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The Use of Terrestrial Laser Scanning Technology in the Documentation of Cultural Heritage: The Case of Bezmialem Valide Sultan Fountain

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Abstract

In order to ensure that the structures are repaired again as a result of possible natural disasters and day-to-day wear and tear of historical structures, it is necessary to create 3-dimensional models. One of the methods used in the realization of this model is terrestrial laser scanning. As a result of scanning the historical structures in question in different sessions with the terrestrial laser scanning method, a point cloud is obtained and used in relay studies. The filtering process is performed first for the use of point clouds. The filtering process was carried out by removing the point data found in the environment during the scanning of the structure to be studied and which were considered noise in our study. In our study, CloudCompare software was used in order to turn the point clouds obtained as a result of different sessions and the filtering process completed into a single structure. In order to combine the point clouds, control points established before the scanning process started and natural points located on the structure were used.

1. Introduction

When we look at the geography in which the Republic of Turkey is located, it is determined that it has hosted many civilizations during the historical process. Therefore, the remains of these civilizations are seen quite a lot in the geography. It should never be forgotten that this cultural heritage in question does not belong only to one country, but is a common value of all humanity. It is important that this heritage is protected, repaired and brought to the common heritage of mankind with current technologies (Fidan & Ulvi, 2022).

Cultural heritage are valuable assets that have survived from past generations to us and should be protected and should be passed on from us to future generations, have universal values and have certain criteria. Historical artifacts or historical assets include tangible or intangible cultural and natural heritage (Ulvi et al., 2019; Sarı et al., 2020; Balcı, 2022).

The sustainability of cultural resources can be achieved through conservation and restoration works, and architecture is an important resource. When cultural assets become unable to meet the new demands and needs that are emerging as a result of technological, social and economic changes, new functions can be acquired to ensure their continuity (Aşptekin & Yakar, 2020; Kanun et al., 2021; Kabadayı, 2023). It is very important to ensure the sustainability and protection of cultural heritage (Yakar et al., 2019; Korumaz et al., 2011; Ulvi et al., 2020; Kabadayı, 2023).

In order to be used for repairing damages that may occur as a result of damage to historical structures, terrestrial laser scanning (TLS) technology can be used to create substrates for creating sections of 3-dimensional (3D) models.

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Traditional geodetic measurement methods, whole ground measurement or real-time (RTK) GPS measurements are not very suitable for quickly accessing geometric and visual information of the object. These allow only individual point measurement. For this reason, these methods are usually slow. Modern reflector-free total stations and other developing technologies also have point-based scanning functions. However, the excessive scanning time, the low number of points obtained, the inability to obtain sets of points suitable for the actual model of the scanned object have brought the terrestrial laser scanning technology to the forefront (Gümüş & Erkaya, 2007).

There are many basic concepts related to photogrammetry in laser scanning. LIDAR technology forms the basis of laser data production in remote sensing and photogrammetry. It is seen that LIDAR technology stands for light detection and ranging. Light amplification by stimulated emission of radiation describes laser beam technology in its abbreviated form. In terms of the physical structure of the laser beam, it maintains the beam structure over long distances, has a monochromatic and consistent structure. (Gümüş & Erkaya, 2007)

When geometric problems come to the fore in remote sensing and photogrammetry, it is seen that laser scanning technology especially comes to the fore. Laser scanning method, which is essentially LIDAR technology, is an active measurement method. The data obtained by the laser scanning system is a point cloud consisting of 3-dimensional (3D) points (Gümüş & Erkaya, 2007). A large number of X, Y and Z coordinates can be obtained, as well as density information for each point and measurement operations of Red Green Blue (RGB) values are also provided. For all the measured points, x, y and z coordinates are determined in a spherical or ground coordinate system in space (Staiger, 2003; Yakar et al., 2005; Fidan et al., 2022).

The laser scanning technique is called laser scanning by calculating the time elapsed between the laser beam coming out of the laser scanning device hitting the surface of the object to be scanned and then reflected and returned to the device, converting it into distance measurement and decoupling it with the photos taken (Şenol et al., 2021; Kaya et al., 2021; Balcı, 2022). Laser scanner devices are systems that can shoot thousands or millions of laser points per second and detect them back in 3D and convert them into data (Memduhoğlu, 2020; Polat at al., 2020; Balcı, 2022). There are two systems in laser scanning devices: mechanical deflection and laser radar. While the mechanical deflection system records the horizontal and vertical angles of the laser signal, the laser radar system calculates the return time from the surface where the beam transmitted from the scanners hits the scanned object to the device again. The 3D and global coordinate network for laser scanning technology are formed thanks to these two systems (Balcı, 2022). Laser scanning technology is divided into two different classes: aerial laser scanning and terrestrial laser scanning.

Aerial laser scanning (ALS): A laser scanning device is a system consisting of Global Navigation Satellite Systems (GNSS) and Inertial Measurement Unit (IMU) and installed on an aircraft. By scanning objects and surfaces from the air with the help of this system, a point cloud containing coordinate values is obtained (Balcı, 2022).

Today, the horizontal and vertical accuracy of measurements obtained by aerial laser scanning has caught up with photogrammetric methods. The ALS system is mounted on a helicopter, drone or aircraft (Polat & Uysal, 2016).

The scanning device calculates the distance between ground objects and the sensor by recording the Deceleration and return time of the laser beam (Meng et al., 2010). Based on this calculated distance, the current position of the platform is recorded with GNSS, while the position of the object measured is calculated by recording the status of the aircraft with IMU (Liu, 2008).

Terrestrial laser scanning (TLS): It is a technology that is frequently used for the documentation of historical and cultural structures, restoration and survey purposes (Gümüş & Erkaya, 2007). Terrestrial laser scanning is the name of the technology that enables fast and easy data acquisition from objects such as buildings and machines with complex geometry (Staiger, 2003). It provides opportunities for the presentation of 3D photorealistic models, classification of real objects and the creation of visual reality by combining the methods of terrestrial laser scanning technology together with terrestrial image photogrammetry (Forkuo & King, 2004). When compared with traditional measurement techniques, it is seen that 3D point information is a measurement technique that can be obtained with very high speed (Altuntaş & Yıldız, 2008).

Engineering applications of laser scanning technologies in general today (Kanun et al., 2021; Kabadayı, 2023), examination of changes in structures, deformation measurements, measurement of mosques, baths, churches, documentation of cultural heritage such as castles and castles on a city scale (Erdoğan et al., 2021; Kabadayı, 2023), it is observed that it is used in areas such as geography and geological applications such as caves and field research, determining the parameters of forests and woodlands (Alptekin et al., 2019; Kaya et al., 2021b; Kabadayı, 2023).

Laser scanners provide imaging in the form of a point cloud by scanning the object to be measured in the form of arrays of dots under a certain angle in the horizontal and vertical directions. For each laser point, the scanner instrument-centered polar coordinates are measured. These are; the inclined distance to the measured point, the angle that the measuring line makes in the horizontal plane with the x-axis, and the angle of inclination that the measuring line makes with the horizontal plane (Lichti & Gordon, 2004).

If the external surfaces of a building are to be scanned for architectural relay, the tool is installed at any point and the area seen on the building surface is scanned. Then, the scanning is performed by installing the instrument in a suitable place so that it scans the adjacent area of the first scan. Each scan is performed in such a way as to create common scanned areas at a certain rate with the previous scan. These common scanned areas are necessary for the joining of point sets (Altuntaş & Yıldız, 2008).

Preparation of relay and restoration projects using the terrestrial Laser scanning method; Laser scanning technique was used to create 3D data of the castle ruins in the study entitled Aksehir Castle Ruins Sample. The focus is on obtaining information about the spatial and structural situation through the use of 3D laser scanning technique. When the results of the study are examined, it is seen that the ground laser scanning method is an appropriate and modern technique for collecting special and 3D data in the documentation of historical heritage. With the work carried out, the documentation of the structural and digital data of the castle ruins located in Akşehir was provided (Karadayı, 2023).

In the study entitled three-dimensional (3D) documentation of ancient tombstones by ground laser scanning (TLS) method, it was aimed to digitally document the ancient tombstones that need to be scanned using a scanning device without being exposed to any contact. In the study where ancient tombstones were scanned from different locations, 3D models were produced and visual presentations were created, and thus the documentation of ancient tombstones was completed (Us, 2022).

The aim of my study is to create 3D models as base data for use in repair operations in case of destruction and damage caused by possible natural disasters and day-to-day wear of historical structures.

In order to create 3D models of the Besiktas Valideshcheshme Bezmialem Valide Sultan Fountain, in order to restore the damage that may occur due to damage to historical structures, the measurement process is carried out using the ground laser scanning technique, and the purpose of cleaning the noise points of the scan data obtained is to perform the registration process.

2. Point Cloud

Laser scanning devices, which can be defined as a motorized total station, obtain the surface data of the objects to be scanned in 3D coordinates. The scanning process is performed systematically and automatically and allows reaching the x, y and z coordinates of thousands of points per second. The set of high-accuracy dots obtained from TLS is usually collected as a point cloud during the scan (Mills & Barber, 2003; Gümüş & Erkaya, 2007).

The sum of the x, y and z coordinates of any object or location in the general reference system of spatial distribution is called a point cloud. A point cloud contains various information called ”Metric“ and ”Visual or Thematic": (Mettenleiter, 2000; Gümüş & Erkaya, 2007)

Metric: It Deciphers the object geometry along with showing the spatial relationships between the objects in the environment.

Visual or thematic: There is added information such as density or RGB value. It can be used to calculate the reliability of distance data for each point and to explain the properties of the object surface.

3. The Working Principle of TLS

Terrestrial Laser Scanning devices work with three different principles: those that process with the arrival and departure time of a laser beam, those that process with the phase comparison method, and those that process with the triangulation method. Terrestrial laser scanning devices that process by triangulation method are divided into two different classes as single camera solution and two camera solution.

3.1. Those Who Make Transactions with the Arrival and Departure Time of a Laser Beam

As in total stations, a laser beam is sent to the object to be scanned, and Decalculation of the distance between the instrument sending the laser beam and the surface of the object to be scanned is provided. The measurement of this distance in question is calculated by measuring the departure and arrival time of the laser. Scanning devices use small rotation instruments for the angular deviation of the laser beam and use simple algorithms for calculating lengths. The typical standard deviations of distance measurements are a few millimeters. Due to the relatively short distances, this accuracy is almost the same for the entire object area. The 3D accuracy is also affected by the angular punctuation accuracy of the beam (Boehler, 2002; Gümüş & Erkaya, 2007).

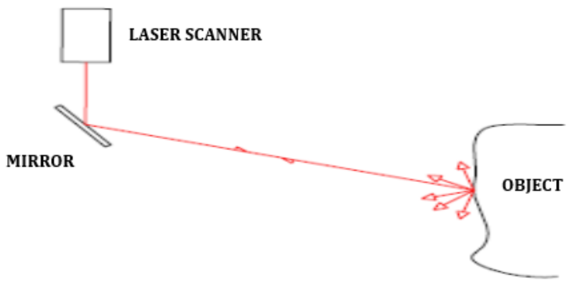


Figure 1. The principle of flight time. (Gümüş ve Erkaya 2007)

3.2. Those Who Make Transactions with the Phase Comparison Method

The transmitted laser is tuned with a compatible wave, and the distance is calculated from the phase deciency between the transmitted and received waves. The results obtained from mixed signal analysis may be more accurate. Since a well-defined return signal is needed, the use of the gas comparison method is more effective at short lengths (Boehler, 2002; Gümüş & Erkaya, 2007).

3.3. Those Who Trade with The Triangulation Method

This method is divided into two different classes: single camera solution and two camera solution.

3.3.1. The Single Camera Solution

Scanners are scanners consisting of a simple beam emitting device.Scanning devices send a laser beam from one end of the mechanical instrument at increasingly varying angles to the object and with a Charged Coupling Devices (CCD) camera that detects laser points. The 3D positions of the reflective surface elements are obtained from the result triangle. It has priorities in research where range finders are used. From this point of view, the accuracy of the range between the instrument and the object is Decently known along with the distance field. Due to application-related reasons, the base length cannot be increased optionally. These scanners play an important role for short distances and small objects in situations that are more accurate than distance scanners (Boehler, 2002; Gümüş & Erkaya, 2007).

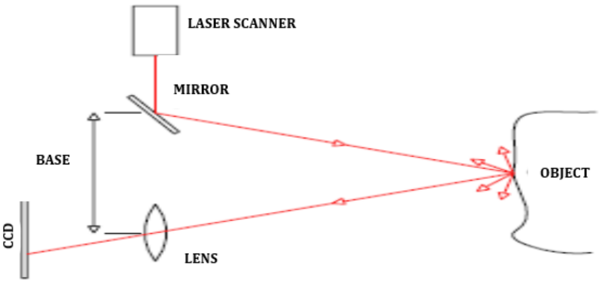


Figure 2. The triangulation principle: A single camera solution. (Gümüş ve Erkaya 2007)

3.3.2. Two Camera Solution

The point or region being examined is produced with a separate light projector that has no measuring function. A broad change of solutions can be seen. The projection consists of a light line of moving ribbon sections. The geometric solution and accuracy results are the same as the single camera principle. Not all instruments that use two cameras provide high ratios and do not produce real-time 3D coordinates. However, if the real-time process of high point rates is provided, these instruments can be considered as an alternative to other specified scanning instruments. (Boehler, 2002; Gümüş & Erkaya, 2007).

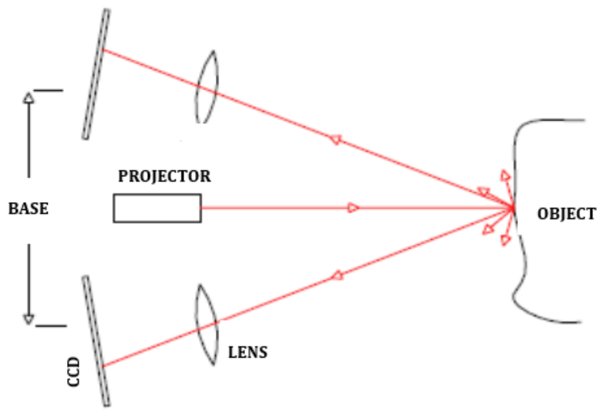


Figure 3. The triangulation principle: Two camera solution. (Gümüş ve Erkaya 2007)

4. TLS DATA STRUCTURE

In the station point instrument-centered coordinate system where TLS are installed, it scans the surface of the object to be scanned in such a way as to obtain the x, y and z cartesian coordinates of thousands of points per second. The data obtained also includes 3D coordinates as well as RGB of the rotating signal depending on the structure of the scanned surface and the measuring distance. Thanks to the recorded RGB density value, it has also become easier to model the scanned object and environment (Altuntaş & Yıldız, 2008).

Laser scanners scan the object to be measured in the form of arrays of dots under a certain angle in the horizontal and vertical direction, allowing it to be displayed as a point cloud. For each laser point, the scanner instrument-centered polar coordinates are measured. These are; the inclined distance to the measured point, the angle that the measuring line makes in the horizontal plane with the x-axis, and the angle of inclination that the measuring line makes with the horizontal plane. Terrestrial laser scanners make measurements based on a completely local coordinate system by accepting the point where they are positioned as the starting point (Lichti & Gordon, 2004).

5. Accuracy of TLS

There are a large number of random errors in the data obtained with laser scanning devices. These errors may be caused by atmospheric conditions, such as measurement system errors caused by beam reflection and beam thickness. By converting the obtained measurements into a geodetic coordinate system, the error amounts caused by the transformation are added to the beam-induced errors. Due to the thickness of the rays sent from the laser scanning device, two different measurement points will be obtained for a laser beam sent from the device, as part of the beam hitting the edge of the scanned object will return to the device, while the remaining part will be reflected from a different surface. By reducing the beam thickness, this error can be reduced to a minimum amount. Atmospheric conditions reduce its effect over short distances. Dust and water vapors will affect the accuracy of the measurements obtained due to the laser beam thickness, and the amount of this error is the same as the amount of error caused by the beam thickness during object edge measurements. This error can also be reduced to a minimum by reducing the size of the laser dot in the same way (Licthi & Gordon, 2004; Altuntaş & Yıldız, 2008).

6. WORKING AREA

Bezmialem Valide Sultan Fountain was built by Bezmialem Valide Sultan on Besiktas Sports Street on the Rumeli side of the Bosphorus in Istanbul in 1839. It is a square fountain with four facades. The fountain was built with the empirical style (URL-1).

The fountain consists of a horizontal wall under the eaves, vertical columns on both sides, an inscription in the middle and a mirror stone under the inscription. Under the eaves with a flat outward flood, there is a fire that rotates along the fountain facades. In the middle of this fire, there is an oval rosette with Sultan Abdulmecit's tugra and a leafy branch motif. There is a horizontal ornament consisting of leaves and tree of life motifs symmetrically on both sides in this fire. There are columns on both sides, one side of which is grooved. In the middle there is an inscription of five lines in a rectangular frame. There is a column at the corners of the facades, vertical fugues have been placed to give the impression that it consists of 12 rows of stones to reduce the visual effect of this column (URL-1).

In the middle of the facade, there is a mirror stone in a rectangular frame with decorations that show exactly the characteristics of the empirical style. Again, high relief leaf decorations are seen emerging from a large girland motif wrapped with a ribbon at the top. Under the Girland motif, there are two torches in the form of high reliefs. These torches are placed crosswise. The tap comes out of a decorated cabaret. It is enclosed in a rectangular frame arranged with floral reliefs on both sides and with floral reliefs on the quadrilateral. Its convex boat is sturdy. On the horizontal rectangular consoles located under the columns, reliefs with rosettes in the middle and herbal decorations on both sides are placed (URL-1).

There is a number of inscriptions in the fountain. The inscriptions on the two facades of the fountain are written on a mirror stone and are enclosed in a frame with gradual erasures. The verses of the inscriptions are Şükri and Ziver (URL-2).

7. Method

TLS was used to create a 3D point cloud of Bezmialem Valide Sultan Fountain. First of all, control points have been established on the structure in order to be able to use it during the merging of scanning data. The scans were performed in the local coordinate system and eight different scanning operations were performed. During the scanning operations, it was taken into account that there were overlays between consecutive scans, that is, there were common control points Decoupled in the scanning data.

Table 1. The number of points obtained as a result of the sessions

Session Number	Number of Points
1	15.205.100
2	4.244.223
3	3.357.137
4	5.093.182
5	2.723.777
6	11.044.989
7	8.572.569
8	12.438.232

The data obtained as a result of the scanning process are in the ".imp" format. In order to process the data, it is necessary to convert from ".imp" format to ".ptx" format. For the format change, the data with the extension ".imp" transferred to the viewer version of the Leica Cyclone software is recorded in the ".ptx" format without any processing in the software. the data in the ".ptx" format is transferred to the CloudCompare software, which is a free software, and the necessary operations are carried out.

During the scanning of the structure, objects in the environment are included in the scanning data. Points other than the structure should be cleaned both because of the high size of the data and because it causes difficulties to the operator during the processing of the data. The filtering operations were carried out manually with the help of CloudCompare, a free software. After only the data belonging to the structure remains in each session, the registration process is performed using CloudCompare software again so that a 3D model of the object can be created. During sequential scanning, the control points common to both scans are matched.

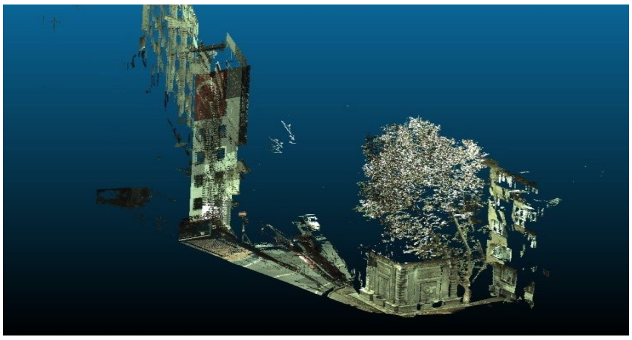


Figure 4. The point cloud obtained as a result of the first session

Figure 5. The point cloud obtained as a result of the second session

Figure 6. The point cloud obtained as a result of the third session

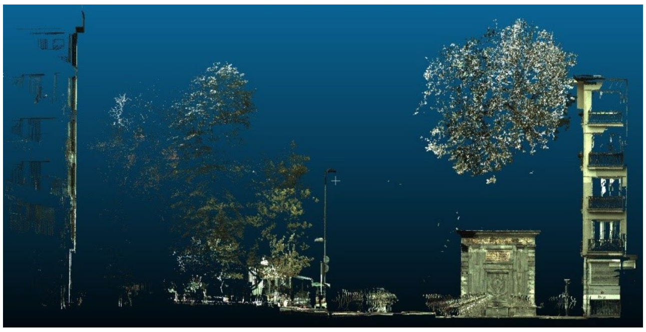


Figure 7. The point cloud obtained as a result of the fourth session

Figure 8. The point cloud obtained as a result of the fifth session

Figure 9. The point cloud obtained as a result of the sixth session

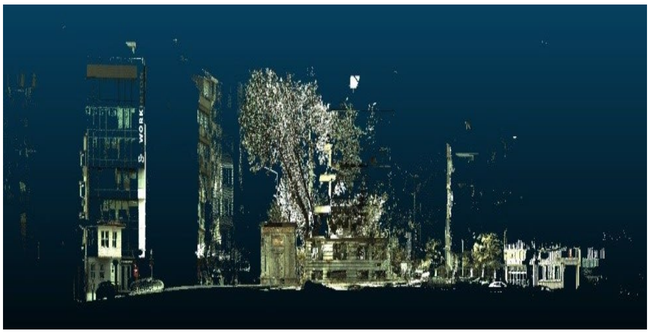


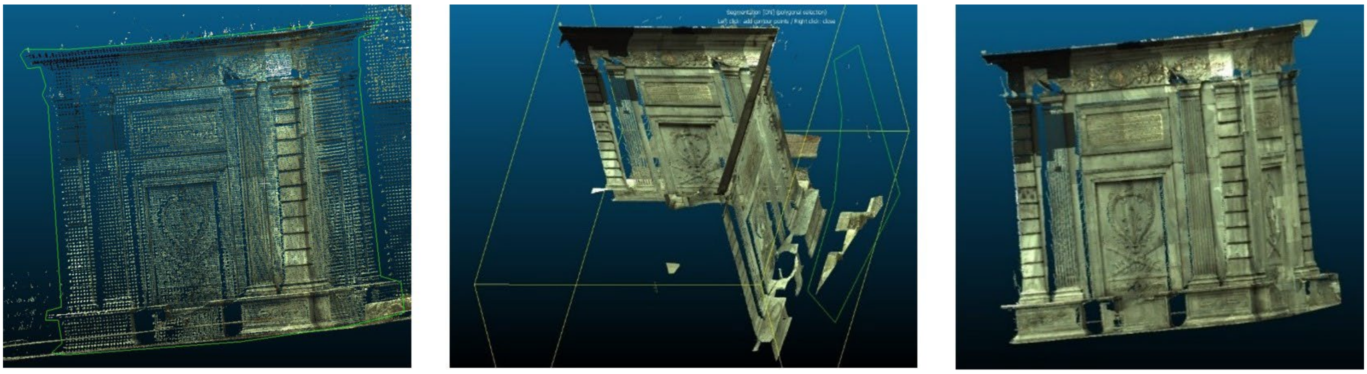
Figure 10. The point cloud obtained as a result of the seventh session

Figure 11. The point cloud obtained as a result of the eighth session

7.1. Filtering the Noise from Point Cloud

Since the work is being performed for a specific object, it is necessary to clear the noise points around that object. The reason for cleaning the noise points is that high-capacity computer technology is needed due to the very large data size and allows the operator, who processes the data obtained as a result of laser scanning, to better distinguish the data and perform more accurate operations. By deleting the noise points, correct interventions can be made to the detail points. Since there will be a significant reduction in the size of the cleared data, time savings will be achieved by reducing the time spent on transactions.

The point cloud data for each scan goes through the filtering process separately. After the data is transferred to the CloudCompare environment, the segment button is selected and the points belonging to the structure that want to be filtering of noise points are surrounded in such a way as to form a closed polyline. By deleting the points remaining outside the selected parts, it is ensured that the noise points remaining around the structure are filtered. In the same way, it is possible to delete the selected parts by selecting noise points. The point cloud is examined from different angles and the filtering process continues until the noise points are detected and only the points belonging to the structure are left. This process is repeated for scanning data for all fronts.



(a) (b) (c)

Figure 12. (a) selection of points belonging to the structure, (b) detection of noise points, (c) point cloud formed by filtering noise points

7.2. Merging The Point Cloud

The registration process is performed in order to Decouple the data obtained in all scans and to ensure that all the details of the structure are contained in a single point cloud. In order for the 3D model to be created precisely, the common surfaces are combined with the matching of control points. Since each successive front screening is carried out by having common control points with each other, matching common control points allows a more accurate model to be created.

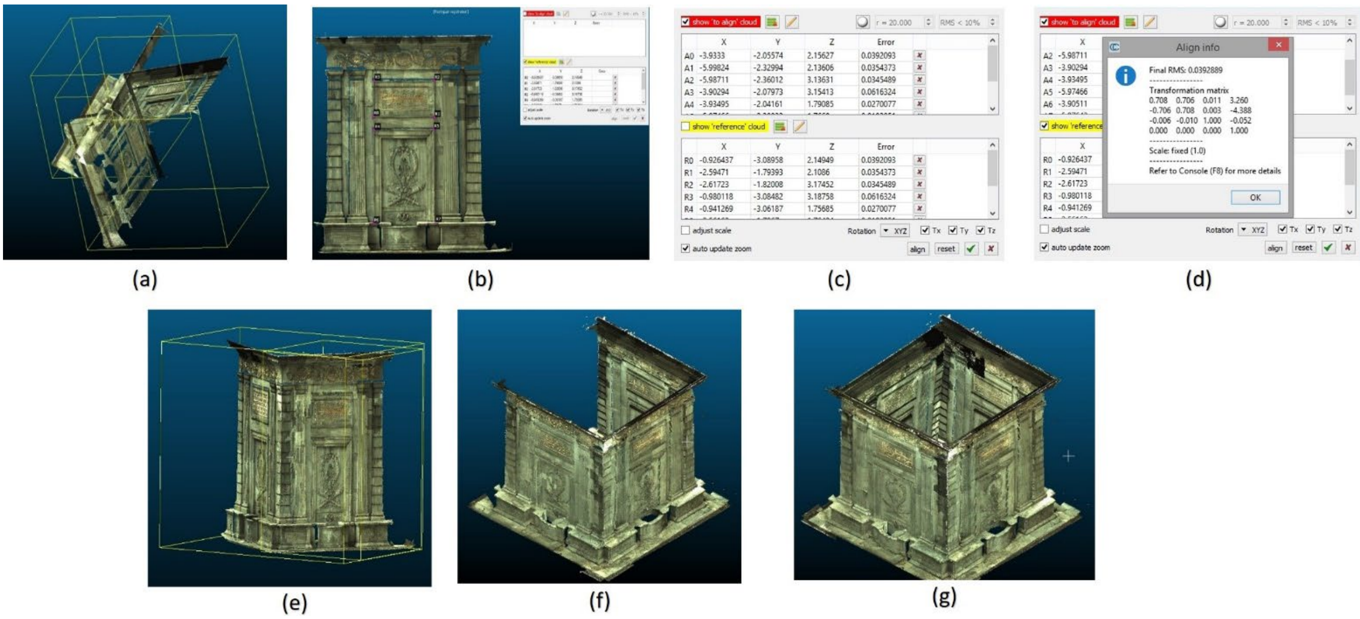


Figure 13. (a) displaying the scan data to be mapped in local coordinates, (b) selecting the control points located on the structure, (c) display of coordinate values in a local coordinate system as a result of selecting control points determined on surfaces with a common scanning area, (d) the align info values obtained at the end of the merge operation are (Final RMS, Transformation matrix and Scale fixed), (e) two facades mapped using checkpoints, (f) three facades mapped using checkpoints, (g) mapping and creating all facades of the structure in a 3D model

8. Results

With the 3D point cloud created, Bezmialem Valide Sultan Fountain will be able to be used as base data in the restoration work that will be carried out to restore it to its former state if it is damaged in any case. When we look at the advantageous side of the process performed, it is ensured that data can be obtained faster and with more precise accuracy compared to classical methods. The roof of the structure was not included in the model because it was not scanned. In order for the roof part to be included in the model, the scanning process can be performed with the help of a drone, and the obtained scanning data can be integrated into the model in the point cloud belonging to the roof. It can be determined how sensitive a model has been created by performing an accuracy analysis of the operations performed. The accuracy of the created model can be determined in future studies.

9. Discussion

By using the CloudCompare software, the point cloud of the desired structure is obtained as a result of clearing the noise points contained in the point clouds obtained as a result of different sessions. After cleaning the noise points, a 3D model of the structure is formed by combining the point clouds obtained, but it is necessary to scan the roof parts with the help of a drone, and thus the model of the structure can be fully realized.

10. Conclusion

By making a comparison with a reference 3D model, the accuracy analysis of the 3D model obtained as a result of the study will be performed and the accuracy of the result data will be determined.

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Author contributions

Conceptualization and design: Berkan Sarıtaş
Data collection: Umut Aydar; Analysis of data and interpretation of results: Berkan Sarıtaş, Beyza Karademir; Writing the first draft of the manuscript: Berkan Sarıtaş, Umut Aydar; Review and editing: Berkan Sarıtaş, Umut Aydar

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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