3D Modeling of Kilistra Ancient City Buildings with Terrestrial Laser Scanning

Adin Adnan Rashid BEG and Lütfiye KARASAKA, Turkey

Key words: Terrestrial laser scanning, 3D Modeling, Documentation, Cultural Heritage

SUMMARY

This paper presents the use of terrestrial laser scanning (TLS) in order to effectively produce, prior to intervention, accurate and high-resolution 3D models of a three main ancient buildings with engravings in the city of Kilistra dating back to the Hellenistic and Roman period. The Cross Church (Haç Kilisesi) , Ceramic Workshop (Siramik Atölyesi), and Başpınar Cistern (Başpınar Sarnıcı) in the ancient city of Kilistra have been scanned by a Terrestrial Laser Scanner and a 3D modelings have been made of the scanned data. This process will be a first step in the operations of cultural heritage restoration in this region and The processed data with this technique can be used to systematically improve archaeological understanding of such complex structures.

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1. INTRODUCTION

Kilistra was most probably founded in the Hellenistic period, in the 2nd century BC. Its development was boosted by the favorable location, right on the so-called Royal Road. This ancient highway was built by the Persian king Darius the Great in the 5th century BC to facilitate communication throughout his empire from Susa to Sardis. This road led through Kilistra to the west, to Antioch of Pisidia, which was visited during the first missionary journey by St. Paul. Because of this fact some researchers speculate that he also visited Kilistra. However, these speculations have not been confirmed so far, and the distance between both places (over 150 km) makes the spontaneous visit of the Apostle in Kilistra very doubtful.

The ancient city of Kilistra which has similar characteristics to natural rock formation and architecture of Cappadocia and Ihlara's formations is located 45 km southwest of Konya. The history of the region dates back to the Bronze Age and the first settled life begins in the Hellenistic and Roman period (2nd century BC - 3rd century BC). The area has been established in five different locations parallel to natural rock formations. The people of Kilistra, who had accepted Christianity during the Roman times, are believed to have chosen the mountainous terrain to protect themselves against assaults from the paganists masses and looters.

The settlement flourished during the Roman period. An epitaph from these times was found in the area of the village, cleverly used by modern residents as a threshold of the house. Thanks to this finding the researchers were able to confirm the ancient name of the settlement. In the Byzantine era in Kilistra, the system of houses carved into the rock was expanded, connecting the rooms with the system of corridors into an underground city. This system is reminiscent of similar settlements, which existed in Cappadocia.

When viewed from a distance, the interior of the settlements, which looked like a natural rock, was carved into large spaces, the lighting and ventilation were camouflaged and provided with potholes and chimney openings. In addition to these formations, chapels, churches, monasteries; social dwelling, cistern, winery, workshop, fountain, tomb; defense and security purposes buildings (watchtower, garrison, police station and shelters) are found too.

The Ancient Cities have become centers of attraction for tourists whose wondering about the traces of different civilizations. Beside the fact of that the ancient city of Kilistra is an open air museum, the region also has an important place for tourists in terms of religious tourism, because the travels of Saint Paul (whose name is given to an ancient church in Kilistra), and the Lystra region and its surroundings were familiar with Christianity.

2. TERRESTERIAL LASER SCANNING

Laser scanning enables a large quantity of three-dimensional measurements to be collected in a short time. It generates a point cloud in a local coordinate system with intensity values; additional information such as RGB values is usually provided by internal or external digital cameras. While the point cloud generated by laser scanning may be useful on its own, it is usually only a means to an end. Laser scanning is generally used to record surface information in order to generate 2D sections, profiles and plans, and 3D models. Laser scanners can operate from the ground or integrated into an airplane. The former is referred to as terrestrial laser scanning (TLS) whereas the latter is referred to as airborne laser scanning or LiDAR, although this latter term applies to a particular principle of operation which includes laser scanners used from the ground (English Heritage, 2007).
TLS might be classified according to its range of measurements or its principle of operation: triangulation, time-of-flight or phasebased. In the first case, the device shines a laser pattern onto the subject and exploits a camera to look for the location of the laser's projection onto the object.

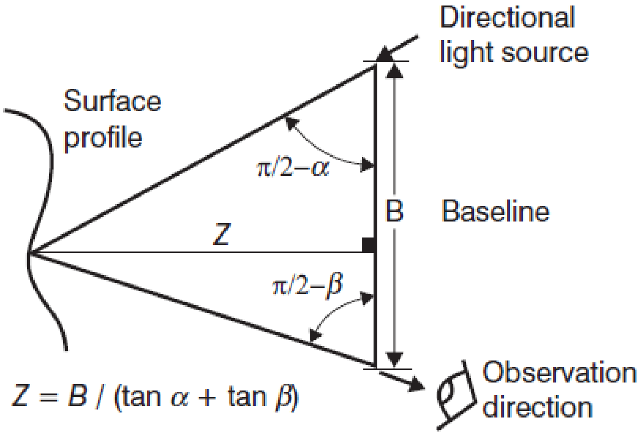
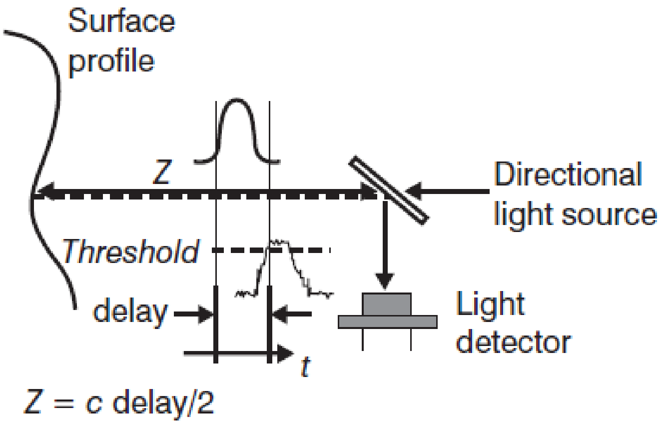


Figure 1. Methods for optically measuring a 3D surface: (a) triangulation (Vosselman, 2010).



(b) light transit time

In the second case, scanners make use of laser pulses to measure a time frame between two events (the returned pulses). The latter principle is also a time-based measuring principle, but it modulates the power of the laser beam, thus measuring the phase difference between the sent and received waveforms (Lerma, 2008). Interferometry can be classified separately as a third method or included with time-of-flight methods depending on how the metric used to measure shape is seen. (Vosselman, 2010).

As mentioned above, some scanners are capable of capturing the colour of measured points, resulting in point clouds much more representative of the scanned object. A rough 3D coloured model from these point clouds can be derived by taking for every triangle the colour of its vertices. This involves the generation of textured models within a resolution of the order of the size of the triangles. Other scanners include a digital camera directly referenced with respect to the point cloud, which is used to obtain colour from the scanner. Nevertheless, the main drawback of these integrated cameras is their low radiometric and geometric resolutions, as well as the non-parallax free colour values they yield for close range measurements. (Lerma, 2010).

3. SITE DESCRIPTION

Figure 2. Location of the ancient city of Kilistra

3.1 Başpınar Cistern

Başpınar Cistern which is located in the northwest of Kilistra is the biggest cistern in the area. The cistern, with its uneven rectangular plan, is made by carving a bedrock under the ground level. The cistern consists of entrance section and main section. The channel in front of it was created by carving the bedrock. A small channel has been added to this channel and it is connected to the cistern with two openings from the entrance front. The entrance of the cistern is a rectangle-shaped opening at 2.40 m. height above the channel level. The main room, which is laid down in five steps in various widths, has an uneven rectangular plan and it is 1.90 m below the entrance. Holders of various sizes, carved into the bedrock, and connected by arches to each other. There is a pit on the floor of the eastern part of the main area. Cistern's water was provided from the hole on this pit. The middle part of the cistern is kept higher than the side parts. All the sections of the cistern are covered with barrel vaults. (Ozkan, 2002).

Figure 3. Main section of Başpınar Cistern

3.2 Ceramic Workshop

Ceramics was one of the most used items in medieval ages. Ceramics, mostly used for making kitchenware, are the raw material of amphorae and jugs where liquids are stored. Ceramic workshop in Kilistra is located in the north of the city consisting of buildings arranged side by side in a neighborhood shows that it was a large production in the city. A large part of the workshops, which are determined by the remains to have a common oven and a large pool, are under ground today. The workshops that are connected to each other with small apertures had pools and niches in various sizes. The ceramic complex consists of three main workshops, an oven and a pool, carved from the north side of a bedrock with the same ground level. In 2003 a restoration work carried out in the area and the top of the entrance was covered with a wooden roof. (Mimiroglu, 2014).

Figure 4. Ceramic workshop

3.3 The Cross Church

The Cross Church is located at Konacak area in the northern part of the settlement center. This church which is made by carving a great bedrock consists of a chapel, apse, naos and a grave chamber. The entrance part of the church which is located at its west side is rectangular shaped and has a barrel vault. In the entrance section there is a rectangular aperture leads to the naos of the church. The grave room on the northwest corner of the chapel is entered through a rectangular aperture too on what so-called the horse's wall of the chapel. The apse and the naos are seperated by a rectagular shaped templon carved in a bedrock and the ground between the apse and the naos is connected by a single step. The apse which is located in the east of the church is internally and externally semicircular and it forms a free cross shape. There are three different kinds of decoration programs in the chapel. The first one is the reliefs carved into the bedrocks. The second kind of decoration is frescoes. The last type seen in the structure is the geometric ornaments made from the red vaccine underneath the fresco marks. (Mimiroglu, 2014)

Figure 5. The Cross Church

4. METHODOLOGY

The approach used to obtain a high-resolution 3D model of the sites with terrestrial laser scanning can be summarised in the following steps

4.1 Data Acquisition

The TLS data acquisition at Kilistra was conducted with the long-range, phase-based scanner FARO Focus3D X 330. The maximum range of this device is 330 m, with a field angle of 360 degree (horizontal) and 305 degree (vertical). This scanner is characterized by its high resolution (up to 3 mm at 10 m distance), field angle and speed.

Figure 6. FARO Focus3D X 330

In projects involving laser scanning technology, the positions of the scanner must be carefully planned to ensure full coverage of the 3D object, appropriate resolution and required accuracy. (Lerma, 2010).
For this project, a total of twenty six scans from twenty six different positions were acquired. In particular, ten scans were set up in Başpınar Cistern, eleven in the Ceramic Workshop and five scans were set up in the Cross Church. The total number of scanned points was approximately 228 million points in the cistern, 224 million in the ceramic workshop and 80 million points in the cross church.

4.2 Point Cloud Processing

The purpose of this step is basically to filter out the raw data delivered by the scanner, deleting gross errors and isolated points. First, point clouds are registered by means of artificial targets provided by the manufacturer (in our case checkerboard targets). This process is also known as alignment or consolidation, and is carried out in order to have all the scans in a single and common coordinate system. The point cloud processing phase begins with the referencing to a single object coordinate system (XYZ) of the filtered raw data captured in the local coordinate system of the TLS. From each station, a unique local coordinate system is set up. Therefore, after the registration step, all the local coordinate systems will be transformed into one (most usually known as master) selected coordinate system. (Lerma, 2010).
For that purpose, checkerboard targets (that act as tie points) have to be placed around the 3D space, trying to occupy the maximum volume. Based on these, it is possible to make a least squares adjustment for all the scans. Up to this point, processing was performed with FARO Scene software supplied by the manufacturer of the scanner and the editing was performed with JRC 3D Reconstructor.

Figure 7. Pre-processed point cloud of ceramic workshop generated with Faro Scene.

Once the point cloud is registered, the whole set of point clouds is oriented to North by means of a digital compass and moved to the coordinates (100, 100, 0) for convenience, in order to facilitate the reading and generation of plans without negative values in planimetry.
Finally, the point clouds are decimated with the help of mathematical algorithms in order to remove redundancies in overlapping areas. In our case, the point cloud was decimated to 1.2 mm for the cistern, 2.1 mm for the ceramic workshop and 1 mm for the cross church.

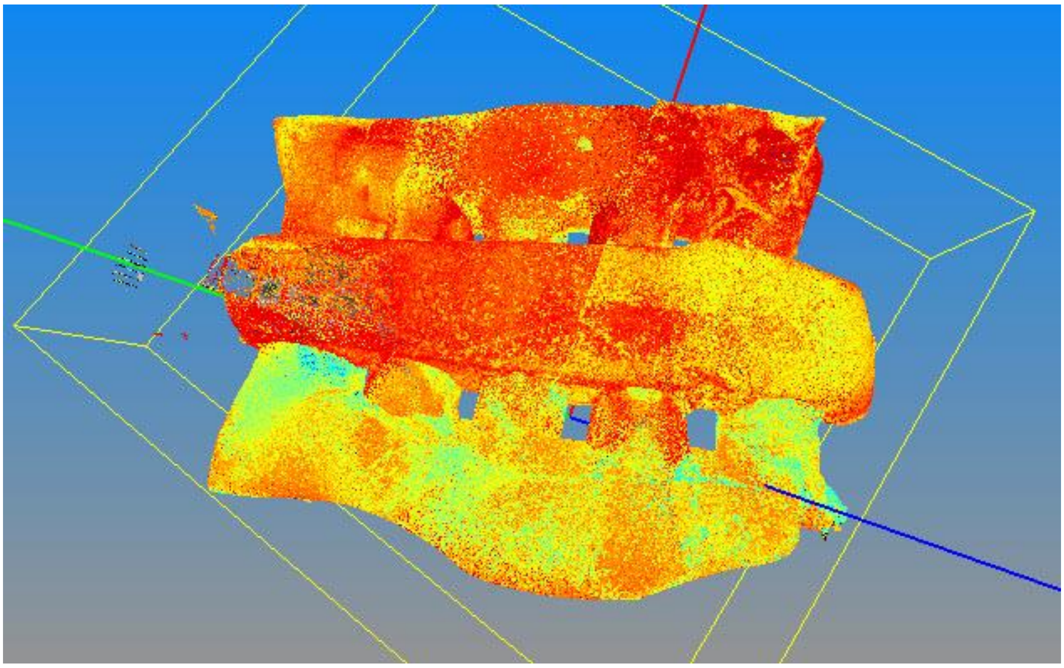


Figure 8. Colored point cloud of Başpınar Cistern generated with JRC 3D Reconstructor.

4.3 Meshing and 3D Modelling

This step involves data triangulation to derive a 3D triangular mesh by means of Delone triangulation. The output is a surface model of the scene. Alternatively, meshing can also be achieved by quadrangles. In order to avoid suffering from insufficient computer memory, the referenced and decimated point clouds are divided into different levels and triangulated separately. After triangulation, topological errors are eliminated, including either triangles that cross each other or more than two triangles that share the same side. Once the triangulations have been refined, the previous registration is optimized with the ICP (Iterative Closest Point) method and partial models are joined. (Besl and McKay, 1992; Chen and Medioni, 1992).
Furthermore, editing includes filling up a number of small hidden areas in order to overcome this awkward issue and reduce their number. The result is a full 3D model.

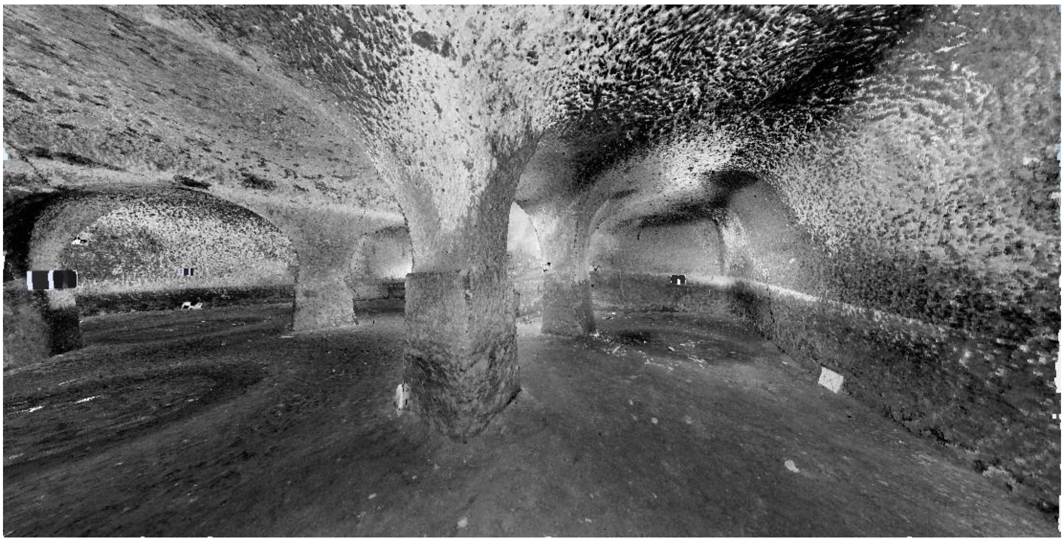


Figure 9. A 3D model of Başpınar Cistern generated with Faro Scene.

Figure 10. A 3D model of the Cross Church generated with Faro Scene.

4.4 Storage

After generating the 3D models from TLS, data should be stored in digital form at maximum resolution without losing texture information and keeping also maximum spatial resolution. It is important to save on different media not only the final deliveries and products but also the original raw data without compression. This allows manipulation and editing of data at any time in order to perform different studies without the need to return to the site. (Lerma, 2010). As contemporary software is neither ready to process huge data sets of point clouds nor meshes, operational problemsmight occur if the TLS data are not divided beforehand. It is recommended to export the data into different formats including also the metadata of the whole project. Proprietary formats are good but public formats are better to guarantee performance and integrity. A good example of public file format for the interchange of 3D point cloud data is the LASer (LAS) file format (ASPRS Standards Committee, 2009).

5. CONCLUSION

In this study, three main ancient buildings were scanned with a terrestrial laser scanner. The data obtained by the scanning were processed in producing 3D models of the sites. The major benefit of the 3D models is the chance it provides to process immediately information in 3D and to extract information about the formation of the buildings by interpreting the 3D models. The 3D models can be scaled and rotated in order to define the best point of view. One of the advantages of having such a high-resolution 3D model of an object is the ability to visualize,

plot, study and extract easily 2D and 3D information from various points of view and at different scales.
Another advantage of the 3D modelling of Kilistra's ancient buildings is that it makes the geometrical calculations easir like area & volume calculations, arcs calculating and generating a full constructional plot of the site or produce maps and cross-sections.
Finally, preservation of historical and cultural heritage is one of the important issues that should concern us to save the history of our kind. Many of our historical and cultural heritage are faced with the danger of disappearance due to natural factors and carelessness. 3D modelling with TLS presents a simple, economic and practical way to achieve this goal by digitally archiving these types of sites.

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BIOGRAPHICAL NOTES

Adin Adnan Rashid Beg was born in (1987). He graduated with a B.Sc (Surveying Techniques) from the Technical College of Kirkuk in 2012. He worked with many surveying and construction companies before joining Selcuk University as a master student.

Lütfiye Karasaka was born in Konya, Turkey. She graduated with a B.Sc (Geodesy & Photogrammetry) in 2001, anr recevied M.Sc. in 2004 and PhD degrees in 2012 from Selcuk University. She is working as Assistant Professor in the Department of Geomatics Engineering at Selcuk University. Her research interests are photogrammetry and remote sensing.

CONTACTS

B.Sc. Adin Adnan Rashid Beg
Selcuk University
Graduate School of Natural and Applied Sciences
Ankara
TURKEY
Tel. +90 539 518 8432
e-mail: aydin.adnan87@gmail.com

Assist. Prof. Dr. Lütfiye Karasaka (corresponding author)
Selcuk University
Department of Geomatics Engineering
Konya
TURKEY
Tel. +90 332 223 1900
Fax. + 90 332 241 0635
e-mail: lutfiye@selcuk.edu.tr