Using Remote Sensing, Laser Scanning and GPS for Documentation of the Historical Byzantine Aydos Castle

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Abstract. Sultanbeyli district, one of the 40 districts in Istanbul in Turkey, is located in the Asian side of the Istanbul Metropolitan area. Aydos Castle in the Sultanbeyli district covers an area of 25,000 m2 on a high hill. It is known from different documents that this castle used to be an important center in the east border of the late Byzantine Empire. During 1326-1328 Ottomans invaded a large part of the Kocaeli Peninsula and parts of the settlements in the Asian side of Istanbul. During this period, the line between Aydos and Pendik defined the border between Ottoman and Byzantine Empires. In 2009, a restoration project of the castle was started. Firstly, there was a need to determine the current situation of the castle and its surroundings and to design a documentation project to be used as a technical basis for restoration studies. For its documentation, advanced techniques, such as remote sensing, digital photogrammetry, terrestrial laser scanning, GPS and different surveying methods were used. To determine the current situation, images were taken from different platforms, such as crane, helicopter and model plane. The 3D model of the castle was obtained from terrestrial laser scanning. The site plan of the castle surroundings was produced by differential GPS system. Weeds and some of the obstructing trees on the hill, based on an agreement with the forest authorities in Istanbul, were cut down; stones inside the castle were removed and the castle became ready for a detailed archaeological excavation. The excavation was undertaken by a team of sixty people under the supervision of the Istanbul Archaeology Museum and two large bastions and walls were revealed. As a result of all these studies, a documentation project was prepared, historical sources were analysed and a comparative restoration report was completed by examining similar castles. This paper gives general information about different documentation methods used during the project.

Keywords. Aydos castle, archaeology, remote sensing, digital photogrammetry, GPS, laser scanning, model plane, 3D model, documentation.

1. Introduction

Recently remote sensing methods are a very powerful tool beside classical methods for archaeological studies. Particularly, images obtained from high spatial resolution remote sensing satellites, model planes and helicopters, ground laser scanning, GPS measurements, LIDAR surveys, and the orthophotos obtained from aerial photographs and geographic information system (GIS), are among the technologies which are mostly used for archaeological studies [1]. The importance of the use of these technologies, especially in surface archaeology, is well known [2], [3], [4]. This study gives brief examples of technologies which were utilised during the documentation of the situations before and after the archaeological excavation within a restoration project of a historical castle located in Istanbul.

2. Study area

Sultanbeyli district, one of the 40 districts of Istanbul in Turkey, is located in the Asian side of the Istanbul Metropolitan area. This district is surrounded by the Pendik district in the east and south,

by the Sancaktepe district in the north and west, and by the Kartal district in the southwest (Figure 1). Central geographic coordinates of the study area are: 40° 56' 59" N, 29° 15' 30" E. Aydos Castle in the Sultanbeyli district covers an area of 25,000 m^2 on a 327 meters high hill. The oval formed castle consists of inner and outsider walls and bastions connected to both walls. It is known from different documents that the Aydos Castle used to be an important center in the east border of the late Byzantine Empire. During 1326-1328 Ottomans invaded a large part of the Kocaeli Peninsula and parts of the settlements in the Asian side of Istanbul. During this period, the line between Aydos and Pendik defined the border between Ottoman and Byzantine Empires [5].

The archaeologists conducted an archaeological excavation in Aydos Castle of which only 15% was above the ground. In this context, it was aimed to prepare the site plan by documenting its status before and after the excavation. For this purpose advanced documentation technologies were used.

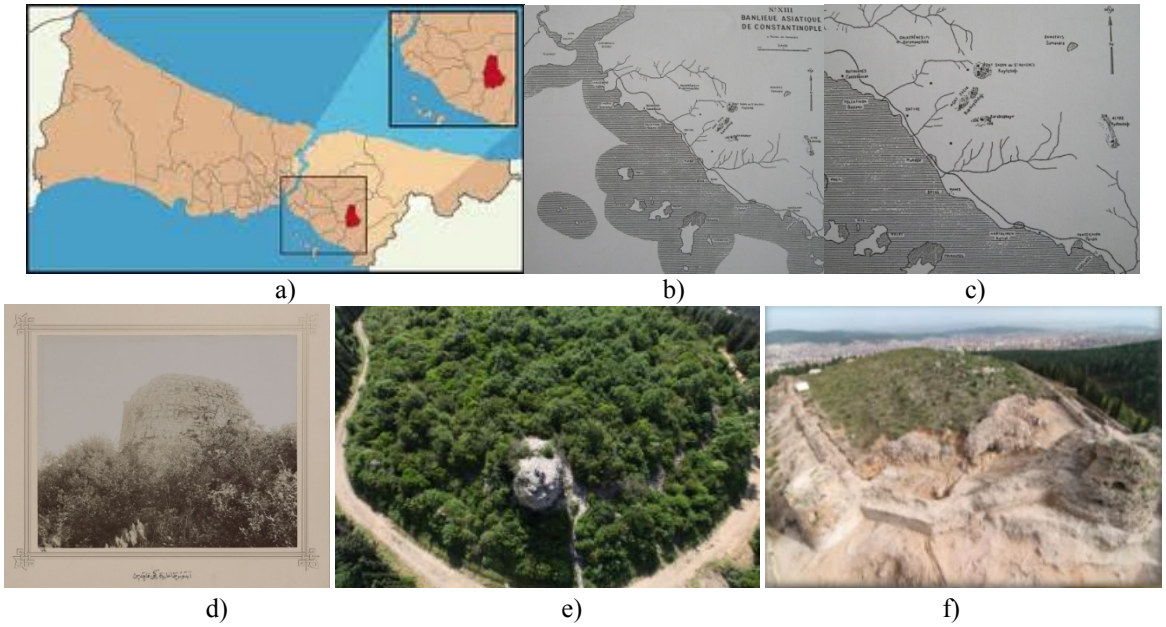

Figure 1: Study area (Aydos Castle): a) geographic location, b) historical map, c) detail of historical map, d) in 1880, e) before excavation, f) after excavation.

3. Documentation technologies

Documentation from model plane: Before starting the excavation and survey, a digital camera was attached to a model plane to document the castle. The digital video camera was a Flycam One 2 – video resolution 640x480 pixel, storage 2 GB (Figure 2) and video shooting duration 1 hour. The reason to prefer model plane to a model helicopter was that the ground was not appropriate for taking off and landing of a model helicopter. The other reason of preferring a model plane was financial concerns because there was no need for a runway for take off, but it was enough to throw the model plane by hand and even it falls down while landing the cost for camera + model plane was lower than the cost of a model helicopter itself. The disadvantages of using model plane were the difficulty of attaching high resolution cameras due their weights, the hardness of keeping the model plane stable in the air, the distorted images due to the vibration, and the difficulty of remote controlling of the model plane. The main purpose of all these studies was to determine the situations of the castle and its surroundings before the excavation.

Figure 2: Flycam One 2 digital video camera attached to the model plane, and images obtained.

Documentation from crane: A pathway wide enough for big vehicles was constructed around the castle. There was a need to high resolution photos taken from a high location to synoptically monitor all processes of the ongoing studies. For this purpose, documentation studies were done using high resolution photos taken from the basket of a crane which can go 20 meters up (Figure 3). The advantages of using a crane are that the basket of the crane is stable, no limitation for the weight of the camera, and there is enough space in the basket for the equipment. The disadvantage is the unavailability of vertical photos from over the castle and thus the photos are oblique. The digital camera used was a Canon EOS 5D Mark II – resolution 4080x2720 pixel (11 megapixels), focal distance 24 mm. The aerial photographs were taken in August 2010. By using the crane - since we could take photos only from the outside of the walls - the vertical photos were used only for drawing of the walls, the oblique photos were just used for determining the situation of the castle before and after the excavation.

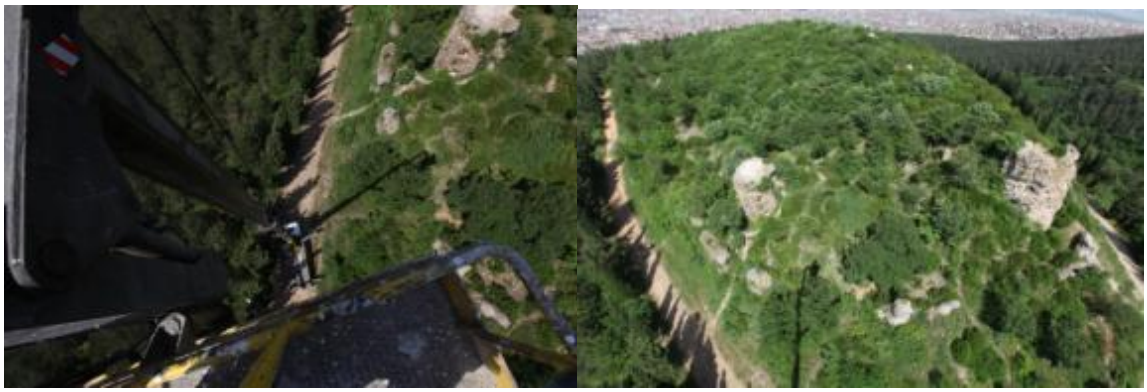

Figure 3: Documentation from crane.

Documentation from helicopter: By renting a helicopter, high resolution photos were taken showing the situations of the castle and its surroundings before and after the excavation (Figure 4). The advantage of using helicopter is the easy positioning of the helicopter in any altitude and angle. Also the obliquity of the photos is less than those of the crane. The disadvantage is that the digital camera can't be attached to the helicopter as parallel to the ground which causes not obtainability of vertical photographs. Another disadvantage is the difficulty and high cost of a runway needed for take off and landing in archaeological sites. For taking photographs from crane on July 27, 2010, a CANON EOS 5D Mark II camera was used. The images obtained were used for architectural and archaeological interpretation of the castle and its surroundings as a whole.

Figure 4: High resolution digital photographs of the Aydos Castle before and after excavation (from helicopter).

Documentation with satellite data and orthophotos: During the project multidate satellite imageries and orthophotos were used (Figures 5, 6). Satellite imageries were used for monitoring the study area in different times (before/after the excavation) and visualizing the area in 3D. They were coordinated and transferred to ArcGIS by using the control points obtained from GPS, total station and laser scanning measurements (Figure 7). In Figure 7, the 3D perspective of the satellite image which was draped over digital terrain model (DTM) by using the data from total station, GPS and laser scanning can be seen.

Figure 5: Aydos Castle: a) orthophoto (1982), b) orthophoto (2009) (Source: Istanbul Metropolitan Municipality web service).

Figure 6: Aydos Castle: a) before excavation (IKONOS, July 19, 2009), b) after excavation (GeoEye, January 2012) (Source: Google Earth Pro).

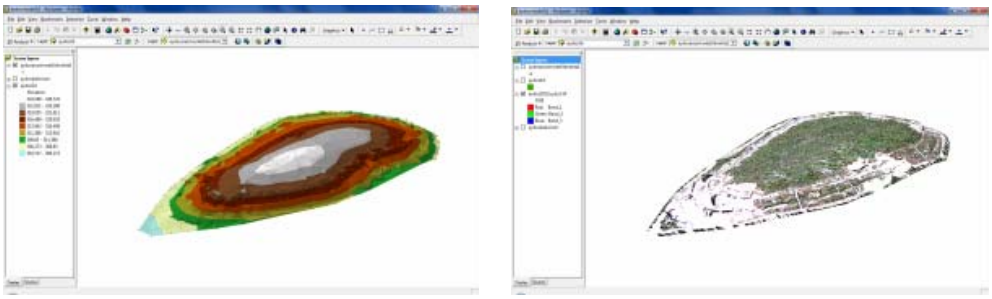

Figure 7: 3D perspective of the satellite image drapped over DTM obtained from total station, GPS and laser scanning measurements.

Documentation with GPS: The polygon points which are necessary for the elevation plan and total station survey were measured by GPS based on the national coordinate system. The coordinates of the polygon points are given in Table 1. For the survey, a double frequency mobile GPS receiver coupled with a GPRS modem was used. The GPS receiver connects to CORS (Continuously Operating Reference Stations) via GPRS modem and gets the corrections, and instantly shows the coordinates of the polygon (measured with 1-3 cm accuracy) without the need for any other calculations. The disadvantage is that sometimes for some locations in the castle, due to weak cell phone signals (3G and GPRS), corrections from the reference station cannot be received and the survey cannot be conducted. The GPS system used is Trimble R8 GNNS.

Table 1. GPS readings of polygon points.

Point nr	Readings (UTC)	Epoch	Data collection period	Number of satellites (GPS/GLONASS)	RMS (m)	PDOP	Horizontal accuracy	Vertical accuracy
ISTN	2010-08-10T19:18:13		1					
100	2010-08-10T19:20:27	1	1	10	0,004	2,25	0,013	0,027
101	2010-08-10T19:26:22	1	1	13	0,005	1,65	0,012	0,022
102	2010-08-10T19:30:59	1	1	11	0,009	1,84	0,024	0,046
103	2010-08-10T19:35:52	1	1	15	0,008	1,37	0,015	0,028
104	2010-08-10T19:37:46	1	1	14	0,006	1,45	0,012	0,022

Point nr	GEOGRAPHIC COORDINATES			COORDINATES (30_3ITRF-ITRF-2005/0)		
	WGS84 Latitude	WGS84 Longitude	Ellipsoidal height (h) (m)	East (y) (m)	North (x) (m)	Elevation (z) (m)
ISTN	40°59'27.46117"N	28°49'53.88232"E	77,15	401684,92	4540227,10	40,39
100	40°56'56.24818"N	29°15'24.55158"E	342,37	437423,94	4535170,87	305,56
101	40°56'56.54344"N	29°15'29.78764"E	348,98	437546,48	4535178,94	312,16
102	40°56'58.41091"N	29°15'33.33714"E	345,32	437629,99	4535235,84	308,51
103	40°56'59.75723"N	29°15'34.06657"E	344,26	437647,41	4535277,23	307,44
104	40°57'01.05724"N	29°15'33.15040"E	343,06	437626,32	4535317,52	306,25

Documentation using surveying methods: We achieved the elevation plan from total station measurements using the polygon points obtained with GPS. Total station survey was conducted before the excavation, after cleaning the territory and after the excavation. The area and volume of the excavated earth were obtained from the elevation survey; hence the related cost was calculated. While creating DTM, the coordinates and elevations of the points obtained from total station measurements were used. Also, we have utilized the total station survey as well as for coordinating the satellite imageries and transforming the laser scanning data into the national coordinate system. By leveling, we have assigned elevation values to the archaeological remains extracted from excavation. We used the Topcon GPT-1004 total station without a reflector. The site plan could be completed by total station survey (Figure 8).

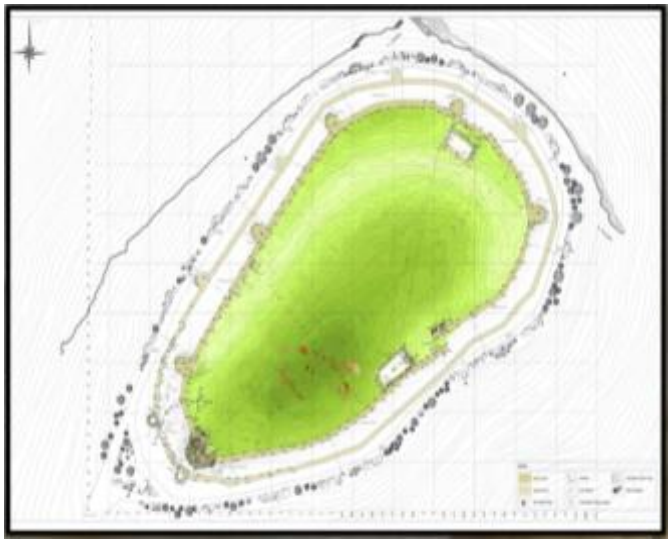

Figure 8: Site plan of the Aydos castle (total station).

Documentation with terrestrial laser scanning and digital photogrammetry: Terrestrial laser scanning (TLS) provides highly accurate 3D images enabling designers to experience and work directly with real world conditions by viewing and manipulating rich point clouds in 3D applications software. TLS derived 3D is a unique and powerful tool for many applications [6]. We obtained 3D modelling and digital orthophotos by using intensive 3D points and the images recorded by the digital video camera attached to the TLS instrument used. Thus the data obtained

were easily visualized. During TLS, we have placed control points on the surface and around of the object, like in the digital terrestrial photogrammetry. With these control points we were able to combine the scans from different stations and to relate them with the reference coordinate system. The TLS instrument used for the project is Trimble GX. The location of other stations when viewed from the station 7 is given in Figure 9 and the registered point cloud of the castle is given in Figure 10.

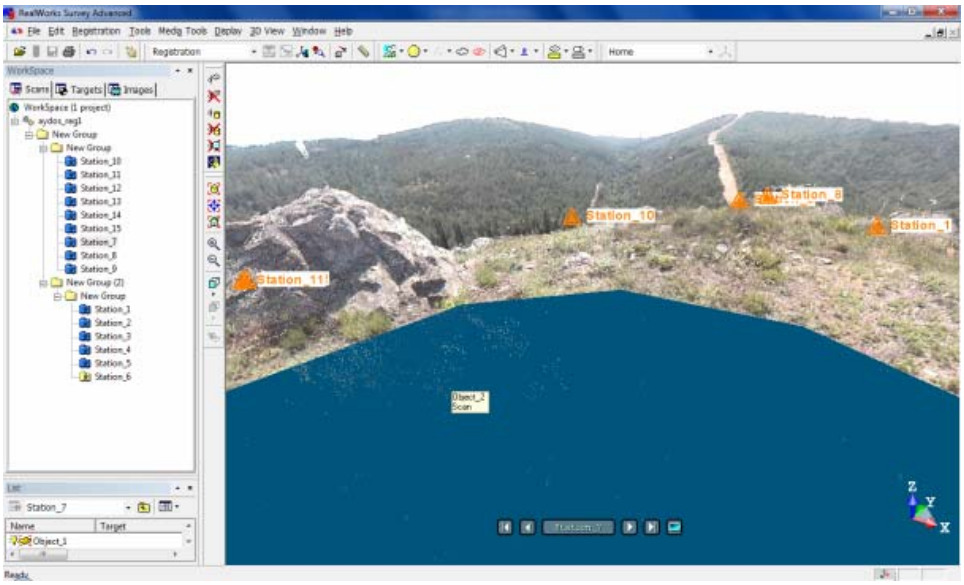

Figure 9: Locations of some stations viewed from the station 7.

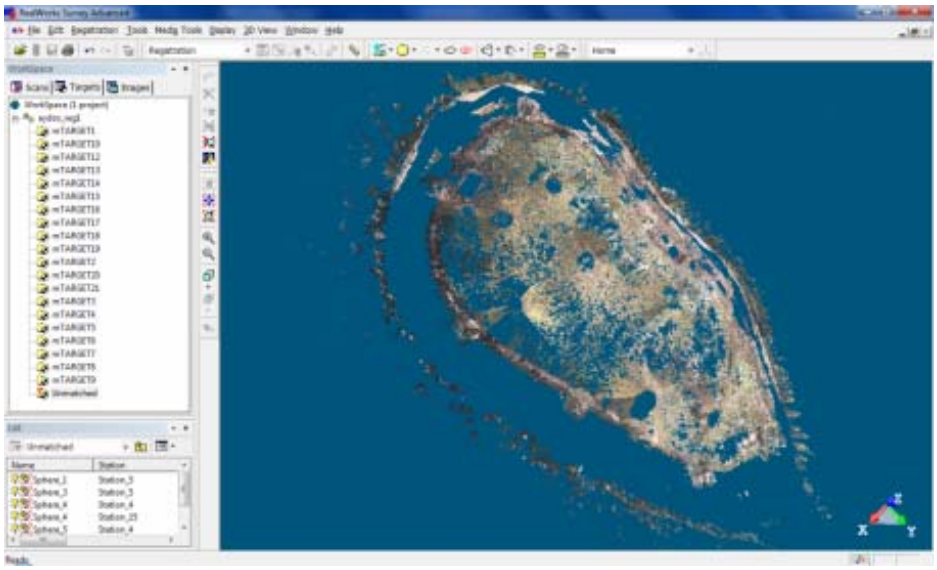

Figure 10: Registered point clouds of the castle.

In this project, an automatic registration was followed. After the registration, the number of the points measured for 15 stations is 16,933,858, and number of the photos is 368. The TLS systematic is given in Figure 11.

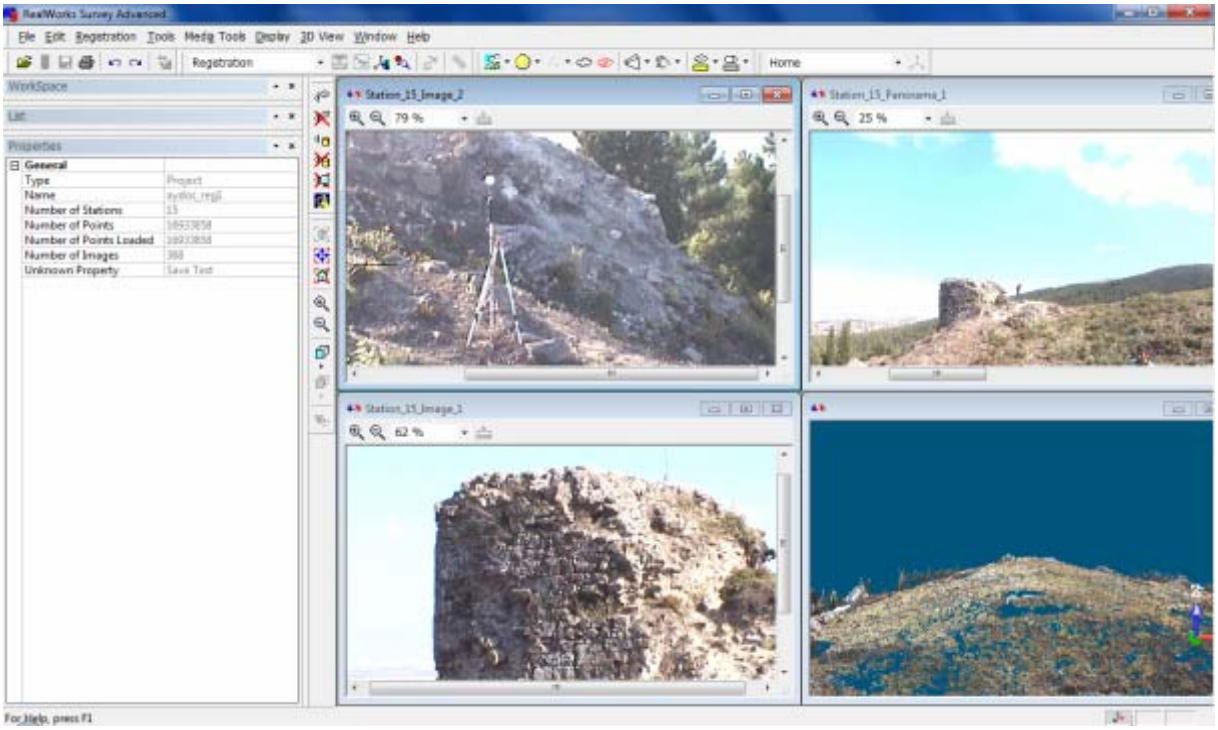

Figure 11: Screen of laser scanning systematics.

On 22 July 2010, the laser scanning was done between 02:00-07:00 pm and the first day the stations 1, 2, 3 and 4 were scanned. On 23 July 2010, between 09:15 am – 06:40 pm, the stations 5,6,7,8,9,10 and 11 were scanned. Lastly on 24 July 2010 between 02:00-04:30 pm, the stations 12, 13, 14 and 15 were scanned. Hence, the TLS process was completed in 17 hours for the castle in an area of 25.000 m^2. The 3D view of the study area is given in Figure 12.

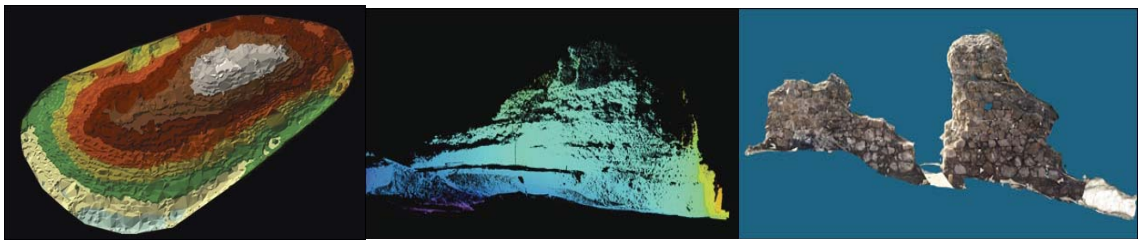

Figure 12: 3D view of the study area.

For the project, the digital photogrammetric software Pictran was used. Firstly, the Nikon D90 digital camera was calibrated in the photogrammetric laboratory of the Istanbul Technical University, and the obliquity of image principal point, the error matrix components sourced from objective distortion and real focal distance were determined. The necessary control points were measured by GPS and total station. Point clouds in the laser data were used to rectify the image. As a result of the documentation studies, the plans of the castle constructions and walls of the castle were obtained (Figure 13).

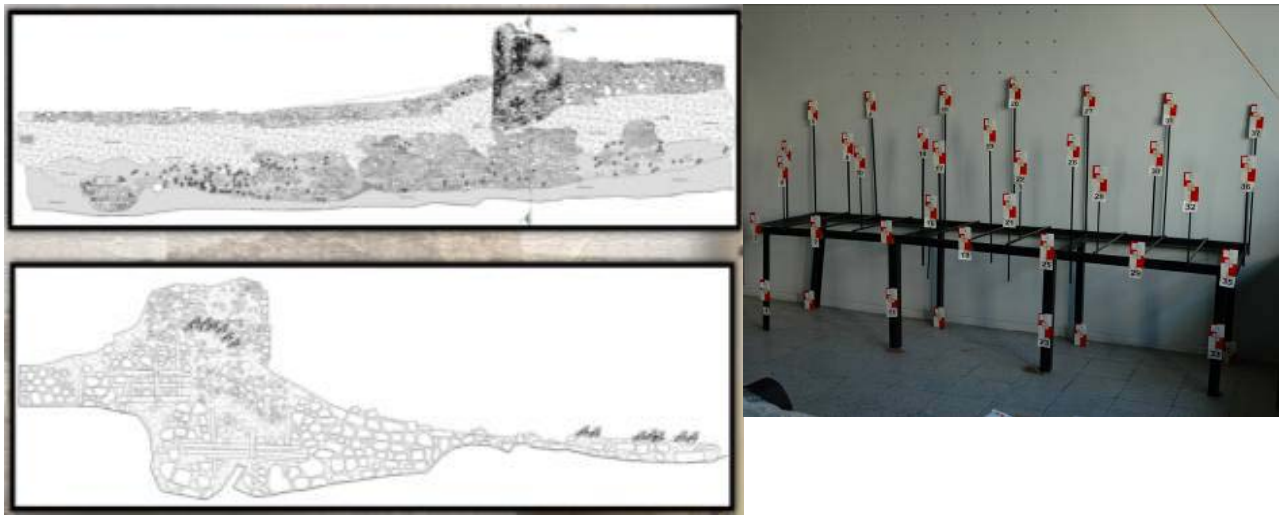

Figure 13: Camera calibration system and the drawings of the caste walls.

4. 3D modelling

After the documentation and survey studies undertaken in the framework of the project, a very detailed plan was obtained. This plan helped to redesign the original structure of the castle. Based on these data, the restitution project (which shows the original structure of the castle based on the historical information, documentation, excavation and survey works) was prepared. After the excavation, the heights of the walls and bastions were estimated using DTM obtained from documentation methods. The 3D model covering the walls and bastions of the castle in Google SketchUp software was created. (Figure 14). It is planned to create a solid model using 4D printers by revision of the model in the future.

Figure 14: 3D model of the Aydos Castle (Google SketchUp).

5. Results

Nowadays, in archaeological studies, particularly in surface archaeology, the space technologies and remote sensing methods are being used intensively. In this study, examples were provided of such new technologies used in a restoration and documentation project, conducted before and after the archaeological excavation of Aydos Castle, one of the examples of the cultural heritage examples of the Byzantine Istanbul. During the project, we utilised images obtained from crane, model plane and helicopter. We have also used GPS survey and terrestrial laser scanning integrated with digital photogrammetry and classical surveying methods during the documentation studies.

On the other hand, this study is a good example of a multidisciplinary work involving social sciences and engineering. Indeed, in this multidisciplinary project, archaeologists, art historians, surveyors, geologists, forest engineers and architects were able to collaborate successfully.

Finally, the documentation of historical buildings is a very important issue, because the data obtained from the documentation directly informs the restoration studies and affects the accuracy of the study. To promote this integrated study we recommend to run lectures on documentation using advanced techniques, such as remote sensing, digital photogrammetry, laser scanning, GPS, GIS, etc. in those educational institutions where mainly architecture and archaeology are taught.

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