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ANCIENT THEATERS IN GREECE AND THE CONTRIBUTION OF GEOINFORMATICS TO THEIR MACROSCOPIC CONSTRUCTIONAL FEATURES

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ABSTRACT

Among the countless monuments of world cultural heritage of Greece, ancient theaters are studied in this work from the engineer's point of view. With the help of aerial and satellite archeology, and of bibliographic research, their positions were determined and their size characteristics were calculated. Images of three different Unmanned Aerial Vehicles, UAV (Remote Control Helicopter, Balloon, Drone), Ikonos-2 satellite images, and images from Google Earth were used. Remote sensing image processing and its products are also presented, such as Digital Surface Models (DSMs) and the ortho images of the ancient theaters with spatial resolutions ranging from 1cm to 2.5m, referenced to the Greek Geodetic Reference System of 1987 (GGRS 87). In addition, information and conclusions were made through Geographical Information Systems (GIS) about the macroscopic characteristics of ancient theaters, such as orientation (the main orientation of the theaters is from 90^o to 270^o, while for the construction of the theaters the average direction of the winds, which should be lateral, was taken very seriously,), area (the area of the koilon of ancient Greek theaters ranges from 56m^2 to 7,640m^2), altitude (the altitudes of the ancient Greek theaters range from 6m to 870m), distances from the coastline (ranges from 11m to 42,559m), visibility (ranges from 0.63% to 100%), etc.

KEYWORDS: Ancient theater; UAV; Remote Sensing; GIS.

1. INTRODUCTION

The ancient Greek theatre appeared in the 6th century B.C. (Archaic Period). It is an open-air amphitheatrical construction of a semi-circular plan around a circular square (Fig. 1). It served religious rituals, music and poetry contests, theatrical performances, municipality assemblies or city-state parliament assemblies, and was even used as a market. The architectural style of the theatre resulted in its stone form around 335-330 B.C. In the centre of the ancient Greek theatre, a circular, often paved square, the orchestra (the stage of today's theatres) is found. The amphitheatrical area that surrounds the orchestra is the koilon (or cavea). The scene is a rectangular, oblong, roofed building, added in the 5th century B.C. in the circumference of the orchestra opposite the koilon. Initially, the scene was on ground level and was used only as a dressing room (such as the current backstage and the dressing room). In front of the scene, to the side of the orchestra, the proscenium is located which was a gallery with columns or semi-columns. At both ends of the scene, the wings (or proskenion) stood out, which were two parts that gave the shape of the Greek letter "Π" to the scene. The koilon is the sloping cone-shape level, in which the spectators' seats are spread amphitheatrically. Its curvature follows the curvature of the orchestra, and its ends end up in retaining walls (or analemmata) made of rectangular stonework. The koilon is usually united with the building of the scene. Between its retaining walls and the edges of the scene, there were corridors for the attendance of the spectators and the entrance of the dance after the opening of the play. These corridors are called parodoi. Horizontal corridors, the diazomata, divided the koilon into zones. Each zone is divided by transverse radial stairs into wedge sections, the kerkides. Above the last row of seats the theatre could be extended, if required by the needs, with the addition of the epitheatron (Kuritz, 1988; Brockett, 1999; Frederiksen, 2000).

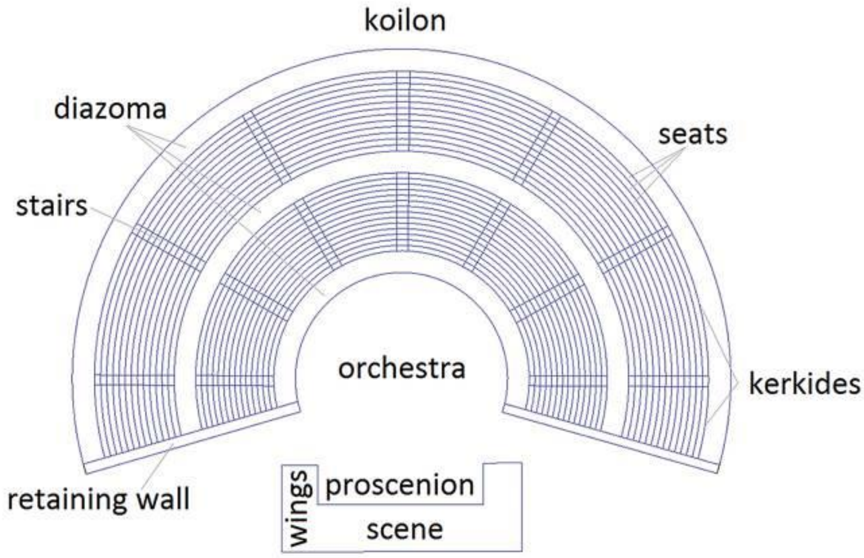

Figure 1. Ancient Greek theatre parts.

There are fifty-seven (57) ancient theaters (Fig.1, Table 1) dating from the 6th century B.C. until the Roman era, which are saved and can be visited (Fiechter, 1933; Renfrew and Wagstaff, 1982; Andreou, 1983; Papadakis, 1983; Kappel, 1989; Preka-Alexandri, 1999; Intzesiloglou, 1991; Kapokakis, 1991; Kolonas, 1994; Isler, 1994; Rizakis, 1995; Bommelaer, 1996; Bonniai and Mark, 1996; Karadedos et al., 1999; Katsikoudis, 2000; Welch, 2000; Tziafalia, 2000; Palyvou, 2001; Karadedos and Koukouli-Chrysanthaki, 2001; Korres, 2002; Gogos, 2004; Karadedos, 2005; Schwandner, 2006; Fraisse and Moretti, 2007; Dietz et al., 2007; Farinetti, 2008; Dyggve, 1960; Spanakis, 1966). Apart from these theaters, there is evidence that there were another 35 ancient theaters (Dyggve, 1960; Spanakis, 1966; Lazaridis, 1989; Velenis and Abam-Veleni, 1992; Livadiotti and Rocco, 1996; Pliakou, 1997). Only a few remains of a small number of theaters are saved (but cannot visited yet), while most of them have not been discovered yet. Their date of construction is unknown.

Table 1. Ancient theaters in Greece.

Theaters that are saved					Theaters known from sources or theaters with few saved remains that can been studied			
A/A	Theater name	Construction century (B.C.)/ Era	Theater's position (latitude N and longitude E in decimal degrees, Reference System: WGS84)		A/A	Theater name	Theater's position (latitude N and longitude E in decimal degrees, Reference System: WGS84)	
			N	E			N	E
1	Dionysus	6th	37,9703327	23,7279769	1	Acharnon	38,077723	23,731602
2	Thoriko	5th	37,7380710	24,0536724	2	Ramnouda	38,219932	24,026795
3	Amphiariou	4th	38,2916302	23,8453615	3	Ikaria in Attica	38,093006	23,898738
4	Zea	4th	37,9372513	23,6447575	4	Amphipolis	40,816335	23,846298
5	Evonimos	4th	37,9159513	23,7415695	5	Samothraki Kaveirio	40,498240	25,528947
6	Epidaurus	4th	37,5961220	23,0794588	6	Kos	36,883588	27,285306
7	Argus	4th	37,6316160	22,7196434	7	Alasarna's	36,775939	27,134882
8	Githion	R.P.*	36,7637603	22,5626825	8	Lindos	36,087538	28,079857
9	Sparta	2nd	37,0820670	22,4235940	9	Lisso	35,238646	23,784354
10	Aigira	5th	38,1285564	22,3778755	10	Fiskardo	38,451776	20,566072
11	Leontiou	4th	38,0303716	21,9130986	11	Ierapytna	35,013771	25,746823
12	Ilidos	4th	37,8937107	21,3760130	12	Argos	38,921456	21,183079
13	Platiana	4th	37,5403669	21,7523220	13	Klitora	38,025330	22,137012
14	Isthmia	4th	37,9164060	22,9944971	14	Kerinia	38,146178	22,146735
15	Corinth	5th	37,9059366	22,8774715	15	Flioudos	37,816628	22,719688
16	Sikyon	3rd	37,9840934	22,7113286	16	Episkopi Tegea	37,484633	22,419257
17	Messini	4th	37,1778204	21,9189859	17	Thebes	38,326495	23,317837
18	Mantinia	4th	37,6182137	22,3924597	18	Kaveirio in Thebes	38,367643	23,177842
19	Megalopoli	4th	37,4101170	22,1272406	19	Feres	39,371512	22,708011
20	Orchomenu	4th	38,4933116	22,9751533	20	Thessaliki	40,629054	22,948161
21	Delphi	4th	38,4824423	22,5005320	21	Avdira	40,931854	24,970205
22	Eretria	4th	38,3986087	23,7905539	22	Isthmos	36,727226	26,953764
23	Pleurona	3rd	38,4136048	21,4086537	23	Lefkada	38,810128	20,705015
24	Makinia	6th	38,3558915	21,7250017	24	Aigina	37,723176	23,475038
25	Stratou	4th	38,6717038	21,3194594	25	Amorgos	36,866993	25,959686
26	Oiniades	4th	38,4095655	21,1989425	26	Androu	37,882714	24,952368
27	Kalydona	3rd	38,3714063	21,5313197	27	Antiparos	36,996542	25,025768
28	Gitanon	3rd	39,5711486	20,2597563	28	Exonis	37,874213	23,765885
29	Nicopoli	1st	39,0234462	20,7372607	29	Elefsina	38,069559	23,508869
30	Kassopi	3rd	39,1467933	20,6717472	30	Kastelorizo	36,139914	29,580195
31	Dodoni	3rd	39,5466906	20,7877600	31	Mithimna	39,367160	26,169745
32	Dimitriada	3rd	39,3434318	22,9242449	32	Paros	37,080661	25,155149
33	Fthiotidis Thebes	3rd	39,2717652	22,7664432	33	Tinos	37,553313	25,138123
34	Larissa I	4th	39,6403469	22,4152704	34	Trizina	37,500849	23,344320
35	Larissa II	4th	39,6403686	22,4120351	35	Tirnavos	39,709605	22,314894
36	Vergina	4th	40,4789741	22,3220385				
37	Mieza	2nd	40,6442142	22,1223950				
38	Dion	3rd	40,1723535	22,4918826				

39	Philippi	4th	41,0128807	24,2866648
40	Thassou	4th	40,7820502	24,7175838
41	Maroneia	3rd	40,8788018	25,5191887
42	Hephestia	5th	39,9645880	25,3181173
43	Mytilene	4th	39,1105642	26,5466536
44	Delos	3rd	37,3970012	25,2680602
45	Milos	4th	36,7378256	24,4208524
46	Thira	3rd	36,3633327	25,4788330
47	Kathrea	1st	37,5604409	24,3297138
48	Gortina (large)	R.P.	35,0634085	24,9457585
49	Gortina (small)	R.P.	35,0592446	24,9493814
50	Koufonissi	R.P.	34,9474206	26,1298520
51	Aptera	3rd	35,4612799	24,1410909
52	Eliros	R.P.	35,2874068	23,7951709
53	Chersonisou	R.P.	35,3188043	25,3891480
54	Orchomenos in Arcadia	R.P.	37,7246118	22,3151961
55	Samos	R.P.	37,6952218	26,9349244
56	Chaeronea	5th	38,4942829	22,8417398
57	Amvrakia	4th	39,1609208	20,9837309

*Roman Period

In this paper, fifty-seven (57) ancient theaters will be studied in particular, which can be documented with the help of aerial and satellite archeology.

The measuring information will be derived from image processing from Ikonos-2 satellite (Hadjimitsis et al., 2012), Google Earth (Kaimaris et al., 2017a), and three (3) different Unmanned Aerial Vehicles (UAVs) (Liritzis et al., 2017; Hatzopoulos et al., 2017).

2. PLATFORMS FOR THE COLLECTION OF IMAGES OF ANCIENT THEATERS AND THEIR DIGITAL PROCESSING

2.1. *UAV/RC helicopter*

The RC (Remote Control) Helicopter (Fig. 2.a) has a lifting power of eight (8) Kg, 1.39 m length, 0.15 m width, 1.53 m helix aperture and 5.10 Kg weight. At the bottom of the helicopter there is the dependence of a Canon 1200D, 18MP digital camera (Patias et al., 2008; Patias et al., 2013).

Of the five (5) ancient theaters depicted with the RC Helicopter, the case of the ancient theatre of Neos Plevronas (Western Sterea Hellas, Fig. 2.d) will be presented. The archaeological position of the great fortification settlement of Neos Plevronas was one of the largest ancient cities of the wider region, which was established after 235 B.C, immediately after the destruction of Old Plevronas by Dimitrios II Aetolikos (King of Macedonia, Greece). It develops at an altitude of 195 to 280 m, at the southwest end of Mount Arakountos (or Libra). Homer states that the city participated in the campaign against Troy. Neos Plevronas experienced great prosperity during the Hellenistic period, but after the Battle of Aktion in 31 B.C. it declined and its inhabitants were transferred to another position by the Romans. The ancient city was built according to the Hippodamian system, on a larger scale than the old city. Having a privileged position with a panoramic view, it retained control of the land and sea pathways, as well as the resources (salines and lagoons). From the rescued monuments of the city, the ancient theatre occupies an important place. It is located at the southwest of the city and its proscenion rests in the inner part of the fortification wall. The orchestra forms a semicircle of about 11m, while the originality of the theatre concerns the incorporation of part of the scene into the structure of the wall. The functionality of the scene is complemented by a tower of the fortification, which was an auxiliary space for the scene and the backstage. The koilon is partly carved into the natural rock and partly built. European travellers E. Dodwell and W.J. Woodhouse were aware of the city's ruins already from the early 19th century. The first excavation research was conducted by R. Herzog and E. Ziebarth in the late 19th century. The German scholar E. Fiechter published the first systematic study of the monument in 1933. A short excavation research was conducted in 1993 in cooperation with the Austrian Archaeological Institute. Since 2002, the ancient city has received and experienced significant interventions by the Hellenic Archaeological Service for the protection, preservation and promotion of its monuments. Geodetic measurements and images were taken with UAV / RC Helicopter for modern measurement documentation of the ancient theatre of Neos Plevronas.

Figure 2. Self-made unmanned aerial vehicles, a. RC Helicopter, b. RC Balloon, c. Drone and d. The positions of the three (3) examples of UAV flights in Greece (the position of Thessaloniki appears only for orientation).

In the ancient theatre, measurements of adjacent ground control points (GCPs), points with 3D coordinates, X, Y, and Z) were made with a ground station (Total Station TCR 305, with or without reflector, LEICA®) of horizontal and vertical accuracy better than 5mm at the Greek Geodetic Reference System of 1987 (GGRS87). GCPs were pre-tagged by archaeologists with special colored material, not detrimental to the monument (Fig. 3).

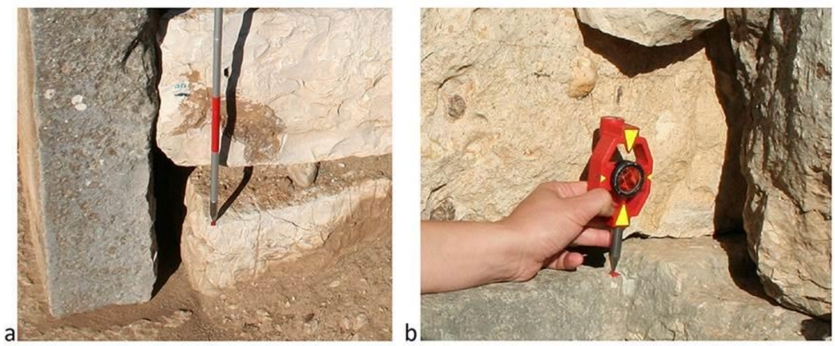

Figure 3. Ground Control Points (GCPs) pre-tagging and their measurement with the ground station (personal file).

The RC Helicopter does not have an autopilot, and therefore cannot carry out an automated image capture. For an average image scale of 1/1,000 (the modern measurement documentation of the ancient theatre demanded the image acquisition of high scale), the relative (not absolute) flight height H = 20m was calculated, as well as the distance between the strips. The above were carefully checked during the manual flight with measurements from the geodetic station. 159 images of average spatial resolution of 4mm were obtained (due to the manual flight many images were collected), with overlapping up to 65-85% per image, and 30-50% per strip (Fig. 4.a). The images were processed in Agisoft PhotoScan®. After the insertion of the study area images and the GCPs the coordinate system was chosen (GGRS87 (EPSG: 2100)), and the automated alignment of the images (accuracy: High) was conducted. For the production of the Points Cloud, High Quality was chosen (specifies the desired reconstruction quality, and higher quality settings can be used to obtain more detailed and accurate geometry). At the stage of dense point cloud generation reconstruction the software calculates depth maps for every image. Due to some factors, there can be some outliers among the points. To sort out the outliers the software has several built-in filtering algorithms. For the construction of the Building mesh in surface type Height field was chosen and in Source data (specifies the source for the mesh generation procedure) Dense cloud was chosen (it will generate high quality output based on the previously reconstructed dense point cloud). Moreover, for the creation of the Texture in Mapping mode, Orthophoto was chosen, and in Blending mode (selects the way pixel values from different photos will be combined in the final texture) Mosaic was chosen (gives more quality for orthophoto and texture atlas, since it does not mix image details of overlapping photos but uses the most appropriate photo) (Kaimaris et al., 2017b). Finally, the Digital Surface Model (DSM) and the ortho image (Fig. 4.b) of the ancient theatre were exported with a spatial resolution of 1cm, at GGRS 87.

Figure 4. a. The 3D model of the ancient theatre of New Plevronas and the images' location (Agisoft PhotoScan®), b. ortho image (spatial resolution 1 cm) of New Pevronas (personal file).

2.2. *UAV/RC balloon*

The RC balloon (Fig. 2.b) has a diameter of 2m. When filled with helium (~5m3), the balloon has a load capacity of 3.6 Kg. It has four hooks, from which the image acquisition system of carbon fiber is anchored. The image acquisition system has a total weight of 1.24 Kg (without the sensor). It consists of a base mounting suitable for any DSLR camera, camcorder, etc., with a weight of up to 1.5 Kg. The digital camera Canon EOS 1200D, 18 MP, was used for images acquisition. The combined movement (servomechanisms actuation) of the four members (base, arm, vertical member and cross edge) allows the sensor to rotate 360°, horizontally and vertically. A turbojet electric motor for controlling the mobility of the balloon is fitted to the vertical member. The blueprint (dimensions, weights) of the image acquisition system's four members was designed in flight-simulation software that determined the lengths of the dependence ropes from the balloon hooks, and the position of the jet engine. Lastly, the controller for the image acquisition system, the horizontal / vertical rotation sensor and the activation of the jet engine is mounted on the console of the ground station (Kaimaris and Patias, 2015).

From the two ancient theaters that have been documented with the RC Balloon, the case of the ancient theatre of Philippi (East Macedonia, Greece, Fig. 2.d).

Philippi was an ancient city of eastern Macedonia (Greece), and has been inhabited since the Neolithic era. Its history begins in 360/359 B.C, when settlers from Thassos founded the first city, Krinides. When in 356 B.C Thassos was threatened by the Thracians, they searched for Philippou's II help. Meanwhile, Philippos acknowledged the city's economic and strategic importance and occupied it, fortified it, and renamed it to Philippi. The city flourished both during the Macedonian Kingdom and during Roman times. The ancient Via Egnatia road (Kaimaris, 2006) passed through the city. In Phillipi, Apostle Paul founded the first Christian church on European territory. The ancient theatre of Philippi dates back to the years of the King of Macedonia (in the 4th century B.C), with the addition of the epitheatron. It was documented in 2012 through pilot flights and applications of RC Balloon (Kaimaris and Patias, 2015).

The RC Balloon does not have an autopilot and, therefore, cannot perform an automated image capture. For an average picture scale of 1/5,000 (random scale selection/pilot flight), the flight height of H = 80m was calculated. During the manual flight, the ability of stability of the system for an extended period of time allows for the acquisition of a small number of images. A total of 6 images of 20mm average spatial resolution were obtained with an overlapping of approximately 60% to 90% per image (Fig. 5.a). In addition to the images, GCPs were measured using Global Position System (GPS) in GGRS87 (horizontal and vertical accuracy better than 15mm). The images were processed (similar to RC Helicopter) in Agisoft PhotoScan® (Kaimaris et al., 2017b). Finally, the DSM and the ortho image of the ancient theatre were exported with spatial resolution of 3cm (Fig. 5.b) to GGRS87.

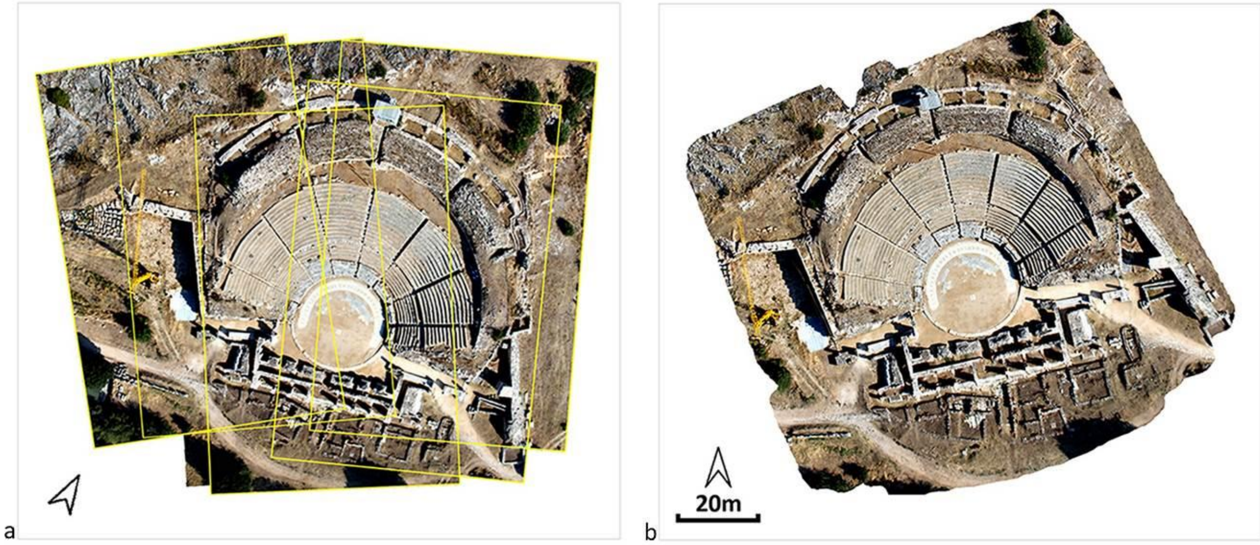

Figure 5. a. The ovelapping of images (1.5cm spatial resolution) collected in 2012 with RC Balloon at the site of the ancient Philippi Theatre, b. The ortho image (3 cm spatial resolution) of the Philippi Theatre (personal fie).

2.3. *UAV/Drone*

The dependency base (camera gimbal) of the camera sensor of the drone (Fig. 2.c) allows its vertical rotation of 180^{o} (± 90^{o} from nadir) during the flight. The used optical sensor is the digital camera DSLR Canon 1200D, 18 MP, while its autopilot, Wookong M of DJI, incorporates Controller, IMU (Inertial Measurement Unit), and GPS. According to the specifications of the autopilot, the GPS horizontal and vertical accuracy are about ±2m and ±0.5m respectively, and the IMU angle measurement accuracy in three axes ranges approximately from 1o to 2o. The UAV can take off and land automatically. The UAV's lifting capacity, beyond its weight, is 2.5 Kg, and its flight time ranges from 10 to 15 minutes, depending on the type of flight and the ambient temperature.

From the documented archaeological sites by the Drone, one only relates to an ancient theatre, which specifically is the ancient theatre of Amphipolis (Eastern Macedonia, Greece, Fig. 2.d), which will be briefly presented (the research is in process).

In 437 B.C Agnon, son of Nikias, sent to eastern Macedonia (Greece) by the Athenians as a settler, occupied the wider area of the position "Nine Roads", removed the Edonoians (Thracian Ancient Gender), and built a city under the name of "Amphipolis". Approximately 2Km northeast of Amphipolis is the archaeological site of the Kasta Tomb. During the Peloponnesian War, specifically in 422 B.C, the city was conquered by Sparta after a fierce battle with the Athenians. For the salvation of the city, the Athenians sent a mission under the leadership of Thucydides (the later historian). The mission failed, which led Thucydides to exile. Afterwards, Cleon was sent, who was killed during the battle of Amphipolis, a violent battle in which the Spartan General Brassis died too. With the "Peace of Nicias", Sparta pledged to render Amphipolis to Athens, which did not happen resulting in the violation of the peace and the restart of the Peloponnesian War. In 357 B.C Amphipolis was captured by Philippos II the father of Alexander the Great and became part of the Kingdom of the Macedonians (Greece). Philippos II transported a large number of his citizens to Amphipolis in order to change the population's composition for his benefit. During the period of Alexander the Great, Amphipolis had become a very important naval base of the Macedonians, and the birthplace of three important admirals, Nearchos, Androstene and

Laomedon. From there, Alexander the Great sailed to Asia (Dadaki, 2012). With the fall of the Macedonian Kingdom by the Romans, Amphipolis became part of the Roman Empire. The fact that Ancient Via Egnatia Road passed through Amphipolis (Kaimaris, 2006) helped to preserve its significance and importance in the Early Christian period. Through the Via Egnatia Apostle Paul passed through the city in 49-50 AD, on his way from Philippi to Thessaloniki. In the later Roman times, the city had a significant economic development, as witnessed by the Early Christian temples of the city of the 5th and 6th centuries AD. After the raids of the Slavs at the end of the 6th century AD Amphipolis is gradually deserted and abandoned in the 8th century AD (Dadaki, 2012).

In the city of Amphipolis there was an ancient theatre, which was recently identified with aerial and satellite archaeology tools (the research is in process). Moreover, a drone was used to capture images of high spatial resolution (Canon EOS 1200D, 18 MP, used for images acquisition) in the area where the position of the covered orchestra of the ancient theatre was determined. The drone has an autopilot, and therefore can perform an automated image capture. For a 1/5,000 (same scale as that of Philippi) mean image scale, a flight height of H = 85m was calculated, allowing 2 cm spatial resolution images to be collected. The flight plan was implemented through four (4) flight strips, with 80% overlap per image, and 40% per flight strips. A total of fifty-six (56) pictures were collected (result of the flight plan). In addition to capturing images, GCPs with GPS (Fernández-Hernandez et al., 2015) measurements (horizontal and vertical accuracy better than 15mm) were performed in GGRS87. The images were processed (similar to RC Helicopter) in Agisoft PhotoScan® (Kaimaris et al., 2017b). Finally, the DSM and the ortho image of the ancient theatre were exported with a spatial resolution of 3cm (Fig. 6) to GGRS87.

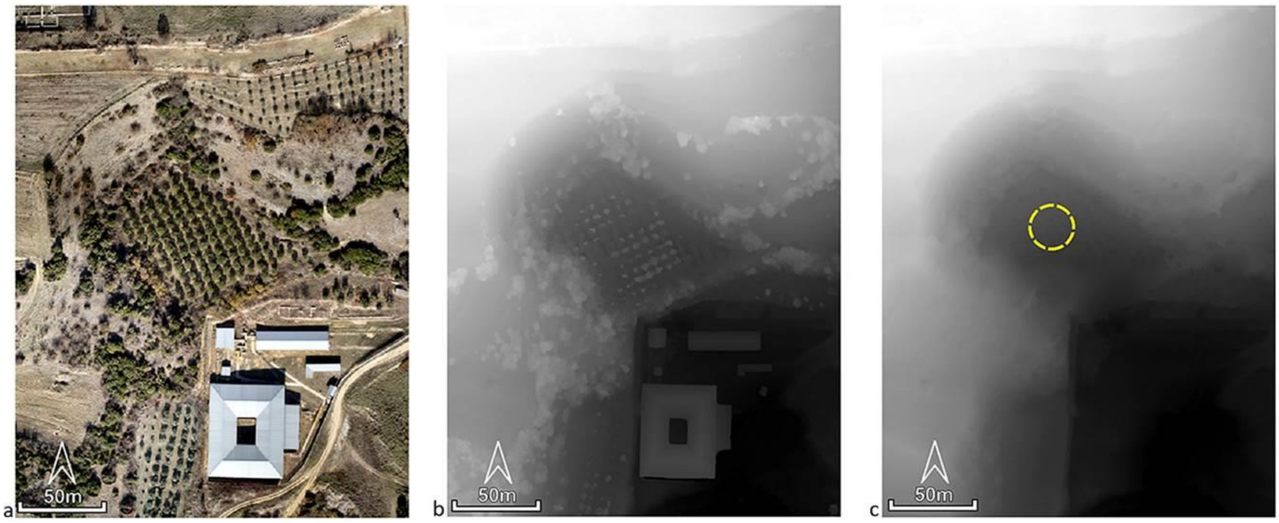

Figure 6. Products of the digital image processing of the Drone. a. Ortho image, b. Digital Surface Model (DSM), and c. Digital Terrain Model (DTM), with altitudes from 79.3m (black) to 123.5m (white), and the possible location (the research is in process) of the theatre's orchestra (yellow color). Spatial analysis of geospatial products of 3 cm (personal file).

2.4. *Satellite Ikonos-2*

The Ikonos-2 satellite sensor (1999-2015) was a high-resolution satellite operated by DigitalGlobe. Its analysis reached 4m multispectral (R, G, B, Near-Infrared (NIR)) and 1m panchromatic resolution. It is an important tool of archaeology prospection (remote sensing archaeology), with hundreds of applications to date (Pavlidis et al., 2001; Campana, 2002; Lambers and Remondino, 2007; Sever and Irwi, 2003; Due Trier et al., 2009; Castrianni et al., 2010; Dore and McElroy, 2011; Caspari et al., 2014; Deroin et al., 2017).

The broader area of six (6) ancient theaters of Table 1 is covered geospatially by six (6) Ikonos-2 satellite images (Fig. 7.a). For the ortho rectification of the images, the Digital Terrain Model (DTM) of the country with 10m of spatial analysis was used, and GCPs collected from the National Cadastre (NCMA 2012), of 1m horizontal accuracy. Image processing (selection of GCPs and ortho rectification of images using DTM) (Kaimaris and Patias, 2016) took place in Erdas Imagine 2015®, where the horizontal accuracy of the produced ortho satellite images in GGRS87 ranges from 1.5m to 2.0m.

Figure 7. a. Ikonos-2 satellite image (B, G, NIR) of the ancient theater of Vergina, b. Google Earth image of the ancient theater of Epidaurus.

2.5. *Google Earth Pro*

Google Earth Pro images were used (Fig. 7.b) to capture the information of the remaining forty-four (44) ancient theaters of Table 1 (Kaimaris et al., 2011). After extracting and storing the images, their geometric correction followed by the use of GCPs collected from Maps of the National Cadastre (NCMA 2012). Image processing (selection of GCPs and geometric correction) was performed on Erdas Imagine 2015®, and the horizontal accuracy of the geometrically corrected images produced in GGRS87 ranges from 2.0m to 2.5m.

3. GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND RESEARCH

3.1. *GIS*

The geometrically corrected images of ancient theaters, the DTM, the borders and the coastline of Greece were imported into the Geographic Information System (GIS). The theatres' koilon were then produced and their areas, their orientation, their distances from the coastline, their visibility, and their altitude were calculated. At the same time, the attribute table was updated with the names of the theaters and their preservation state. With the help of GIS, the following research was carried out.

3.2. *The location of ancient theatres*

In figure 8.b presents the positions of the ancient theaters in Greece. The coastal presence (mainly) of the ancient theaters is observed, with the exception of the regions of Peloponnese, Western Greece and Attica (Fig. 8.a), where several theaters appear in the inner area. No theaters appear in central Greece (Thessaly), in the northern part of Macedonia, ie in the regions of Western, Central and Eastern Macedonia and Thrace, in the southern part of Central Macedonia (Halkidiki) and in the islands of the region of Central Greece. Uniform theatre distribution is observed in Peloponnese, Western Greece and Crete.

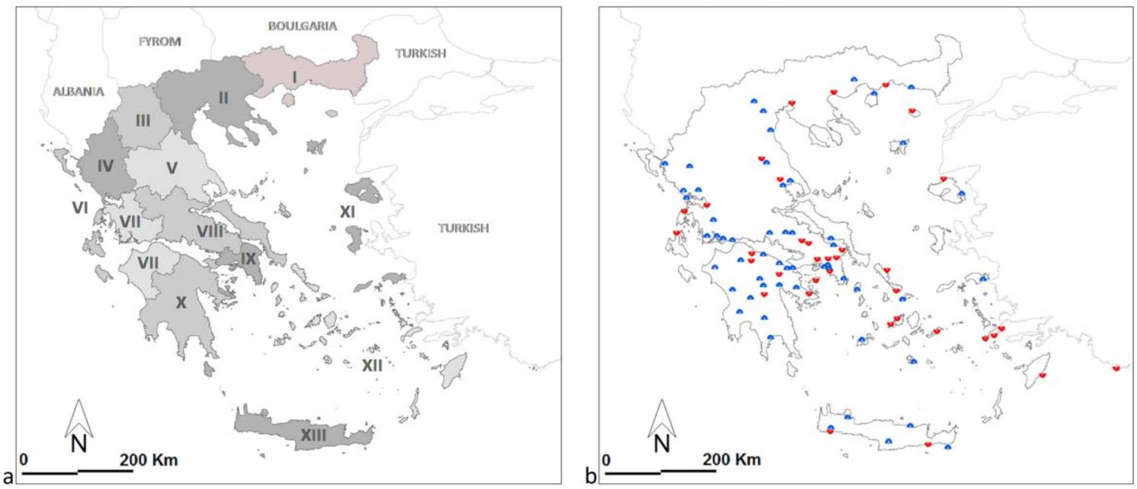

Figure 8. a. The regions of Greece: I. Eastern Macedonia and Thrace, II. Central Macedonia, III. Western Macedonia, IV. Epirus, V. Thessaly, VI. Ionian Islands, VII. Western Greece, VIII. Central Greece, IX. Attica, X. Peloponnese, XI. North Aegean, XII. South Aegean, XIII. Crete. b. With blue the location of ancient theaters, from the 6th century B.C to Roman times. In red, the wider area of the ancient theaters which are known only by historical sources or minimum remains of them are saved but cannot be studied by archaeologists.

3.3. The construction era of theaters

In figure 9.a two (2) theaters of the 6th century B.C are presented in the Attica region and in the south of Western Greece. Four (4) theaters of the 5th century B.C appear around the Attica region, and one (1) theatre in northern Aegean. Twenty-five (25) theaters of the 4th century B.C are located in almost every part of Greece, except in the region of Crete. Also, thirteen (13) theaters of the 3rd, two (2) theaters of the 2nd, and two (2) theaters of the 1st century B.C are presented. Finally, eight (8) theaters of the Roman period appear in Peloponnese, Central Aegean and Crete.

3.4. Preservation state of the theaters

The state of preservation of the ancient theaters that can be studied is divided into two categories. The first category is the good state of preservation (Fig. 9.b), in which monuments are preserved and / or restored at a large scale, can be visited and can be studied. The second category is the moderate state of preservation, in which the preservation rate is low. They may have been partly restored and they can be visited and be marginally studied. Twenty-five (25) theaters belong to the first category, while thirty-two (32) theaters are in the second category. With a ratio of 1 to 1.3, unfortunately category B is superior. Most of the A 'class Theaters are concentrated mainly around the Attica region.

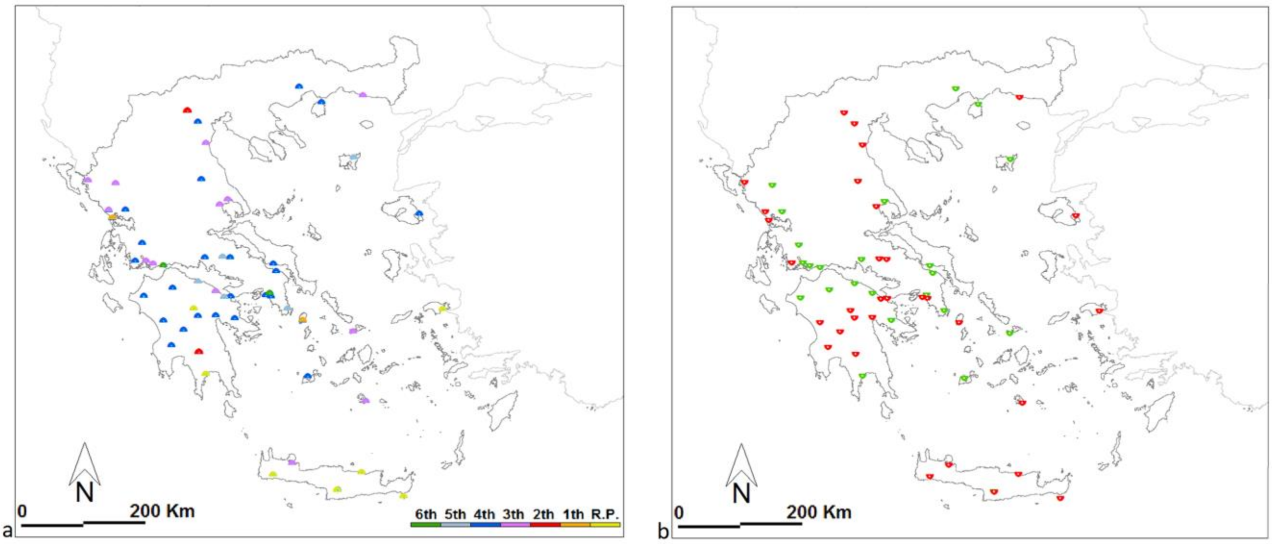

Figure 9. The construction era of the ancient theaters. b. The state of preservation of the ancient theaters, green in good condition, and red in moderate conservation status.

3.5. The areas of the koilon of the ancient theaters

The determination of the outline of the koilon of each theatre in its initial phase requires an in-depth study of each monument, something which has not been conducted in the present paper. The theaters have been altered over the years, meeting the needs of their times. Today, the remains of their structures are in the form of their last phase, before the decline of the ancient cities that created them.

The area of the koilon of ancient Greek theaters ranges from $56m^2$ (Amvrakia Theater, 4th century B.C) to 7,640m2 (Theatre of Dionysus, 6th century B.C). 50% of the theatres' total areas range from $56m^2$ to $1,500m^2$ (Fig. 10), while the remaining 50% range between $1501m^2$ to $7.640m^2$. The theaters with the largest areas appear in the regions of Attica, Peloponnesus, Epirus and North Aegean (on the island of Mytilene).

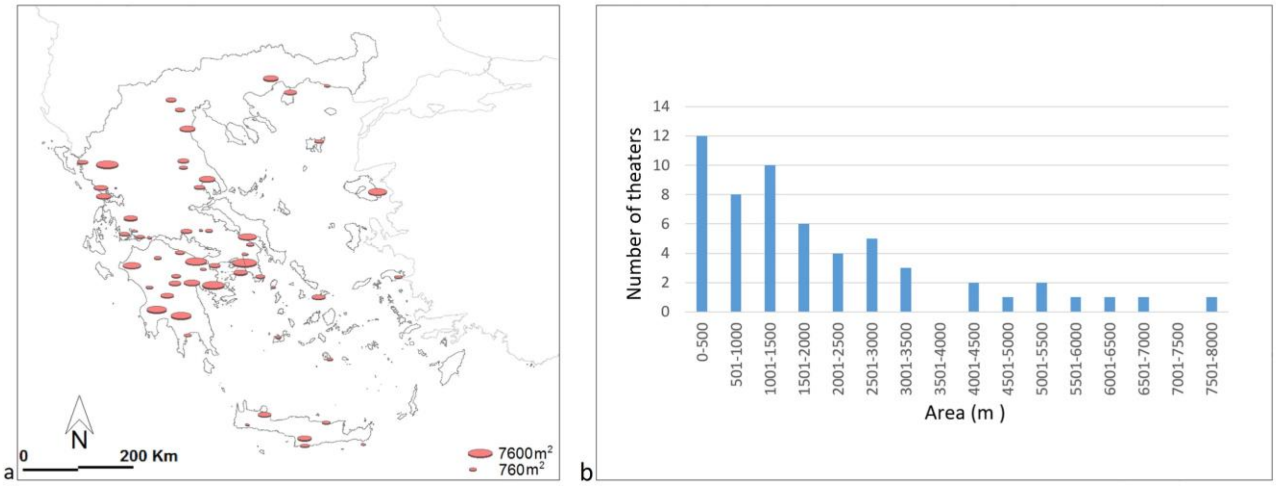

Figure 10. a. The areas of the koilon of the ancient theaters. b. The diagram of the distribution of theaters according to the area of their koilon.

3.6. Distance of the theaters from the coastline

The distances of ancient Greek theaters from the coastline were calculated in GIS. The distances (Fig. 11) range from 11m (Koufonissi theatre, Roman Period) to 42,559m (Mieza's theatre, 2nd century B.C). 33.4% of the theaters are up to 1,000m way from the coastline, 33.3% range between 1,001m to 11,000m, and the remaining 33.3% range between 11,001m to 42,559m from the coastline. In other words, 21% of the theaters lay at a distance of 11m to 500m, and 44% at a distance of 501 to 7,500m.

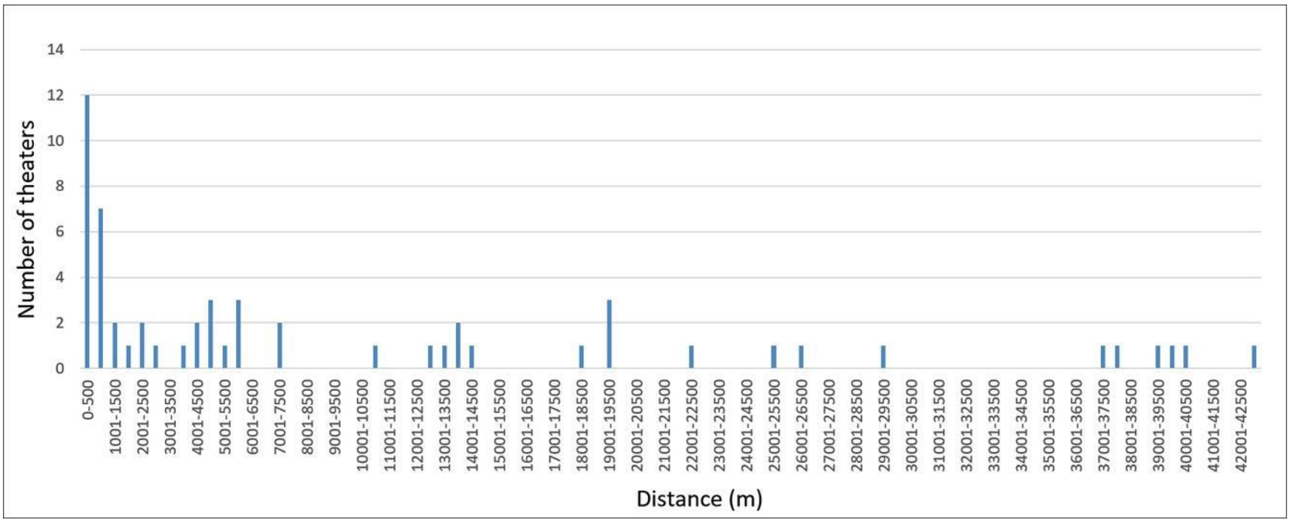

Figure 11. The diagram of the distribution of theaters according to their distance to the coastline.

3.7. Mountainous and foothill location of the theaters

Utilizing the country's DTM, the altitudes (altitude of a point in the center of the koilon) of the ancient Greek theaters were determined in the GIS. The altitudes (Fig. 12) range from 6m (Githion theatre, Roman Period, and theatre of Kathrea, 1st century B.C) to 870m (Orchomenos Arkadia theatre, Roman Period). 74% of the theaters are located in flat areas of low altitude (0m to 200m), 12% in flat areas of higher altitude (201m to 500m), and the remaining 14% in semi-mountainous areas (501m to 1000m). Analysing the results in a different way, 33.4% of the theaters have an altitude of 6m to 50m, 21.1% range from 51m to 100m, and the remaining 45.5% from 101m to 870m.

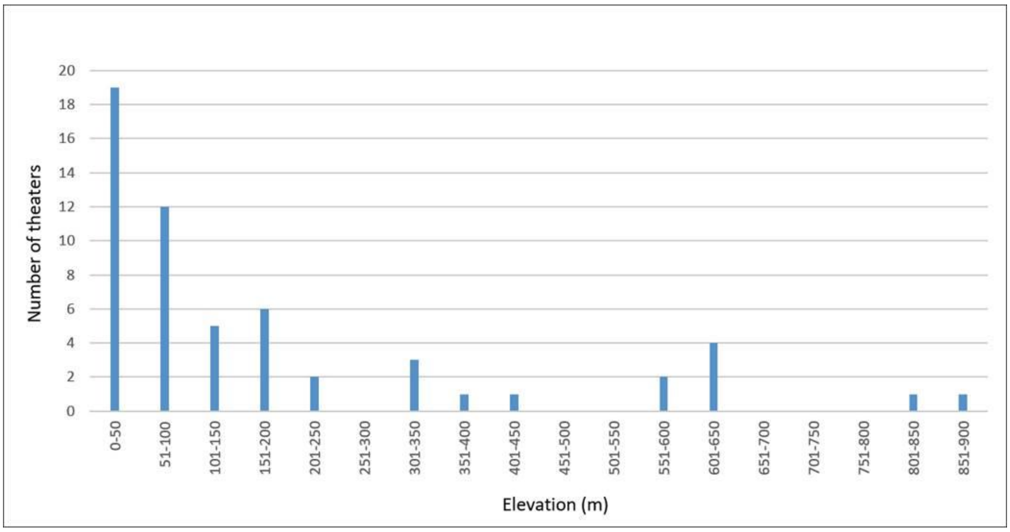

Figure 12. The diagram of the distribution of theaters according to their altitude.

3.8. *Orientation of the theaters*

Using GIS tools the projected azimuth of the axis of each theatre was calculated. In other words, the angle that the viewer who is in the centre of the koilon and looks towards the centre of the orchestra creates with the direction of the geographic North (Fig. 13.a) was calculated. The main orientation of the theaters is from 90° to 270°, since thirty-nine (39) theaters are included in the above value variation (Fig. 13.b). Most of them have southeast, south or southwest orientation. Twelve (12) theaters are oriented from 0° to 90°, and six (6) theaters from 270° to 360°.

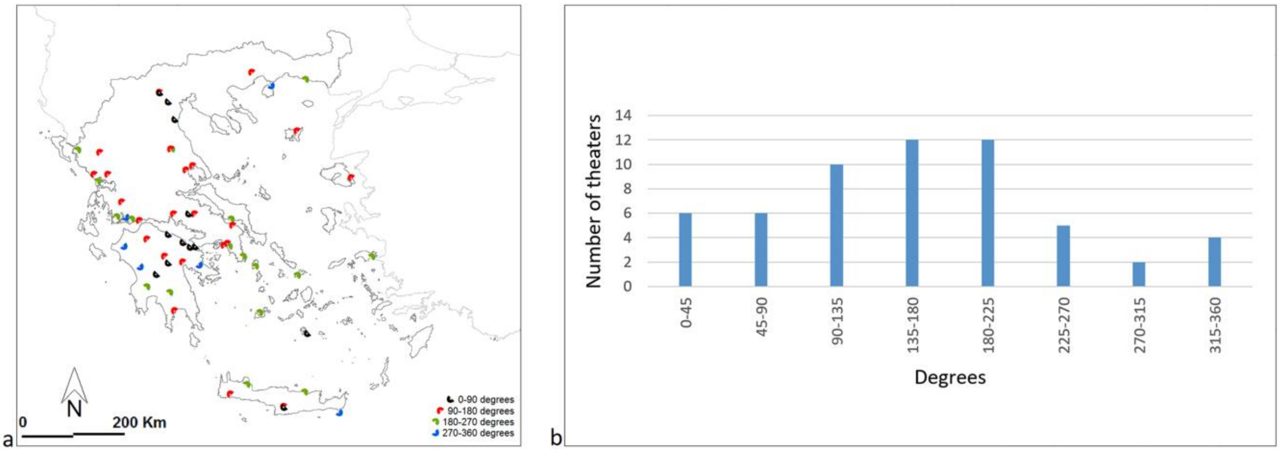

Figure 13. a. The orientation of the ancient theaters. b. The diagram of the distribution of theaters according to their orientation.

By studying figure 13.a, it appears that there is no pattern of orientation of the ancient theaters in Greece. However, it is interesting to study the mean wind direction at theatre locations. This requires the assumption that the mean directions of the winds have been preserved since antiquity to this day. From the website of the National Meteorological Service (HNMS, 2017), the data of the wind direction (from mid-spring to mid-autumn) in the wider regions of thirty (30) out of a total of fifty-seven (57) of ancient theaters were gathered (for the other twenty-seven (27) theaters there is no relevant information). For each theatre, the difference between the angle of orientation of the theatre and the wind direction was calculated in GIS (Fig. 14). In 13.33% of the theaters the differences are positive with values from 90° to 135°. A corresponding percentage is observed for the negative differences from -90° to -135°. 40% of the theatres' differences are positive with values from 45° to 90°. Finally, in 33.34% of the theaters the differences are negative with values from -45° to -90°. In no theatre, the difference in angles, either negative or positive, has a value ranging from -45° to 45° or from -135° to 135°. In conclusion, it seems that for the construction of the theaters, the average direction of the winds, which should be lateral, was taken very seriously. This would allow for the smooth ventilation of the structures. The above conclusion is reinforced by the fact that if the air would blow from the scene to the koilon or the inverse, it would disturb either the spectators or the actors.

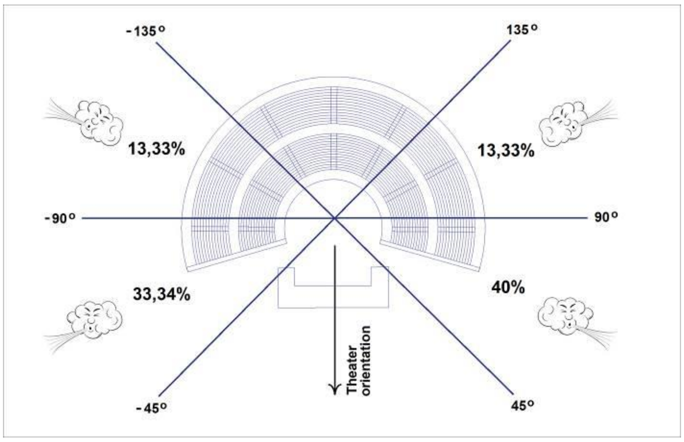

Figure 14. The directions of the winds and the percentages of the theaters in which corresponding winds blow.

3.9. Visibility of the theaters

Visibility refers to the ability to view the horizon at a certain predefined location, or in other words measures the sense of openness from a certain point. In this case, the visibility rate measures the percentage of horizon view of a viewer who is in the centre of the koilon and looks towards the direction of the centre of the orchestra. Using the country's DTM of the 10m spatial analysis, the percentage of visibility was calculated for each theatre. A visibility distance of 10 kilometers (indicative value) and a visibility range of 120°, i.e. ± 60° from the observed axis (Fig. 15a) was set. The processing was undertaken in GIS (Kaimaris et al., 2017c).

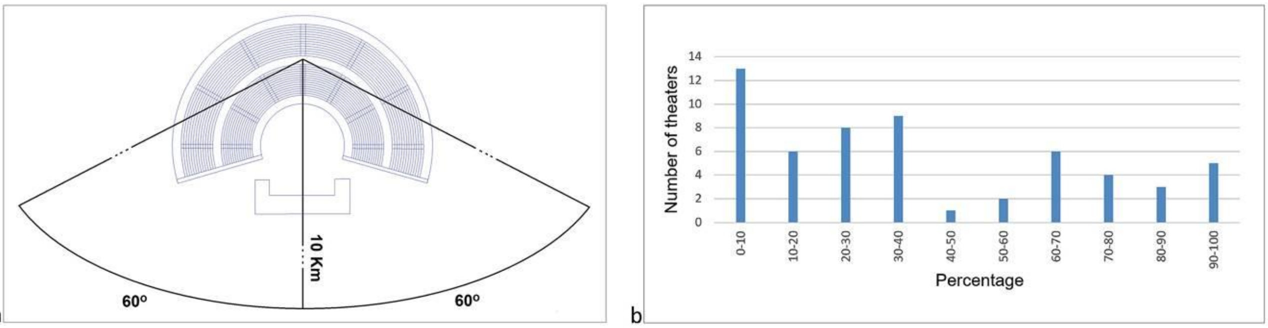

Figure 15. a. Visibility specification, and b. The diagram of the distribution of theaters according to the percentage of visibility.

Visibility rates (Fig. 15.b) range from 0.63% (Theater of Karthia, Larissa II, Amvrakia and Korinthos) to 100% (Theatre of Argos, Philippi and Thira). About 50% of ancient Greek theaters have a visibility rate of 0.63% to 30%, and the remaining 50% is from 30% to 100%. By looking at figure 15.b, about 1/4 of the theaters have a visibility from 0.63% to 10%, 1/4 visibility from 10% to 30% (Fig. 16.a), 1/5 visibility from 30 % to 60%, and 1/3 of the theaters have a visibility rate of 60% to 100% (Fig. 16.b).

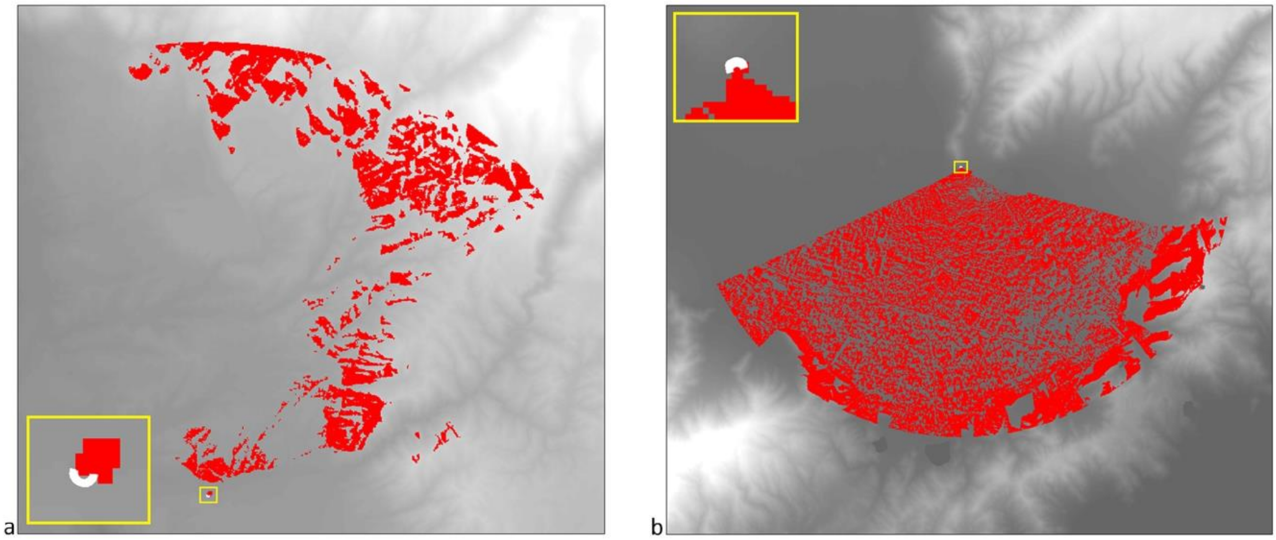

Figure 16. a. Visibility 25%. DTM background (altitude gradient from white to dark grey, from high to lower altitudes), the red surface of the terrain is visible from the theatre, and the magnification of the theatre position in the yellow frame. b. Visibility 90%.

4. CORRELATION OF DATA

By combining all the above information, namely the state of preservation of the theaters, the era of their construction, their distance from the coastline, their orientation, the area of each theatre, their altitude, and the visibility rate, an attempt to identify any correlations between the data was conducted, creating a correlation table (Table 2).

The only (and expected) correlation with a satisfying percentage of 47.03% is between the distance from the coastline and the altitude of the theatre (with p-value: 0.002, less than 0.05). Therefore, there is no pattern for the construction of ancient theaters that exploits all or some of the characteristics and / or properties of Table 2.

Table 2. Correlation of data.

Data	State of preservation	Construction era	Distance from coast-line	Orientation	Area of the koilon	Altitute	Visibility rate
State of preservation	1.000	-0.2942	0.1172	-0.1880	-0.2202	0.0637	0.1552
Construction era	-0.2942	1.000	-0.038	-0.1091	0.1670	-0.0477	-0.1134
Distance from coastline	0.1172	-0.038	1.000	-0.2264	0.1219	***0.4703***	-0.0380
Orientation	-0.1880	-0.1091	-0.2264	1.000	0.0777	-0.1294	-0.1497
Area of the koilon	-0.2202	0.1670	0.1219	0.0777	1.0000	0.0723	-0.0147
Altitude	0.0637	-0.0477	0.4703	-0.1294	0.0723	1.000	-0.0092
Visibility rate	0.1552	-0.1134	-0.0380	-0.1497	-0.0147	-0.0092	1.000

5. CONCLUSIONS

The tools of geoinformatics, which are some of the tools of archaeological prediction, such as aerial and satellite images (from RC Helicopter, Balloon, Drone, Ikonos-2, Google Earth Pro), GIS, etc, have allowed for the measuring documentation of ancient Greek theatres. GCPs with spatial accuracy from 5mm to 1m (in GGRS 87) have been used for the production of Digital Surface Models (DSMs) and ortho images of the ancient theatres with spatial resolutions from 1cm to 2.5m (in GGRS 87). Moreover, the tools of geoinformatics allowed the extraction of their measurement features, such as distance from the coastline, orientation, koilon area, altitude, and the percentage of their visibility. After their appearance in the 6th century BC, the highest number of construction is observed in the 4th century BC. Most of the ancient theatres are concentrated around Athens, the capital city, which, on the one hand, are currently in good conservation status, and on the other hand have a large area of coverage. As far as the latter is concerned, about half of ancient theatres have a koilon area of $56m^2$ to $1{,}500m^2$. The altitudes of the ancient Greek theatres range from 6m to 870m, while their distances from the coastline range from 11m to 42,559m. Most of them are oriented from 90° to 270°, while about half of the theatres have a clear visibility only up to 30% up to a distance of 10Km. Moreover, an attempt to combine these data and to check possible correlations was made, aiming at the macroscopic comprehension of their constructional features. Unfortunately, the only (and expected) correlation with a satisfying percentage is between the distance from the coastline and the altitude of the theatre. Apart from these facts, it was interesting to study the orientation of the ancient theatres in combination with the direction of the winds in each location. This study proved that during their construction, ancient engineers orientated theatres in such way that the wind in the area was lateral.

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