CONSTRUCTING MONUMENTS, PERCEIVING MONUMENTALITY & THE ECONOMICS OF BUILDING

THEORETICAL AND METHODOLOGICAL APPROACHES TO THE BUILT ENVIRONMENT

edited by
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6

Three-dimensional documentation of architecture and archaeology in the field

Combining intensive total station drawing and photogrammetry

Jari Pakkanen

6.1 Introduction

Imposing images, presentations and videos are widely used to present architectural and archaeological research projects to the public and their role should not be underestimated. They are often central to public understanding of the projects, securing future finances and communicating the research to colleagues. The promotional material can be directly created from the three-dimensional documentation and reconstructions of the architectural and archaeological remains, so the additional amount of work required is in most cases limited. However, the principal aim of three-dimensional recording must be efficiently producing accurate documentation which can be used in analyses of the documented features and publication of the project results. When the work is carried out professionally, the resulting models are precise representations of the geometry and textures of the targets, thus making it possible to extract the required two-dimensional publication illustration, to carry out further analyses and to produce digital reconstructions of the fragmentarily preserved monuments.

Traditionally, the principal illustrations in archaeological publications have been two-dimensional hand-drawn line-drawings of the documented features and photographs. Currently, one of the most cost-effective ways of producing precise two-dimensional line-drawings of monumental architecture is combining photogrammetry with intensive stone-by-stone documentation using reflectorless total stations: the two-dimensional projections can be produced to any required direction, including plans, elevations and sections. The benefits of the method

In: Brysbaert, A., V. Klinkenberg, A. Gutiérrez Garcia-M. & I. Vikatou (eds) 2018. *Constructing monuments, perceiving monumentality and the economics of building: Theoretical and methodological approaches to the built environment*. Leiden: Sidestone Press, pp. 117-140.

presented here include speed of production, higher measurement density and precision compared to hand-made drawings. It also allows for more time to be used in the actual study of the architectural features. For large complexes photography using an Unmanned Aerial Vehicle (UAV) can significantly shorten the time needed in the field. Here, several case studies of combining intensive total station drawing with land-based and aerial photogrammetry are discussed in detail. The projects are chosen so that they illustrate examples of combining different types of three-dimensional documentation in the field – total station line-drawings, point clouds and textured models – and deriving two-dimensional illustrations from these data. The presented case studies of superimposing reconstructions on three-dimensional data include sketching the main outline of maritime structures of the medieval harbour at Kyllene and a detailed partial reconstruction of the shipshed complex at Naxos in Sicily. A statistical study of the building block dimensions of a Hellenistic tower at Kyllene provides an example of the importance of accurate architectural documentation and how it can be used in an analysis of Greek measurement units.

Ancient architecture is in most cases fragmentarily preserved and, therefore, our perceptions of the scale, monumentality and relationship of the structures with other buildings are largely based on their reconstructions. Reconstructing Greek and Roman monumental architecture requires a good understanding of the regional and temporal variations of the buildings and of the combination of their conservative and innovative characteristics.[268] However, because of the conventional nature of the ancient architectural orders and the proportional rules guiding them, the completed structures can be quite reliably reconstructed based on a limited range of *in situ* archaeological features and preserved blocks.[269] Well-argued and documented three-dimensional visualisations of the built environment are an important aspect of communicating the significance of architecture both inside the scholarly community and to the wider public.[270] For example, the Classical shipshed complexes in the Piraeus were part of the great Athenian civic building programmes and their digital reconstruction serves several purposes. The three-dimensional model relates an interpretation of what the now lost ancient built environment looked like. It is also an important starting point for econometric calculations of the construction costs which, in turn, make feasible an analysis of the social significance and context of the shipsheds.[271]

Due to recent development in hard- and software, full three-dimensional documentation is fast replacing traditional means of architectural recording. Even though the cost of laser scanning can still be prohibitive, all fieldwork projects have access to good digital cameras and most to a reflectorless total station. Therefore, the methodology presented here can be applied at other archaeological sites enabling efficient, accurate and detailed documentation.

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268 Coulton 1977; Wilson Jones 2000; Pakkanen 2013a.
269 See e.g. Salmon 2001, 195; Pakkanen 2013a, 75-109.
270 See e.g. Pereda 2014; Pfarr-Harfst 2015; Vitale 2017.
271 Pakkanen 2013b.

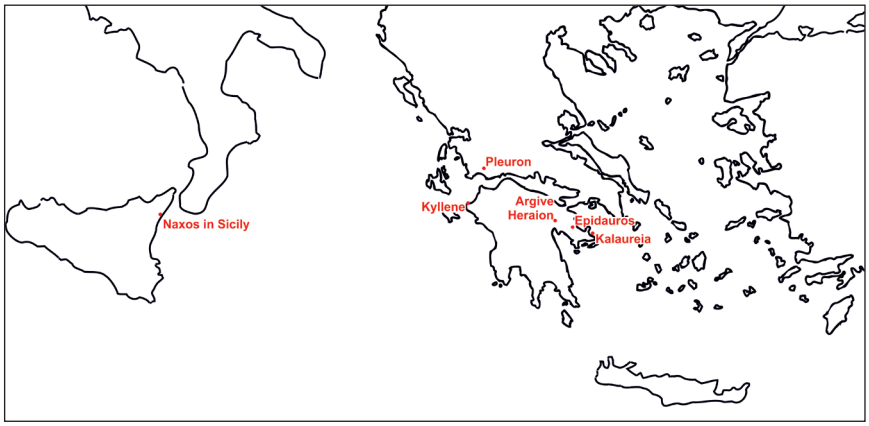

Figure 6.1: Map of the sites mentioned in the text (image by Jari Pakkanen).

6.2 Intensive documentation using total stations and line-drawing with laser

The strategy for intensive and extensive[272] total station documentation was an integral part of two large-scale projects which both started in southern Greece in 2007. The Kalaureia Research Program on the island of Poros was directed by Berit Wells and Arto Penttinen of the Swedish Institute at Athens, and the Kyllene Harbour Project is a collaboration between the Finnish Institute at Athens and the Ephorate of Underwater Antiquities.[273] A map of the sites mentioned in this paper is presented in Figure 6.1.

The methodology and the first version of the software for intensive total station documentation were developed in conjunction with these two projects by the author of this paper.[274] The software for converting the total station documentation into a three-dimensional CAD drawing was programmed using the script language of the statistical package Survo MM. The current version employs the same algorithms as the first, but as a console program it is very fast and works on any Windows platform.[275] The operator of the total station codes the beginning and end of a line (or an individual point) and the characteristics of the target before taking the point and recording the three-dimensional coordinates of the object into the instrument memory. Afterwards, the computer program translates these data into a layered CAD drawing.

272 'Intensive' in this context refers to density of points and lines to draw the archaeological and architectural features using reflectorless total stations: for example, the three-dimensional documentation of a single typical foundation block of the Hellenistic Stoa C at Kalaureia comprises c. 20 lines based on c. 250 points, and the total recording of the building remains comprises over 4,300 lines. 'Extensive' refers mainly to the size of the area with buildings and other architectural features: c. 200 m × 100 m at Kalaureia and c. 300 m × 150 m at Kyllene.

273 Penttinen *et al.* 2009; Pakkanen *et al.* forthcoming.

274 Pakkanen 2009.

275 The software *ts2dxf.exe* has been developed in collaboration with Relator Ltd, a private company based in Finland, as part of the Three-Dimensional Development Programme of the Finnish Institute. A test version and instructions how to use the program are freely available from the author of this paper via email.

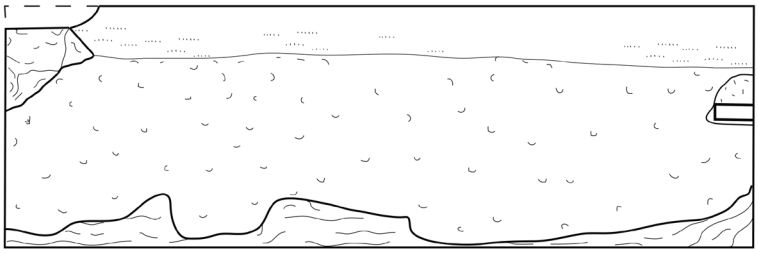

Figure 6.2a: Kalaureia Research Program, 2007-2008. Sanctuary of Poseidon. Documentation of the Hellenistic statue base blocks. Drawing of the top surface of Block A based on hand measurements (Anne Hooton).

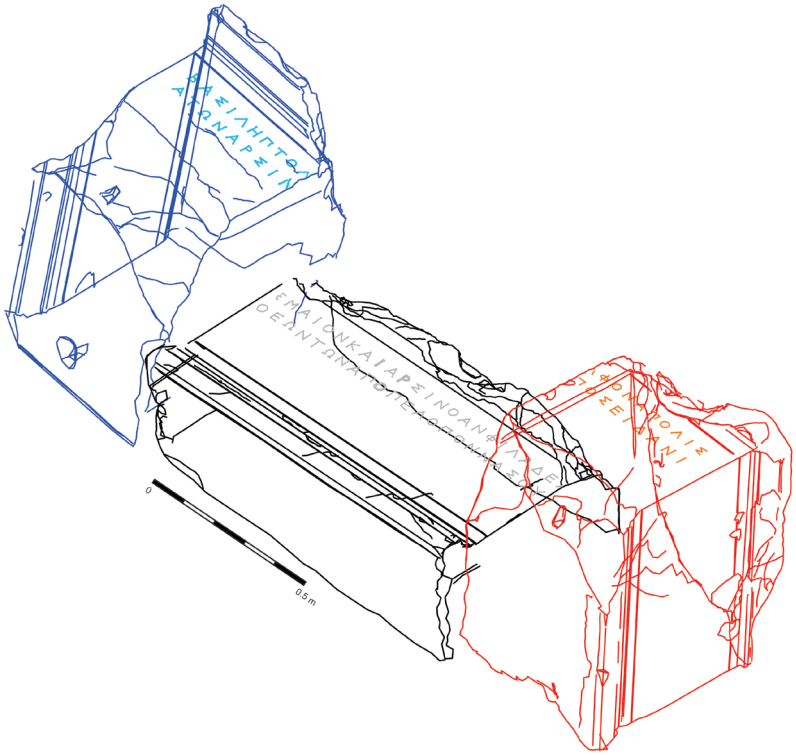

Figure 6.2b: Kalaureia Research Program, 2007-2008. Wireframe model of the raw measurement data recorded in the field: Blocks B, C and D (image by Jari Pakkanen).

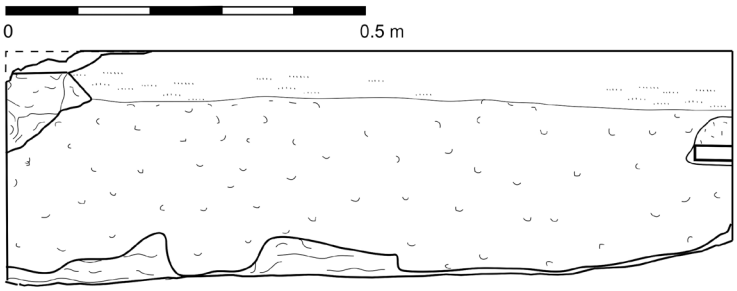

Figure 6.2c: Kalaureia Research Program, 2007-2008. Published illustration of the top surface of Block A directly derived from three-dimensional total station documentation (image by Jari Pakkanen).

During a normal working day several thousand points can be recorded to create a detailed line representation of the target.[276]

With a temple, four *stoai* framing a large central open space and a monumental entrance building, the sanctuary of Poseidon at Kalaureia on Poros is among the principal ancient sites of the Saronic Gulf. Its architectural importance is on par with other large nearby sanctuaries such as Epidauros and Argive Heraion, both in the Argolid. The temple of Poseidon is a small late Archaic *peripteral* building at the northern edge of the sanctuary, and one of the *stoai* and the entrance building are also Archaic. The two *stoai* on the northern flank of the open space are Classical and the fourth one is Hellenistic. This paper presents as a case study one of the early challenges of the research project: the documentation of a Hellenistic statue base comprising four separate limestone blocks discovered in 2007 to the southwest of the temple temenos.[277]

During the preparation of the publication illustrations in 2008, I could not make the hand-drawn blocks of the statue base fit with each other despite their excellent preservation. The problem encountered was that even professional illustrators are affected by the strong tendency of the human brain to perceive regularity where it does not exist (Figure 6.2a). The monumental statue base as a whole is highly symmetric, so it is not surprising that this regularity also has an impact on the documentation of the individual blocks. In this case the irregularity of the block sides facing the inside of the statue base was missed in the field documentation based on hand-taken measurements. In the lower right corner the discrepancy between the drawing in Figure 6.2a and the block is c. 6 cm. Increasing the number of accurate measurements adds to the detail of documentation but there is an understandable limit to how many dimensions can be taken when drawing by hand, as this is a slow and cumbersome process always involving a degree of approximation.

Therefore, in order to fit the four blocks of the monument together, it was necessary to return to the field to redo the drawings, but this time avoiding any hand measurements (Figure 6.2b). Using a reflectorless total station to draw the architectural and archaeological features requires abandoning the normal stationary way of working with surveying instruments and making them an active part of the documentation process. Using the laser requires a good reflection of the recorded surface and glancing shots of oblique surfaces should be avoided, so a dense network of laser backsights is required to be able to move the station to an optimal position whenever necessary.[278] When very high precision of the recorded target in the field is required, it is advisable to quickly reshoot the co-ordinates of the four to five backsights in use to minimise the positional and angle errors in subsequent short local moves of the instrument. An additional advantage of the method is that using the reflectorless laser instead of infrared with a prism target reduces the size of the survey team from two persons to one. Also, aban-

276 Metrology-grade tracking systems have also been used to produce three-dimensional line-drawings of archaeological excavations (Smeets *et al.* 2014), but the system is slower, more expensive and more cumbersome than reflectorless total station documentation.

277 Wallensten and Pakkanen 2009: The architectural importance of this particular statue base is that the inscription ties the used mouldings to the period after the death of Arsinoe the second and when Ptolemaios the first was still alive, c. 270-246 B.C.E.; Wallensten and Pakkanen 2009, 157-164.

278 Pakkanen 2009, 3-6.

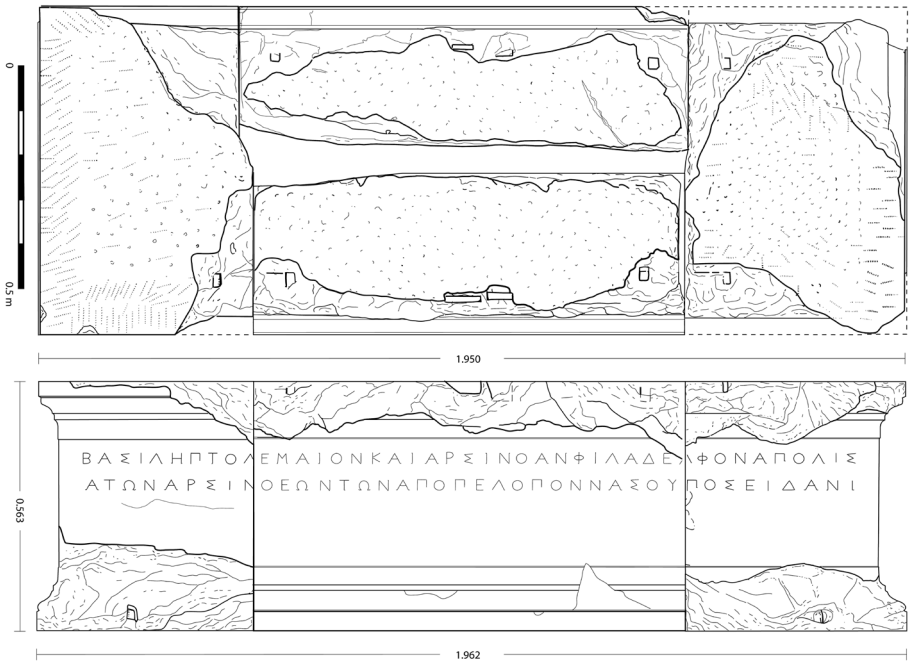

Figure 6.3: Kalaureia Research Program, 2007-2008. Sanctuary of Poseidon. Dedication to Arsinoe and Ptolemaios from the polis of Arsinoe in the Peloponnese (c. 270-246 B.C.E). Final illustrations generated from the reflectorless total station line-drawings (Wallensten and Pakkanen 2009, figure 6).

doning the use of the optical telescope of the total station and using the laser pointer, instead, makes it possible to directly observe what exactly is being recorded.[279]

Photogrammetry has quickly established itself as the preferred choice for three-dimensional architectural, archaeological, and topographical documentation.[280] However, when precise line-drawings are needed, photogrammetric models require retracing in a computer program,[281] while with reflectorless total station recording a line-drawing can be produced directly from the data. Automatic tracing of exported images tends to result in broken lines and the relationship between these lines and the traced target is not always straightforward. Subtle changes in texture and detail are often difficult to discern in orthomosaics and point clouds. This is apparent in all the case studies discussed in the next section: superimposing the total station data on the models makes it easier to read what the significant features of the target are.

The wireframe model presented in Figure 6.2b is based on unedited total station data. The varying colours of the drawing are produced by giving the blocks and the inscriptions different codes when shooting the points. All details are directly recorded as lines in order to simplify further processing of the data. The density of points depends

279 Pakkanen 2009, 3-5, figure 3.

280 E.g. Sapirstein 2014; Sapirstein 2016; De Reu *et al.* 2016; Sordini *et al.* 2016; Thomas 2016; Murray *et al.* 2017; Sapirstein and Murray 2017.

281 Cf. e.g. Thomas and Kennedy 2016, table 1 and figure 6.

on how much detail is required in the final drawings and on the scale in which they are published. Another critical factor is the available time for recording. The lines along the cracked surfaces in Figure 6.2b are documented at 5-10 mm intervals and the straight lines with approximately a 10 cm interval.

The final published drawings can be made in any vector-based drawing program by exporting from CAD the relevant two-dimensional elevation or plan view of the recorded target. The line weights and representations of the different surface textures can be modified to produce a 'traditional-looking' line-drawing of the target (Figure 6.2c and Figure 6.3).

I have experience of training colleagues and students in three-dimensional documentation in the field for 10 years and they have all learned the basics within a couple of days. The number of repetitions and field practice, however, need to be intense enough so that the procedures become automatic. Direct three-dimensional drawing can be monotonous work, but the excitement of seeing the results the same day on the computer screen often makes up for that.[282]

6.3 Total station line-drawing and photogrammetry

Since 2014 we have integrated the use of three-dimensional total station drawings with photogrammetry in the fieldwork projects of the Finnish Institute at Athens. The case studies of the application of these techniques illustrate their potential, especially how the integration can assist in documenting and analysing different types of features of the architectural and archaeological data. First, I discuss the documentation of an ancient harbour at Kyllene, Greece. Second, at Pleuron in Western Greece, in collaboration with Lazaros Kolonas, a large-scale Hellenistic reservoir was recorded 2015 and 2016.[283] Finally, examples from the on-going research at Naxos in Sicily, carried out by the Museum of Naxos and the Finnish Institutes at Athens and in Rome, are discussed.[284] For the locations of the sites, see Figure 6.1.

6.3.1 Kyllene Harbour Project

The Kyllene Harbour Project is an interdisciplinary study of the coastal and underwater remains of an ancient naval base and a medieval harbour. In 2007-2011 the main emphasis was on documenting all the archaeological and topographical features of the research area using total stations and underwater remote sensing methods. Since 2013 the project has concentrated on underwater excavations, monitoring coastal erosion of archaeological layers and in 2016-2017 also on aerial-based photogrammetry of the coastal and underwater remains (Figures 6.4a and 6.4b).

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282 The three-dimensional field documentation courses of the Finnish Institute at Athens were initiated in 2014 by the author of this paper and during the two-week courses it has been possible to train students without previous experience in archaeological documentation to use the method. In 2014-2015 the courses were run in collaboration with Ann Brysbaert (Leiden University) at Tiryns, and in 2016 the training course was arranged in co-operation with her ERC-funded SETinSTONE project on Salamis. The latest course in the summer of 2017 was also carried out at Ambelakia on Salamis.

283 Kolonas and Stamatis 2016, 117-118, 190.

284 Lentini *et al.* 2015.

The harbour is at the northwestern corner of the Peloponnese. In antiquity Kyllene was the second major port of Elis, the city-state controlling the sanctuary of Zeus at Olympia. By late fifth century B.C.E. it was a major Spartan naval base against the Athenian naval forces. In the Hellenistic period the harbour remained of key strategic importance and it is frequently mentioned in the written sources on the Macedonian and also Roman military campaigns in the region. Pausanias (6.26.4) comments on its suitable anchorage in the second century C.E. In 1205 C.E., after Constantinople was sacked at the end of the Fourth Crusade, western Peloponnese was seized by the Franks. The old Greek and Roman harbour was rebuilt and due to its ideal location between the eastern and western Mediterranean, it emerged quickly as one of the most important harbours of medieval Greece. The Frankish name of the coastal town was Clarence, and in Greek documents Klarentsa or Glarentza. It flourished for nearly two centuries but between 1407 and 1428 C.E. it changed hands five times. In 1431 C.E., Konstantinos Palaiologos, who later became known as the last Byzantine emperor, destroyed its walls to prevent another capture of the town. Because of the destruction of the towers at the harbour entrance and subsequent siltation, the inner basin became impossible to use, and in 1435 C.E. the town is reported as deserted.[285]

Considering the good preservation of the medieval harbour installations at Kyllene, very little archaeological interest has been shown to the maritime part of the site. The only previous plan of the port remains is a rough sketch published in the 1960.[286] The European Union Third Framework project in 2002-2005 has resulted in major research and improvements being carried out in the fortifications of Glarentza. Hellenistic and Roman pottery and coins have been documented in the medieval strata, thus verifying that the medieval fortress was built over the remains of the ancient town.[287]

The largest harbour installation is the great breakwater (S6 in Figure 6.5c) which has a maximum width of c. 17 m across the top platform and c. 35 m at the bottom of the sea, and its *in situ* remains on the surface project c. 120 m into the sea from the modern shore line. Other recorded structures can be interpreted as fortifications related to the medieval harbour entrance (walls W1 and W2, structures S1b, S1c, S2a, S3 and S4) and sea walls (S2b, S2c and S5b). The maximum distance between the installations measured in the east – west direction is 320 m between S1b and W7b and in the north – south direction 160 m between the north end of S6 at the bottom of the sea and W5 on the current shoreline. The typical medieval Frankish fortifications and harbour installations were built in mixed technique employing reused ancient ashlar blocks and rubble set in mortar. The discovery of the foundations of an ancient Greek tower (structure S1a) between the Frankish wall W1 and fortification S1b confirm that the medieval installations were built directly on top of the Greek and Roman harbour.

In 2016, the first attempt to build a three-dimensional model of the underwater harbour structures using UAV photography was made. The fieldwork has been annually conducted in late August and September to take advantage of the quiet period in the prevailing wind patterns. It was soon evident that the ideal conditions to take aerial photographs of the underwater structures are at 6:50-7:30 am, a little before and after

285 For discussions of the ancient and medieval sources, see Servais 1961 and Athanasoulis *et al.* 2005.
286 Bon 1969.
287 Athanasoulis *et al.* 2005.

Figure 6.4a: Kyllene Harbour Project, 2016-2017. Documentation of underwater targets using aerial photography. UAV DJI Phantom 4 ready for flying and waiting for the sunrise (image by Jari Pakkanen).

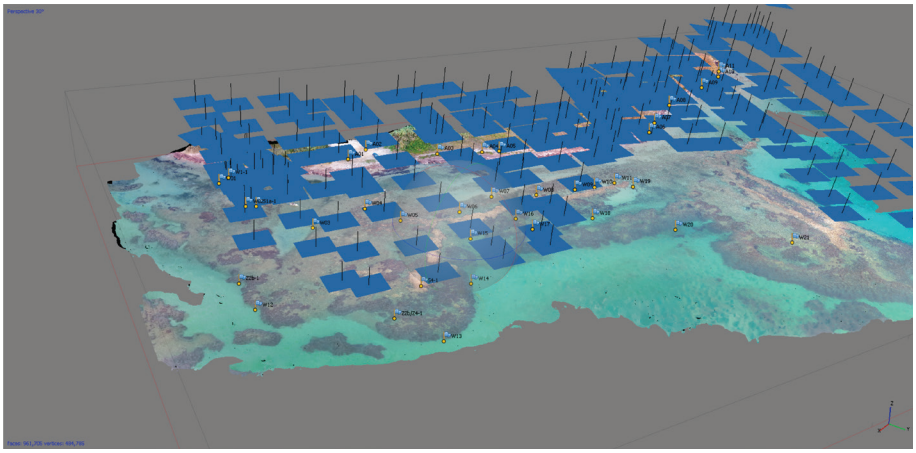


Figure 6.4b: Kyllene Harbour Project, 2016-2017. Modelling of underwater targets using aerial photography. Textured photogrammetry model with the locations of the drone photographs indicated by blue rectangles (image by Jari Pakkanen).

the sunrise. On several occasions there was great underwater visibility, with just enough light, no reflections of the sun on the water, and few surface ripples (Figure 6.4a). The textured model view in Figure 6.4b shows the locations of the 196 aerial photos taken on 4/9/2016 as blue rectangles: this was the first set which could successfully be used to build a model of the underwater structures from the UAV images.

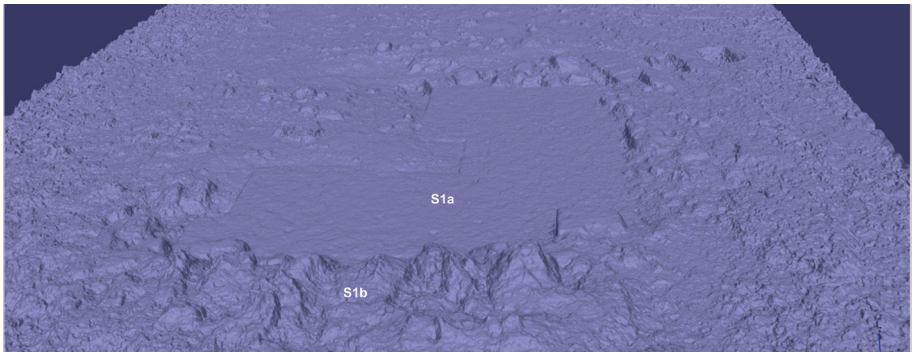


Figure 6.5a: Kyllene Harbour Project, 2016-2017. Three-dimensional surface model of underwater features derived from aerial photography: area of the Greek tower S1a (image by Jari Pakkanen).

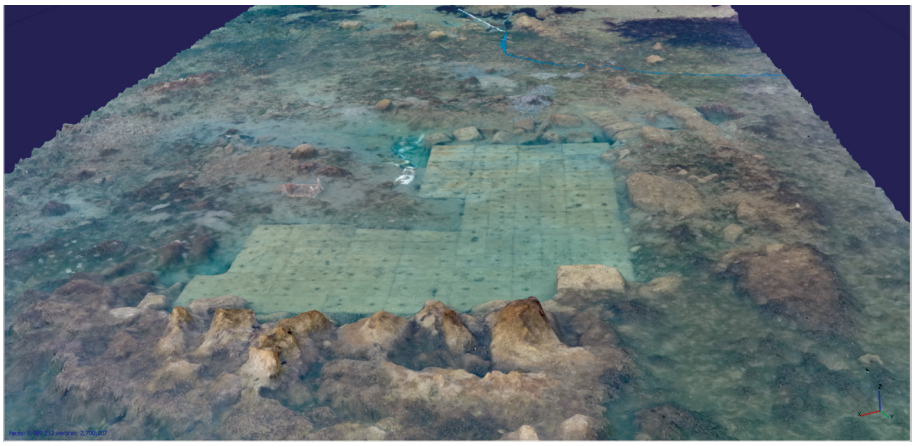


Figure 6.5b: Kyllene Harbour Project, 2016-2017. Three-dimensional textured photogrammetry model of the area of the Greek tower S1a (image by Jari Pakkanen).

Figures 6.5a and 6.5b present two perspective views of the model of the area around the foundations of a Greek tower S1a: the first model shows the three-dimensional surface model of the area and the second the textured model. The eroded blocks in the foreground are part of the Frankish harbour installation S1b. The highest points of the stones are c. 0.3 m above the sea level. The top surfaces of the preserved blocks of S1a are c. 0.6 m below the sea level. Despite refraction between air and water, it is possible to build a precise representation of the sea floor. The standard method of dealing with refraction in photogrammetry has been to use a complex algorithm and run several iterations to correct the surface geometry of the three-dimensional model.[288] However, as is demonstrated here, a different method using underwater reference point markers can achieve similar results as the computational approach of the standard method. Due to shallow water and small height differences only nine reference markers on the seabed were needed to correct the distortions of the model in this area. The detailed model

288 Georgopoulos and Agrafiotis 2012; Skarlatos and Savvidou 2015.

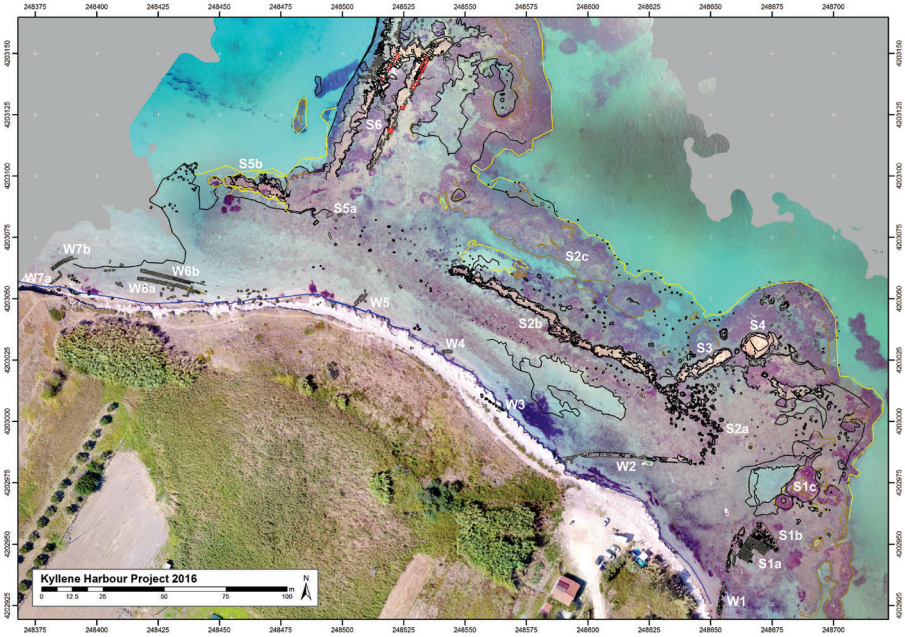


Figure 6.5c: Kyllene Harbour Project, 2016-2017. Total station survey data (line drawing) superimposed on top of the orthomosaic of the harbour (image by Jari Pakkanen).

shown in Figures 6.5a and 6.5b is based on 104 photographs taken at an altitude ranging from 7 to 15 m.

The model of the harbour structures in Figure 6.5c is created from 385 aerial photos. The deepest points of the model at the north end of the breakwater S6 are c. 6 m below the surface of the sea. In order to rectify the geometry of the model it was necessary to use 59 markers across the whole area. The resulting model matches very well with the stone-by-stone total station survey of the study area. The three-dimensional model can be used to create a two-dimensional rectified and scaled projection using the mosaic of individual photos. The readability of this orthomosaic is greatly enhanced by superimposing the total station line-drawing on top of it.

The high-precision total station documentation of the area of the Greek tower S1a was carried out in 2008-2011 using a three-person survey team and working only when there were no afternoon waves: the team working in the water consisted of a snorkeller pinpointing the mini prism tip and a relay person communicating with the surveyor behind the total station. The underwater model and the total station line-drawing of the ashlar blocks match well together (Figure 6.6a). However, due to slight surface ripples, it would not be possible to measure the dimensions of the individual blocks from the orthomosaic as accurately as from the total station data. The benefit of UAV-borne photogrammetry is the possibility of documenting the surface textures of both the manmade and natural features of the study area and, especially, the speed of recording: it is unlikely that a highly time-consuming project of underwater stone-by-stone line-drawing of the whole harbour would be initiated now that a faster alternative is available.

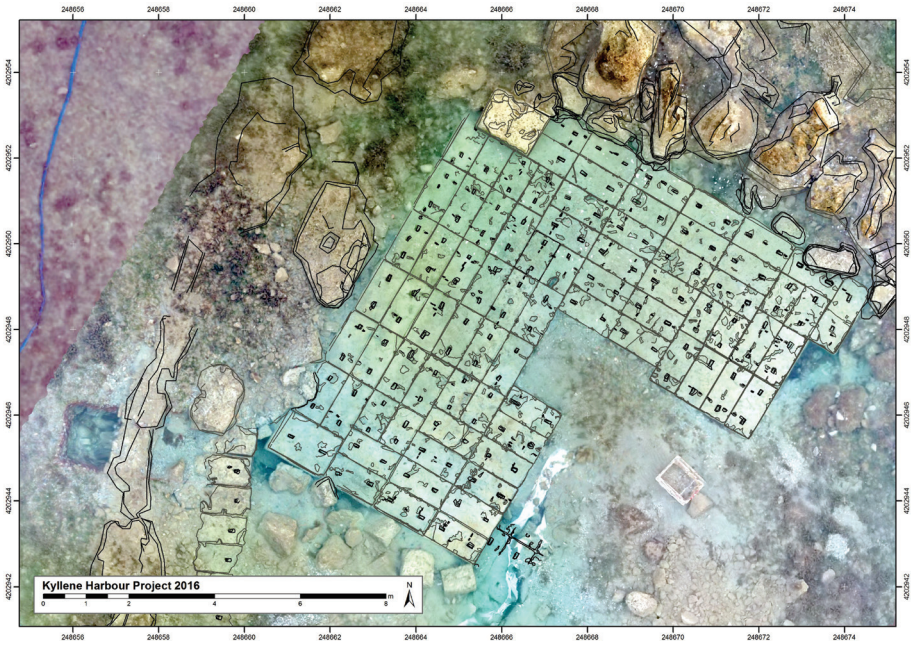


Figure 6.6a: Kyllene Harbour Project, 2014-2016. Total station survey data (line drawing) superimposed on top of the orthomosaic of the Greek tower S1a (image by Jari Pakkanen).

However, the first phase of documentation of the Greek tower S1a can be used as a case study to demonstrate why accurate three-dimensional total station data are necessary for architectural analyses. No scholarly consensus exists regarding the question of lengths and standardisation of possible Greek foot units. Where no inscriptional evidence exists, quantitative analysis of architectural measurements can provide an alternative approach.[289] In the Greek tower S1a, the width of nearly all the blocks is in the range 0.66-0.69 m and the length 1.34-1.38 m, so the block length is clearly twice their width. Cosine quantogram analysis provides a robust statistical method which can be used to estimate the length of a measurement standard based on a set of dimensions.[290] The larger the sample, the more probable it is that the quantitative method is able to detect an underlying basic dimension in the data set. Cutting building blocks to approximately fixed sizes was a relatively common practice in Greek monumental construction projects.[291] This made, for example, ordering the blocks from the quarries easier. Therefore, it is not a great surprise that the 162 block measurements from the Kyllene tower produce a statistically significant result. In Figure 6.6b the highest peaks q_1 and q_2 are the most probable candidates for the foot-standard. The length of the detected unit is unexpected: the two peaks in Figure 6.6b give very strong support to the hypothesis that a standard of 0.340-0.341 m was used for this particular building, and it is a foot-unit that has never previously been suggested for Greek architecture. The typical suggestions for the 'long' Greek measurement-standards are the 'Doric' foot of 0.325-0.329 m and the 'Samian'

289 Pakkanen 2013a, 11-22.
290 Kendall 1974; Pakkanen 2013a.
291 See e.g. Pakkanen 2006, 277-279.

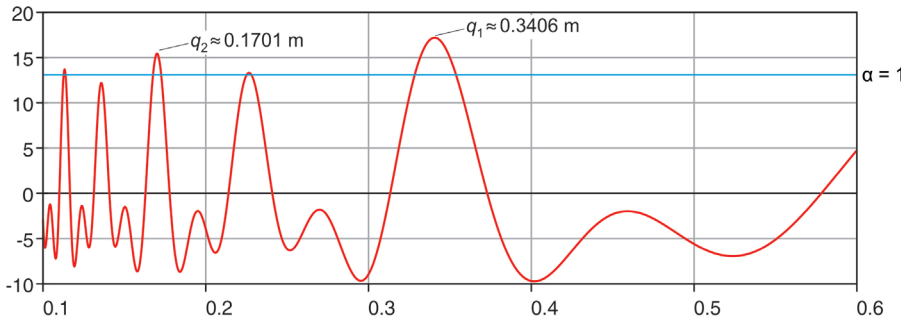


Figure 6.6b: Kyllene Harbour Project, 2014-2016. Cosine quantogram analysis of the block dimensions of S1a (n = 162) (image by Jari Pakkanen).

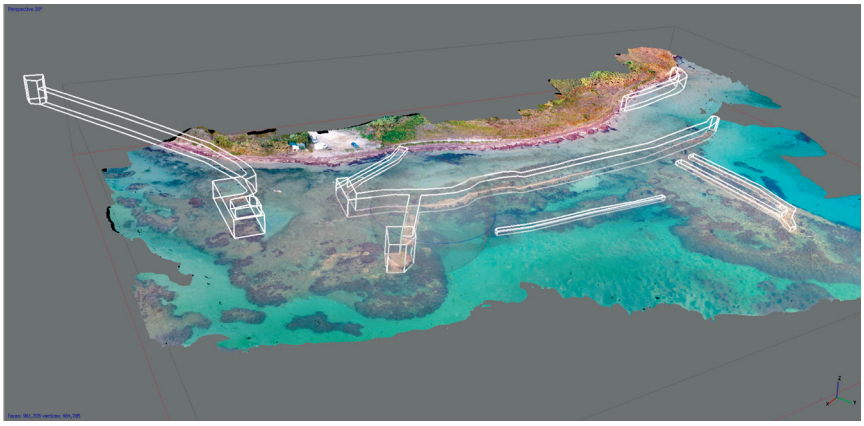


Figure 6.6c: Kyllene Harbour Project, 2014-2016. Hypothetical three-dimensional reconstruction of the harbour installations superimposed on top of the textured three-dimensional model. Projection from north (image by Jari Pakkanen).

foot of 0.348-0.350 m.[292] As this example demonstrates, metrological studies starting with preconceived notions of standardised Greek foot-units can result in invalid hypotheses of the design principles behind the analysed buildings. Methodologically sound analyses employing statistics are necessary if we wish to reach a scholarly agreement on this topic.[293]

The monumentality of the harbour installations can best be appreciated based on a reconstruction (Figure 6.6c). The quick three-dimensional sketch was produced in CAD and then superimposed on top of the textured photogrammetry model. There are, at present, too many unknown factors to produce a photorealistic model of the installations, but a wireframe image gives an idea of the possible heights and volumes of the constructions, and of the narrow entrance of the harbour.

292 See e.g. Wilson Jones 2001.
293 Cf. Pakkanen 2013a, 11-12.

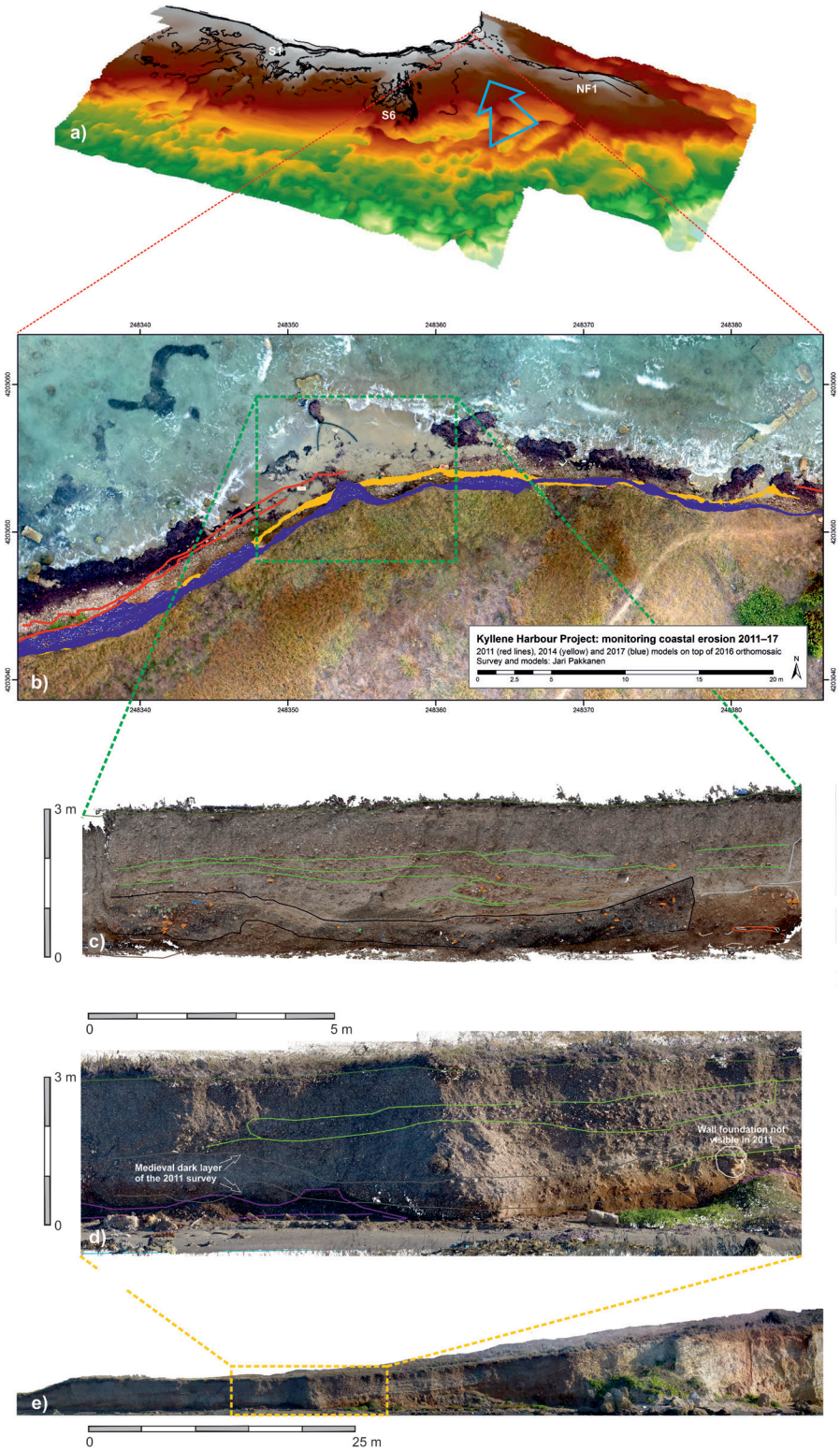
6.3.2 Monitoring coastal erosion to the west of the Kyllene harbour

The coastal scarp immediately west of the Kyllene harbour consists of archaeological occupational layers from antiquity to the end of the middle ages. Every winter, the waves directly hammer the archaeological layers of the site, critically endangering this part of the site (Figure 6.7). A programme of systematically monitoring the annual erosion of the cliff face was established in 2014 to collect data on the archaeological stratigraphy and its rate of destruction.

There are two features which jointly increase the destructive power of the waves: a finger of natural bedrock (NF1) and the great breakwater (S6) extend respectively c. 400 m and c. 150 m into the sea, and together they funnel the waves into the direction of the scarp (Figure 6.8a). One and a half metres of the cliff face disappeared into the sea as a result of the winter storms between 2011 and 2014. The sea floor data has been collected using an echo sounder, and in Figure 6.8a this information is combined with the total station survey data to produce a combined digital elevation model of the study area.

Figure 6.7: Kyllene Harbour Project, 2014-2016. Total station documentation of the cliff face with archaeological layers (image by Jari Pakkanen).

Figures 6.8a-e (right page): Kyllene Harbour Project, 2011-2017. Documentation of the fast erosion of the cliff face exposed to the sea. a) Digital elevation model of the coastal zone based on sonar and total station measurements (G. Papatheodorou, M. Geraga and J.Pakkanen). b) Orthomosaic and surveys 2011-2017 (image by Jari Pakkanen). c) Elevation of the cliff in 2014: total station survey and photogrammetry point cloud; black = medieval black layer; other colours indicate various stratigraphical layers and materials (image by Jari Pakkanen). d) Elevation of the cliff in 2017: total station survey and photogrammetry point cloud (image by Jari Pakkanen). e) Orthomosaic of the cliff face from the North in 2017 (image by Jari Pakkanen).


a)
S4
S6
NF1
b)
248340
248350
248360
248370
248380
4203060
4203050
4203040
Kyllene Harbour Project: monitoring coastal erosion 2011–17
2011 (red lines), 2014 (yellow) and 2017 (blue) models on top of 2016 orthomosaic
Survey and models: Jari Pakkanen
0
2.5
5
10
15
20 m
N
c)
3 m
0
0
5 m
d)
3 m
0
Medieval dark layer
of the 2011 survey
Wall foundation not
visible in 2011
e)
0
25 m

Since 2014, the area has been monitored annually by using photogrammetry and total station drawing. Figure 6.8b illustrates the annual changes of the cliff from 2011 until 2017. In certain places the archaeological layers forming the cliff face are quite resistant to weathering, but when these layers erode away, the changes are fast: up to 2.6 m of erosion has been recorded in the worst affected areas between September 2011 and September 2017.

Figures 6.8c and 6.8d show details of the cliff face elevations with the three-dimensional stratigraphical total station drawings superimposed on the dense point cloud generated using photogrammetry (the 2014 and 2017 views are of the same area). The textured surface models in photogrammetry are produced from dense point clouds. Importing the point clouds to CAD programs can be more straightforward than using the textured models. The model of Figure 6.8c was created from only 39 photographs taken with a handheld 12-megapixel digital camera. The model in Figure 6.8d was produced using 147 photographs taken with a 12-megapixel camera on the UAV. Several stratigraphical layers are visible both in the total station line-drawing and the point cloud, but the total station data is critical for the interpretation of the scarp especially in the case of the 2017 data where the lighting conditions for taking UAV photographs were not optimal. Finally, Figure 6.8e gives an orthomosaic of the cliff face as it was surveyed in 2017 viewed directly from the north.

6.3.3 Three-dimensional documentation at Pleuron

The ancient town of Pleuron was founded in 230s B.C.E. and it is located in Aitolia in western Greece (Figure 6.1). The early Hellenistic city walls, theatre and reservoir are particularly well-preserved. The maximum dimensions of the rock-cut reservoir were established in the new architectural survey: they are 13.0-20.7 m when measured north – south, 25.2 m east – west and 8.8 m deep at the western end. If filled all the way up to the brim, it would have been able to contain c. 3,700 m^3 of water. The reservoir at Pleuron is very difficult to document using traditional methods or even photogrammetry because of its size, depth and the presence of closely set partition walls inside. In 2015, the first attempt to build a three-dimensional model based solely on handheld digital photographs was not fully successful: from the top it was not possible to cover all features of the structure. Therefore, a new digital survey was carried out in 2016 using a combination of UAV-borne and handheld photography. Total station documentation for a line-drawing of the plan was also completed during this field season.

Figure 6.9a presents the locations of the aerial and handheld photographs: it was possible to fly the UAV between the walls and the bedrock in all of the compartments with the exception of the western-most one which has a width of only c. 1.4 m. Terrestrial photos were taken all around the monument and a total number of 410 images were used to produce the model in Figures 6.9a and 6.9b.

The reservoir plan, elevation of the second partition wall from the west, and the section in Figures 6.10a-c are directly derived from the three-dimensional model.[294] Aerial and terrestrial images can be combined to produce a single model, but the orthomosaics derived from the model need to be carefully checked: some photos can produce blurred sections and have to be excluded.

294 For an initial publication of the plan, elevation and section, see Kolonas and Stamatis 2016, 190.

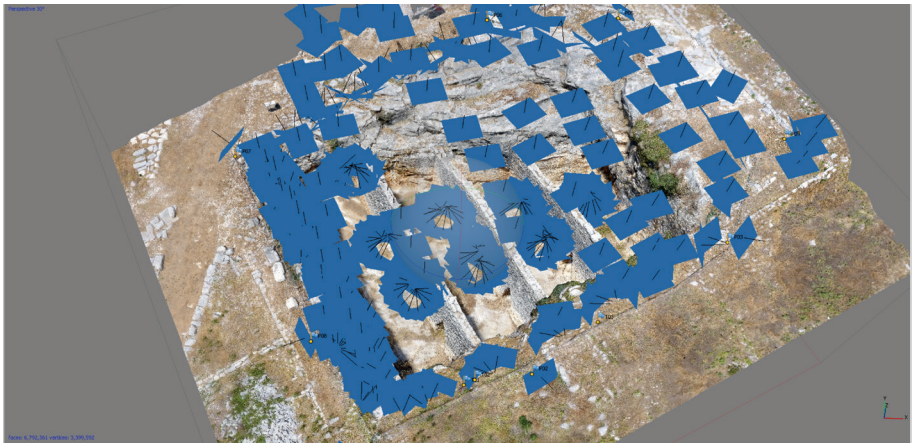


Figure 6.9a: Finnish Institute Three-Dimensional Development Programme, 2016. Hellenistic reservoir at Pleuron. Combining land-based and aerial digital photography to produce three-dimensional models using photogrammetry. Model with locations of the UAV and hand-held camera photographs indicated by blue rectangles (image by Jari Pakkanen).

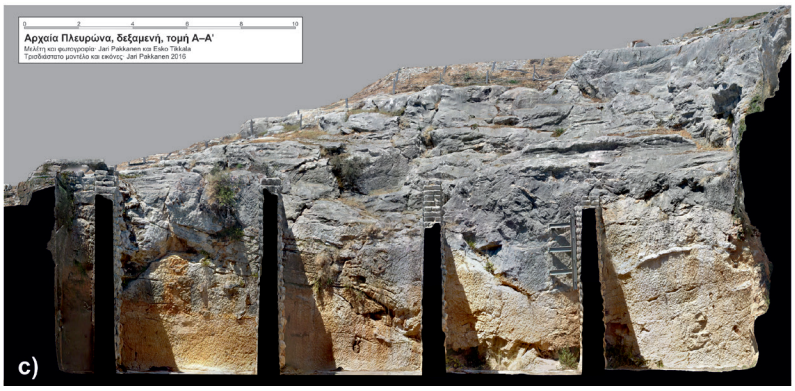
Figure: 6.9b: Finnish Institute Three-Dimensional Development Programme, 2016. Hellenistic reservoir at Pleuron. Textured photogrammetry model (image by Jari Pakkanen).

6.3.4 The shipshed complex at Naxos in Sicily

Since 2012, the city-scape project at Naxos in Sicily has concentrated on a thorough re-evaluation of the whole urban territory. The project has had three main aims: documenting the architectural remains unearthed since the 1950s, carrying out geophysical prospection inside the city walls, and excavating new small-scale test trenches at strategic locations.[295] The settlement was the first Greek colony in Sicily and it was founded in 734 B.C.E. by *oikists* from Chalcis on Euboia and Naxos in the Cyclades. The town was completely destroyed by Syracuse in 403 B.C.E. and subsequently abandoned. The Classical orthogonal city-grid is the best-known urban aspect of the town. The agora

295 Lentini *et al.* 2015.

Figures 6.10a-c: Finnish Institute Three-Dimensional Development Programme, 2016. Hellenistic reservoir at Pleuron. Plan, section and elevation derived from the three-dimensional model (JP in Kolonas and Stamatis 2016, 190). a) Plan. b) Elevation B-B′. c) Section A-A′ (image by Jari Pakkanen).



and the shipshed complex are both located in the northern sector of the town next to one another.[296]

Naxos had only a modest fleet of triremes and this is reflected in only having four slipways in the shipshed complex. The ships would have been pulled up the sand ramps to protect them from the elements and also from shipworms. The complex is an example of monumental utilitarian architecture. The size of the four slipways is more than twice the size of the largest temple in the city, Tempio B in the southwest sanctuary; also, the roof of the first phase of the shipsheds was decorated with gorgon and silenos-mask antefixes which are more often associated with sacred and civic than utilitarian architecture.[297] The Naxian shipsheds provide a case study of the possibilities of integrating total station line-drawings and a photogrammetry model with a digital reconstruction. Having an accurate three-dimensional model speeds up considerably the process of superimposing a reconstructed digital model on site documentation and fitting it with the features on the ground.

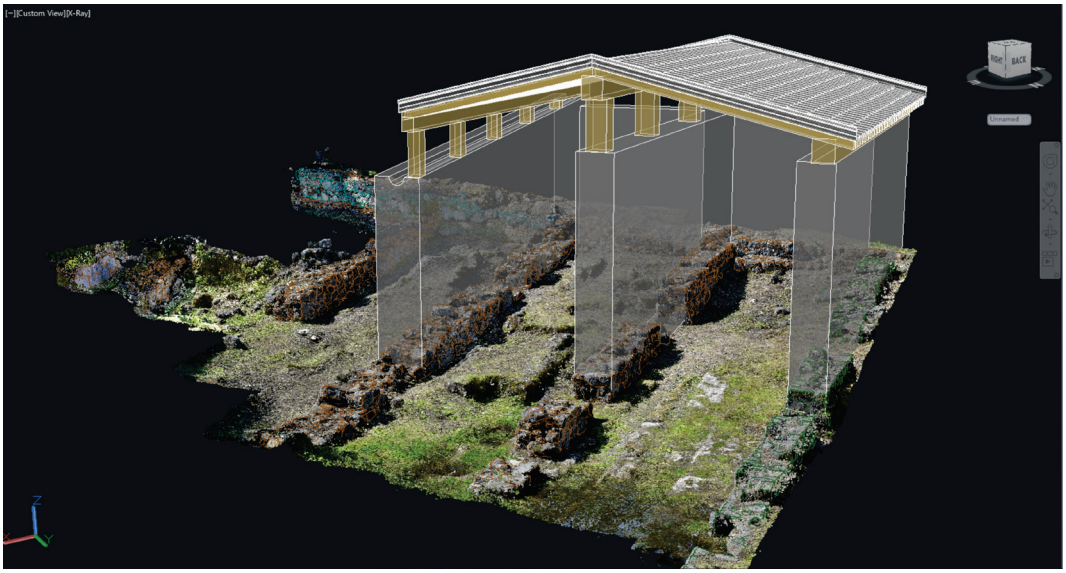
The shipshed complex in the northern part of the city was cleaned and documented in the spring of 2016. All walls were drawn using three total stations, but the delicate sand ramps were left covered with geotextiles. The produced photogrammetry model is based on 556 photographs and 40 georeferenced markers. Figure 6.11a presents the total station survey superimposed on the site orthomosaic and the different phases are marked with colours following the period classification in general use at the site: the late Archaic walls are drawn in orange, the north wall constructed as part of the Classical remodelling is green and the late Roman wall cyan. During the cleaning it was revealed that the diagonal wall at the back of slipways 3 and 4 is only related to the late Roman phase of the site and not to the Classical shipsheds: the previously presented interpretations of the architectural complex and its relation to the street behind it will need to be revisited.[298]

In Figure 6.11b the total station line-drawings are integrated with the dense point cloud of the photogrammetry model. The three-dimensional reconstruction in the northwest corner of the shipsheds covers only parts of slipways 1 and 2. The point cloud, line-drawing and reconstruction are combined in CAD. An earlier version of the reconstruction has been previously published,[299] but in order to produce Figure 6.11b it was georeferenced: this will make its future use in digital reconstructions of the city easier. Using photographs as the background of reconstructions has been the traditional approach of communicating to the wider public what the site looked like in the past, but finding the correct perspective to fit the model with the site photo can be time-consuming and it is limited to one particular view. When the digital reconstruction is integrated with the three-dimensional field documentation, the production of any projection or an animation of the target becomes a straightforward matter.

296 Pakkanen 2013a, 52-59.
297 Lentini *et al.* 2008, 379-385.
298 Lentini *et al.* 2008, 375-379; Lentini *et al.* 2015, 26, figure 9.
299 Lentini *et al.* 2008, figure 55.

Figure 6.11a (left): Urban Landscape Project of Naxos in Sicily 2016-2017. Shipshed complex. Orthomosaic of the complex with total station data (image by Jari Pakkanen).

Figure 6.11b (below): Urban Landscape Project of Naxos in Sicily 2016-2017. Shipshed complex. Reconstruction of the north-west part of the complex superimposed on the photogrammetry point cloud and total station line-drawing of the in situ architecture (JP image by Jari Pakkanen).



6.4 Conclusions

Photogrammetry has fast established itself as the mainstream method of documenting architecture and archaeological features in the field. This is largely due to low costs in hard- and software and also the user-friendly software which makes experimenting with sets of photographs feasible. The plans, elevations and sections are fast to do and they contain more information than traditional drawings. Being able to produce the documentation more rapidly could potentially result in more time devoted to the actual study of the monument. If traditional-looking line-drawings are preferred for publication, total station documentation using reflectorless laser produces more precise data than traditional two-dimensional drawings derived from hand-measurements and estimating the positions of the features. Using the laser setting on the total station decreases the time needed for recording to a fraction compared to surveying with a prism, and there is no need for the second person. Also, the relevant plans, elevations and sections can conveniently be exported from the CAD program into the preferred vector-based drawing program for final editing.

Aerial photography has the advantage of being able to rapidly record large areas and to obtain better views of the recorded targets. The relatively low resolution of most UAV images compared to hand-held digital cameras can be compensated for by flying at low altitude. Despite refraction between air and water, even underwater targets can be modelled using aerial documentation when careful attention is paid to the time of day and conditions when the photography is carried out.

One of the main advantages of superimposing total station data on top of the photogrammetry point clouds or textured models is enhancing the readability of the produced image. It is a good way of separating features and chronological phases of the documented monument, and it is possible to highlight certain elements of the recorded targets. In the completed three-dimensional models and orthomosaics subtle changes in colour and texture can be difficult to distinguish: when features are recorded in the field with total station line-drawing, this method of documentation can be combined with photogrammetry in the post-processing phase.

Acknowledgements

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CONSTRUCTING MONUMENTS, PERCEIVING MONUMENTALITY & THE ECONOMICS OF BUILDING

In many societies monuments are associated with dynamic socio-economic and political processes that these societies underwent and/or instrumentalised. Due to the often large human and other resources input involved in their construction and maintenance, such constructions form an useful research target in order to investigate both their associated societies as well as the underlying processes that generated differential construction levels. Monumental constructions may physically remain the same for some time but certainly not forever. The actual meaning, too, that people associate with these may change regularly due to changing contexts in which people perceived, assessed, and interacted with such constructions.

These changes of meaning may occur diachronically, geographically but also socially. Realising that such shifts may occur forces us to rethink the meaning and the roles that past technologies may play in constructing, consuming and perceiving something monumental. In fact, it is through investigating the processes, the practices of building and crafting, and selecting the specific locales in which these activities took place, that we can argue convincingly that meaning may already become formulated while the form itself is still being created. As such, meaning-making and -giving may also influence the shaping of the monument in each of its facets: spatially, materially, technologically, socially and diachronically.

The volume varies widely in regional and chronological focus and forms a useful manual to studying both the acts of building and the constructions themselves across cultural contexts. A range of theoretical and practical methods are discussed, and papers illustrate that these are applicable to both small or large architectural expressions, making it useful for scholars investigating urban, architectural, landscape and human resources in archaeological and historical contexts. The ultimate goal of this book is to place architectural studies, in which people's interactions with each other and material resources are key, at the crossing of both landscape studies and material culture studies, where it belongs.

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