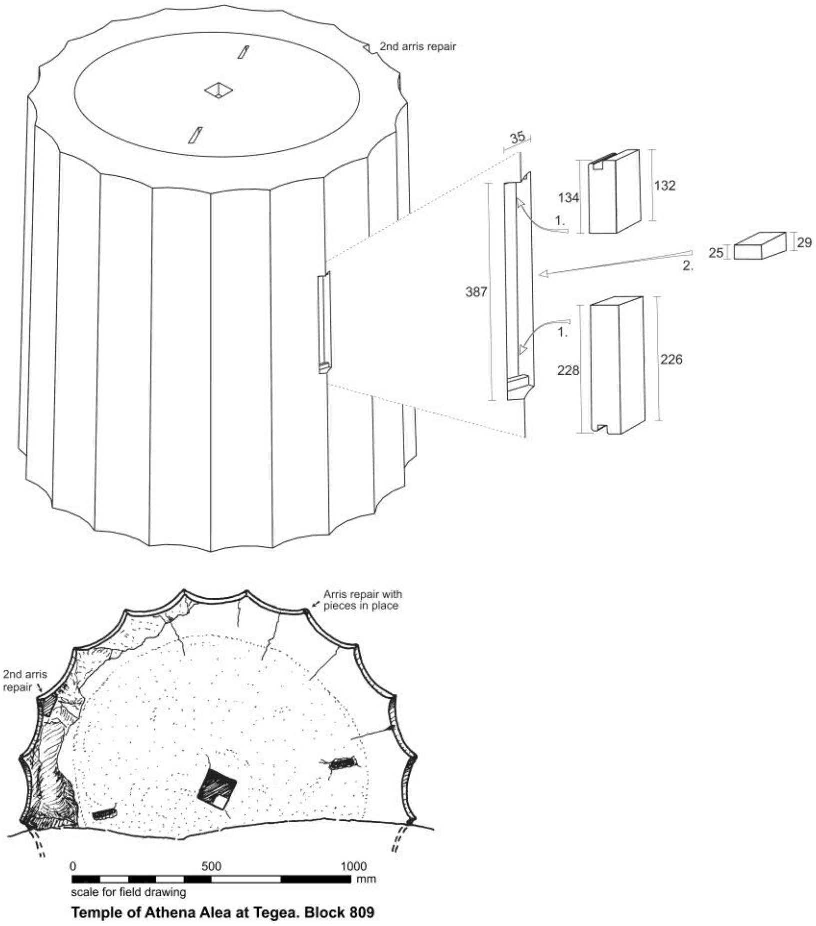


Fig. 6. Reconstruction of arris repair on Block 809 and field drawing of the top surface (drawing by the author)

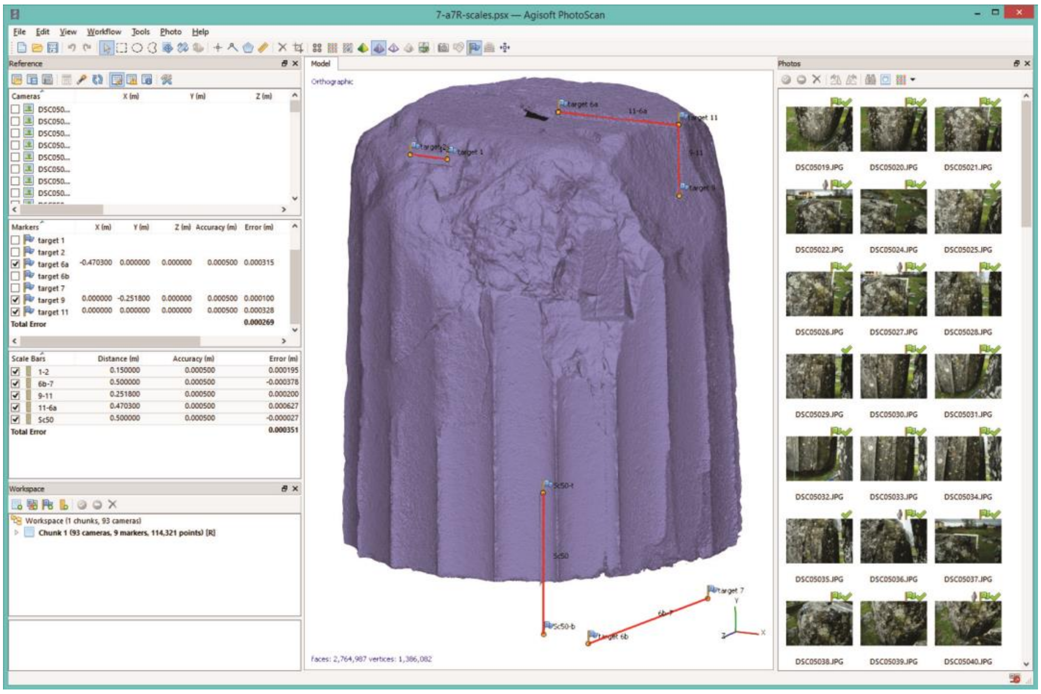


Fig. 7. Solid 3D photogrammetry model of Block 7 with dimensioning scales highlighted (model by the author)


Fig. 8. Solid and textured side and top surface views of Block 7 (illustration by the author)

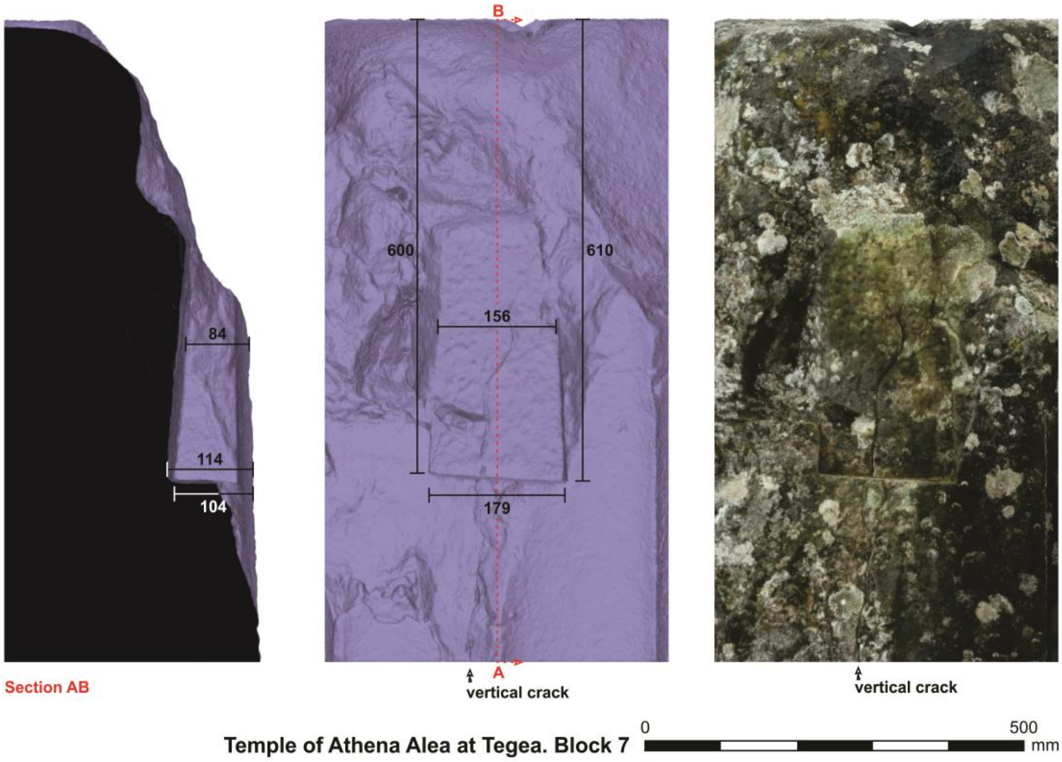


Fig. 9. Section and solid and textured views of the architectural repair on Block 7 (illustration by the author)

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