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AN EXPERIMENTAL APPROACH FOR THE DOCUMENTATION WITH TERRESTRIAL LASER SCANNING OF THE 1035 AD CHURCH OF THE REDEEMER

Ramazan Alper Kuçak

Department of Geomatics Engineering, Faculty of Engineering, Niğde Ömer Halisdemir University (akucak@ohu.edu.tr)

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ABSTRACT

The archaeological site of Ani is located in the city of Kars in northeast Turkey. The archeology area provides a thorough account of the development of medieval architecture and showcases virtually all of the numerous architectural advances that the area experienced between the seventh and thirteenth century AD. The Redeemer Church is one of the architectural monuments of the medieval city of Ani, "known as the city of the thousand and one churches or the city with 40 Doors." The Redeemer Church is one of the few structures still standing in Ani from the prosperous Armenian Bagratid era of AD's tenth and eleventh. In this study, the Church, scanned with 3D terrestrial laser scanning technology by World Monument Fund (WMF) partner Solvotek, was modeled and analyzed using an Open Source program (Cloud Compare) and MatLab Program for 3D documentation. The 3D mesh models, the non-uniform rational B-spline (NURBS) surfaces, and the inscriptions of the Church were firstly generated after analyzing the object details measured by Light Detection and Ranging (LiDAR) in this study. Also, a new approach is proposed to automatically extract the surfaces and the inscriptions (such as handwriting and complicated shaped surfaces) of historical artifacts using parametric features. When the results are evaluated, the RANSAC algorithm applied for NURBS surfaces has extracted the surfacial information successfully. Furthermore, the lines were obtained by using geometric features and the inscriptions on the wall both were obtained automatically with available applications, but with new approaches; the newly proposed approaches have shown that they can be applied successfully in cultural heritage studies.

KEYWORDS: Archaeological site, Cultural Heritage, Ani, Church, 3D Documentation, LiDAR, Laser Scanning, Algorithm, Photogrammetry, RANSAC, Delaunay Triangulation, NURBS

1. INTRODUCTION

Historical artifacts and archeological sites are exposed to many natural or unnatural destructions from the past to the present. Because; the studies carried out to protect the cultural heritage and archeological sites for informing the next generations about the history are accelerating day by day all over the world, and their importance is increasing to a great extent (Kuçak, 2014; Kuçak et al., 2016)

The northeastern Turkish city of Kars is home to the ruined medieval Armenian city-site Ani (Greek ancient name of Anion) archaeological site. The Turkey-Armenia boundary lies inside the confines of Ocaklı village, which is located on the western bank of the Arpacay River (Fig. 1). Due to its strategic location on a fortifiable plateau surrounded by lush river valleys at a critical entry point for the Silk Roads into Anatolia, Ani was home to a population of around 2500 years. With examples of practically all the many architectural advances of the region between the 7th and 13th centuries, the archeological section provides a thorough overview of the history of medieval architecture. Historical processes have a special place in gaining the feature of world cultural heritage. In this context, Persians, Karsaks, Kamsarakans, Byzantines, Umayyads and Abbasids, Bagrats, Seljuks, Shaddats, Georgians, Celayirs, Mongols, Timurids, Karakoyunlus, Akkoyunlus, Ottomans owned the old medieval city and as a result of the war between 1877-78. the city was left to the Russians. It was later captured by the Turks. (Özlü and Kaleli, 2019)

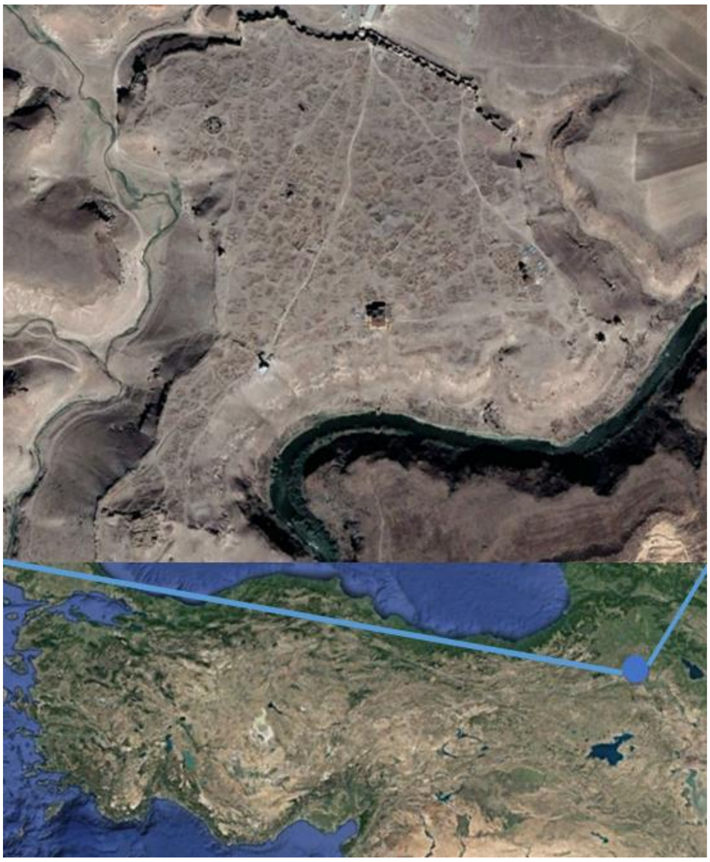

Figure 1. The location of Ani archelogical site in the northeast of Turkey by using Google Earth image.

The Ani site was added to the tentative list by UNESCO in 2012 (Özlü and Kaleli, 2019). Ani Ruins are the first melting pot of Turkish-Islamic, Armenian and Georgian-Christian civilizations and symbolize cultural diversity. Due to this role, it was added to the endless list of UNESCO's World Cultural Heritage and was taken under protection in 2016. According to the information given by Ateş (2018); "Systematic excavation and restoration works started on 11 July 2016 at the Istanbul Congress Center and since 2008, as a result of the evaluations, in cooperation with the World Monuments Fund and the Ministry of Culture. As a result, ani Archaeological Site, also known as the City of 1001 Churches or the City of 40 Doors, has been registered on the World Heritage List. (Özlü and Kaleli, 2019)

The first archaeological excavations at the site were started in 1892 by the Georgian-origin Russian archaeologist Nikola Marr, and until 1917 İ.A. Orbeli and D.A. continued with Kipshidze. Then, finally, it was brought to the present day with the excavations carried out by prof. Dr. Kilic Kökten, Prof. Dr. Kemal

Balkan, Prof. Dr. Beylan Karamağaralı, Prof. Dr. Yaşar Çoruhlu. Today, Excavations are continued by Prof. Dr. Fahriye Bayram. The findings found as a result of archaeological studies are exhibited in the Kars Archeology Museum. (Özlü and Kaleli, 2019)

Since 1988, the archaeological site of Ani has been listed on the national inventory as a 1st Degree Archaeological Conservation Site encircled by a 3rd Degree Archaeological Conservation Site. The site's limits have also been continuously expanded. Due to these registrations, the property is now protected by National Law No. 2863 of Turkey. The primary government agency in charge of preserving and maintaining the site in the Republic of Turkey is the Ministry of Culture and Tourism, structured both at the national and local levels. For the two registered sites, a Conservation Oriented Development Plan was authorized in 2011 after a process based on scientific principles and the involvement of stakeholders at various levels. On February 3, 2016, the Ministry adopted a Strategic Conservation Master Plan that had been created by the Ministry with scientific backing from specialists. On March 30, 2015, the property's management plan was authorized. Among the priorities listed in the two plans for the years, 2015 to 2020 are emergency actions against seismic and environmental risks to ensure the intact survival of monumental buildings, context excavations and research to reveal their urban setting, and improvements to visitor and research facilities at the site, improvement of Ocaklı Village through better integration with the property, and educational programs geared toward these goals. (URL 1)

The Redeemer Church is one of the architectural monuments of the medieval city of Ani, "known as the city of the thousand and one churches or the city with 40 Doors." (Özlü and Kaleli, 2019). The Redeemer Church is one of the few structures still standing in Ani from the prosperous Armenian Bagratid era of AD's tenth and eleventh. Located in the heart of the archaeological site of Ani in the city of Kars in Turkey, the Redeemer Church was built in 1035 by Prince Abulgharib Pahlavuni as a relief for part of the True Cross (Ateş, 2018). Located in the southeast of Ani, the church is one of the most typical Armenian churches. Tall and exquisitely crafted inscriptions found on the walls of the church record that prince Abulgarip Pahlavid had this church built to house the True Cross (Kılıçbey, 2012).

The Church, which has 19 faces from the outside, has eight diagonals inside in terms of church technique. The structure, built with the construction method of medieval Armenian churches, was built as a single, holistic structure in terms of walls, roofs, foreheads, dome, columns, and apses. Due to this construction technique, half of the church would be destroyed in case of any collapse. This feature stands for "all or nothing" in terms of structure (Kılıçbey, 2012).

Various potential data formats might be dynamically combined to build layers of information for virtual archaeology or virtual cultural heritage. It would significantly aid us in appreciating the world around us if displayed in a dynamic and navigable fashion. This is particularly important for cultural heritage investigations where investigative diagnostic imaging generates a wide range of disparate data modalities that call for a more comprehensive visualization framework to experience and fully appreciate the contextual tapestry of data that may inspire further scientific investigation (Psalti, et al., 2022). The ability to digitally record multiple approximations of physical reality is available to researchers studying cultural heritage (Khalloufi et al., 2020). Typically, this entails a systematic survey of data elaboration and hands-on interpretation that leads to creating models, maps, reports, and other "deliverables" useful for further study. First, this involves surveying and applying available digital technologies to acquire various kinds of objective raw data about the site (Bianchini et al., 2013). The issue, especially for large-scale LiDAR scan or Structure from Motion (SfM) imaging activities, is that most digital record is practically unavailable until the products of the elaboration processes are accomplished. (Petrovic et al., 2014)

According to English Heritage's classification of metric survey approaches, direct and indirect processes are primarily employed in cultural heritage documentation (Heritage 2011; Ulvi and Yakar, 2014; Yılmaz and Yakar, 2006; Elyamani, 2018; Khalloufi et al., 2020; Korumaz, 2021). Aerial photogrammetry, rectified photography, close-range photogrammetry, remote sensing, terrestrial laser scanning, and airborne lidar are indirect techniques. Remote sensing, rectified photography, close-range photogrammetry, and remote sensing are examples of direct techniques. A combination of these technologies and associated approaches may be the best choice in most cases, depending on the final products. But each of them has some limitations and drawbacks as reported also in earlier relative works (Georgopoulos, 2016; Grussenmeyer et. al., 2008; Alptekin et al., 2019; Korumaz, 2021).

The detailed generation of a 3D model allows the geometry, appearance, and other visual aspects of historical sites (Petrovic et al., 2014). Nowadays, non-contact methods based on light waves, notably active or passive sensors, are primarily used to create 3D models for cultural heritage or archaeological sites. Currently, there are four approaches to object and scene modeling:

1. Image-based rendering, which does not create the geometry of a 3D model but may be preferred as a potential approach for creating virtual elements
2. Image-based modeling, such as photogrammetry, is a popular technique for creating geometric representations of architectural things and documenting cultural heritage (Altuntas, et al., 2017).
3. The scientific community and non-expert users, such as experts in cultural heritage, are increasingly turning to range-based modeling (like laser scanning).
4. The combination of image and range-based modeling both have benefits and drawbacks, and their integration can enable the efficient and speedy creation of detailed 3D models. (Almagro and Almagro Vidal, 2007; Kuçak et al., 2016; Kuçak, 2022)

While being visualized or analyzed for 3D surfaces, 3D model acquisition (terrestrial and airborne LiDAR or Structure-from-Motion (SfM)) and 2D imaging approach turn data into models such as 3D mesh and parameter surfaces (Petrovic et al., 2014). The most popular technique for reconstructing the surfaces of 3D models is parameter surface, which is also one of the powerful methods for defining geometric shapes. It has the elements of a functional display. Bezier, B-spline, and Non-Uniform Rational B-spline (NURBS) surfaces are examples of well-known parametric surfaces. Gordon was the first to suggest a reconstruction technique using a B-spline surface. Surface representation reconstruction is now usually performed using NURBS. NURBS surfaces are more flexible and efficient than B-spline surfaces and can more realistically represent freeform surfaces. (Yu et al., 2018)

This study presents acquiring point clouds, analysis, and 3D modeling methods of the Church of the Redeemer located in the archeological site of Ani via terrestrial LiDAR technology. Based on NURBS, a three-dimensional model of the Church is shown. The findings demonstrate that the Church's precise and thorough three-dimensional geometric structure can be acquired by terrestrial laser scanning, offering reliable primary data for follow-up inspections; it is of significant cultural and historical value. This study aims to be a 3D mesh model, and 3D analysis of the Church of the Redeemer scanned with terrestrial laser scanning technology by WMF partner Solvotek. After analyzing object details by scanning with the terrestrial laser scanner, the 3D mesh models and NURBS surfaces of the Church were generated. Moreover, a new approach is proposed to automatically extract the parametric surfaces and the inscriptions in the 3rd arcade west of the entrance of the church using multiscale features. In these inscriptions it says: "*In the year 791 (A.D. 1342), by the grace and mercy of God, the benefactor and friend of men, I. at'abek Vahram, son of Ivane, son of the great and strong Zak'aria, again restored the dome of this St. P'rkitch, for my long life and in memory for us and for our ancestors. I, therefore, Asil, son of Grigor was sent with the order of the patron at'abek Vahram and, when come, I did, with great effort and fatigue, what had been ordered by me*" (Uluhogian 1984). In conclusion, the advantages and disadvantages of open-source code software were evaluated for obtaining NURBS surfaces and handwriting inscriptions by performing various surface analyses using an Open Source program (Cloud Compare) and MatLab Program for 3D documentation.

2. THE CHURCH OF REDEEMER (THE CHURCH OF SURB PRKICH)

The Redeemer Church is one of the architectural monuments of the medieval city of Ani, "known as the city of the thousand and one churches or the city with 40 Doors." (Özlü and Kaleli, 2019). The Redeemer Church is one of the few structures still standing in Ani from the prosperous Armenian Bagratid era of AD's tenth and eleventh. Located in the southeast of Ani, the church is one of the most typical Armenian churches. Tall and exquisitely crafted inscriptions found on the walls of the church record that prince Abulgarip Pahlavid had this church built to house the True Cross. The Church, which has 19 faces from the outside, has eight diagonals inside in terms of church technique. The structure, built with the construction method of medieval Armenian churches, was built as a single, holistic structure in terms of walls, roofs, foreheads, dome, columns, and apses. Due to this construction technique, half of the church would be destroyed in case of any collapse. This feature stands for "all or nothing" in terms of structure. (Kılıçbey, 2012)

The church has endured medieval reconstructions and repair in 1912 and has been kept inside Ani's remains despite its western half's poor preservation. First, Surb Prkich's historical information, historiography, and architectural design have been examined by the writers, two Turkish architects, and a Russian architectural historian. They then presented the outcomes of the site's cleaning and archaeological digs, and in 2012 the stability and conservation program for the monument was launched (Kazaryan et. al., 2016).

Figure 2. The Redeemer Church (see at the end URL 2)

The Church, built with a tuff stone floor consisting of two domes with a circular plan, is one of the most typical Armenian churches (Özlü and Kaleli, 2019). While the Church, which has cross motifs on the exterior, has 19 faces from the outside, it has eight diagonals inside it. The structure, built with the construction method of medieval Armenian churches, was built as a single, holistic structure of walls, roofs, foreheads, dome, columns, and apses. Due to this construction technique, half of the Church would be destroyed in case of any collapse. This feature stands for "all or nothing" in structure (Kılıçbey, 2012).

The church was completed around 1035, and its long and elegantly carved inscriptions on the walls tell a lot about its history. It is written in the inscription on the walls of the church " *In the year 480 (A.D. 1035), I, Ablgharib marzpan (general) took an edict on behalf of Smbat shahanshah (king of kings) to Michael, Emperor of the Greeks, at Constantinople, and with great effort and great expense I bought a fragment of the Holy Cross, and when I returned, completed this temple....* ") (URL 3). The inscriptions seen in Fig. 3 is that " *In the year 791 (A.D. 1342), by the grace and mercy of God, the benefactor and friend of men, I. at'abek Vahram, son of Ivane. son of the great and strong Zak'aria, again restored the dome of this St. P'rkitch, for my long life and in memory for us and for our ancestors. I, therefore, Asil, son of Grigor. was sent with the order of the patron at'abek Vahram and, when come, I did, with great effort and fatigue, what had been ordered of me*" (Uluhogian 1984) (Fig. 3).

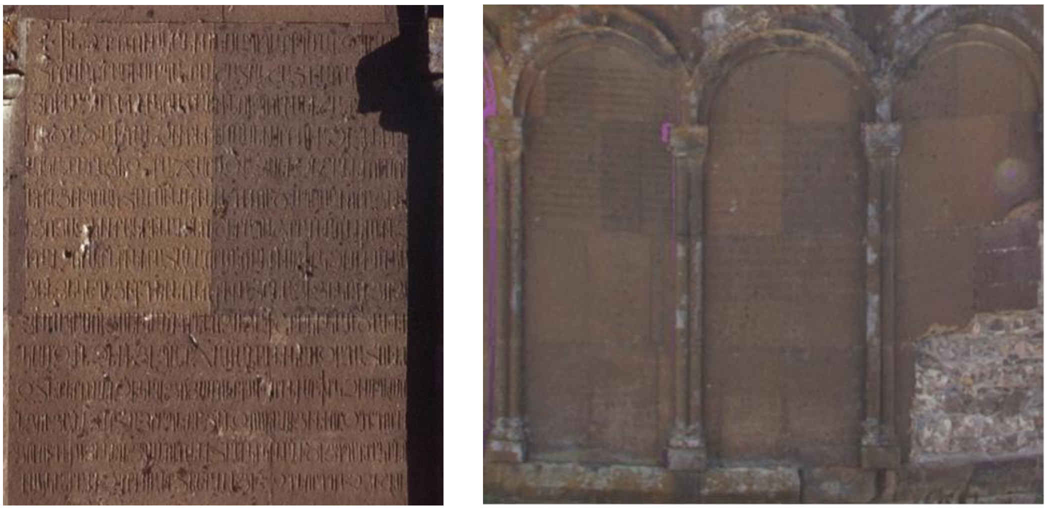

Figure 3. The inscriptions (Left figure, URL 3) on the walls of The Redeemer Church

3. DATA AND METHODOLOGY

3.1. *Terrestrial Laser Scanning (TLS)*

LiDAR (Light Detection and Ranging), which can be used on the ground or in the air, is one of the technological systems that makes it possible to gather much 3D data from the surface of the earth quickly (Popović et al., 2021). With the help of internal or external digital cameras, it generates a point cloud with intensity values in the local coordinate system; other data, such as RGB values, are typically provided (Kuçak et al., 2016; Kuçak et al., 2017). This LiDAR scan can offer archaeologists information that would otherwise be impossible to distinguish due to the region's circumstances (for example, thick vegetation) (Psarros, 2022).

TLS is a robust technology for rapidly gathering 3D data dispersed across a vast area (Kuçak et al., 2014 Kuçak et al., 2016, Kuçak et al., 2020). Lasers, carefully calibrated receivers, timing, swift micro-controlled motors, and precise mirrors make up TLSs (Fowler and Kadatskiy, 2011). The virtual point cloud created by all the 3D points from the surfaces measured in unison is the fundamental data gleaned from each scan (Scaioni, 2005). According to the traditional measuring methods, a 3D dense point cloud can be created using the TLS system's power and accuracy (Çelik et al., 2020). The quality of the 3D models is affected by registration errors; hence the registration of TLS scans must be done correctly. In conclusion, the process from the measurement of laser data to the registration must be done precisely; Have high modeling accuracy.

In this study, The Church of the Redeemer has been surveyed with CyArk's (CyArk Foundation is a non-profit entity whose mission is to digitally preserve cultural heritage sites) digital preservation methodology by WMF partner Solvotek. The data was downloaded from "openheritage3d.org" site (Fig. 4). This site is an open data site that includes cultural heritage 3d models from all over the World.

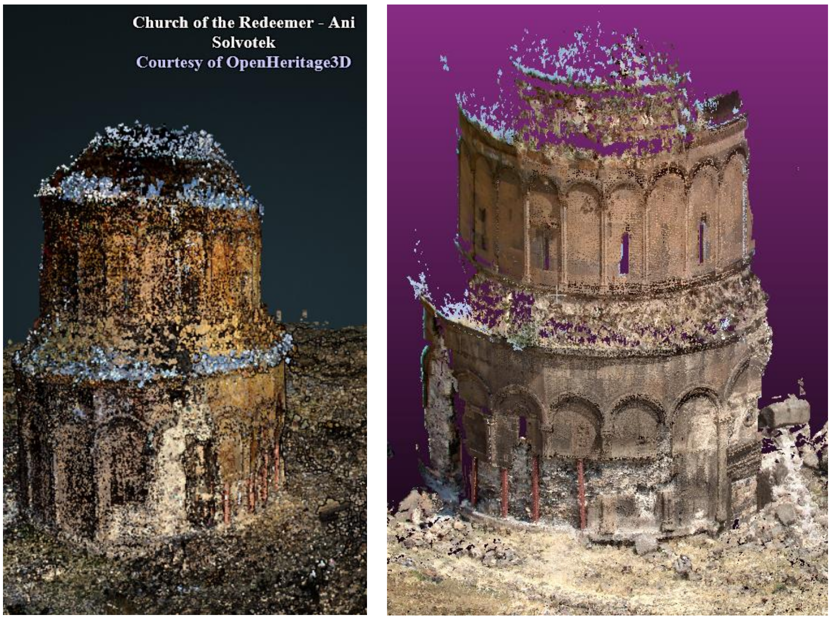

Figure 4. The Church of the Redeemer downloaded from "openheritage3d.org" site

The data was obtained by using the Z+F IMAGER 5006i TLS System, which can get approximately 500,000 points per second with 10 mm / 50 m accuracy and use Phase difference method for distance measurement (Table 1).

Table 1. Technical characteristics of the Z+F IMAGER 5006i TLS System (Kersten, 2009).

Criterion	Z+F IMAGER 5006
Measuring principle	Phase difference
Field of view [°]	360 x 310
Scan distance [m]	< 79
Scanning speed [pts/sec]	≤ 500000
Angular resolution [°] V	0,0018
Angular resolution [°] H	0,0018
Spot size at 10 m	3,2 mm
Precision position	10 mm / 50m

3.2. NURBS surfaces and Mesh Models

Parameter surface, one of the effective techniques for defining geometric shapes, is the most often used method for reconstructing the surfaces of 3D objects. It has all the components of a helpful display. Well-known parametric surfaces include Bezier, B-spline, and Non-Uniform Rational B-spline surfaces (NURBS). NURBS is currently frequently used in the restoration of surface representations. NURBS surfaces can more accurately depict freeform surfaces than B-spline surfaces because they are more flexible and efficient (Yu, Y. et al., 2018). Although the technique of collecting 3D survey data is well-established, current research has focused on processing and developing the survey's raw data. Through this method, which requires a logical and practical procedure of segmenting and categorizing the raw data gathered from the survey, an accurate and thorough 3D model that can be utilized as a support for the recording and study of the cultural heritage object can only be reconstructed. (Croce et al., 2021).

Managing large volumes of metric data from a LiDAR survey and reproducing high-quality 3D models from them are still challenging issues to resolve. NURBS-based techniques that guarantee great modelling details provide an excellent solution. However, NURBS models must be parametrized before they may be utilized directly on Building information management (BIM) platforms. Cultural heritage assets can be surveyed with sufficient accuracy to be managed within a Heritage Building Information Management (HBIM) platform, taking into account the data to be merged and the analysis capabilities of the HBIM platform. The metric acquisition is the first phase, and it can be completed using various methods, including a photogrammetric or LiDAR approach (e.g., terrestrial and UAV). The "as-built" 3D model can be made using the obtained point clouds of the object and associated RGB values (Diara and Rinaudo, 2019).

The parametric or 3D models can be built using various techniques using the original point cloud as a foundation. Most automated processes are built using form identification algorithms to create parametric surfaces; various research has used the The Random Sample Consensus (RANSAC) algorithm (Croce et al., 2021). RANSAC stands for Random Sample Consensus (Fischler and Bolles, 1981). The RANSAC method extracts forms by randomly drawing minimal data points to create candidate shape primitives. The candidate shapes are then compared to all points in the dataset to determine the number of points representing the best match. A typical reverse engineering strategy is to fit primitives like planes, cylinders, and cones locally using RANSAC-based algorithms (Schnabel R. et al., 2009; Grilli et al., 2017).

The RANSAC algorithm seeks out simple shapes in a 3D point cloud (plane, sphere, cylinder, cone, and torus). By selecting minimal groupings of points at random and fitting primitive shapes, it recovers primitive shapes from point cloud data. The RANSAC algorithm determines a basic shape's characteristics by drawing at random the most miniature set of points (a minimum set) that might define it. The algorithm then searches the point cloud for more points and determines whether or not they match the fitted primitive shape. The number of data points that the possible primitive forms can accurately mimic is determined by comparing them to all of the data points. In each round of iteration, the RANSAC algorithm compares the primitive form of the discovered candidate with the most recent one saved. The previous form will be changed if the new one is better suitable. The best shape is a basic form approximating the greatest number of significant points; its parameters were generated during the segmentation process, and its points may be projected onto the surface. The RANSAC algorithm derives a simple form from the point cloud before segmenting the remaining points. The primitive forms that are found are color-coded. Thus, primitive shapes such as plane, sphere, cylinder etc. easily can be discriminated. As a result, the general working logic of the RANSAC algorithm is as described above (Kuçak, 2022).

The Delaunay Triangulation is a multi-purpose structure that is commonly utilized in computational geometry. A triangular net known as a Delaunay triangulation is one in which each triangle meets the Delaunay condition. According to the Delaunay condition, a triangle's circumcircle only contains the triangle's vertex. In other words, there are no other triangles' vertices inside the circumcircle. Boris Nikolaevich Delone (1890–1980), who invented the Delaunay Triangulation in 1934, was a pioneer in computational geometry. A triangulation is meant to create a mesh. Continuous surfaces are frequently represented using meshes. A set of points serves as the input for triangulation, and the output is a set of linked edges or triangles that do not overlap (Zimmer, 2005). In conclusion, the general working logic of the Delaunay Triangulation is as described above. Delaunay Triangulation come up with different problem. Some important applications of triangulation are Digital Terrain Modeling, Feature Surface Modeling, Computer Graphic, Scientific Visualization, Robotic, Computer Vision (Dinas and Banon, 2014).

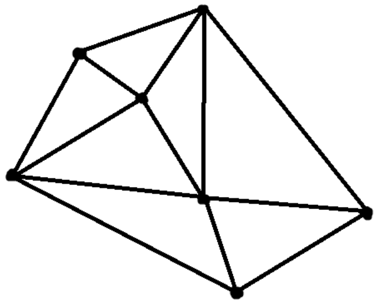

Figure 5. Delaunay Triangulation

Surface parameters help explain the local geometry of the surface. These surface features are nowadays widely applied in point cloud analyses. They are aimed to extract these geometric features (surfaces, lines, corners and key points). Surface parameters (Table 2) can be calculated by the eigenvalues (λ_1, λ_2, λ_3) of the eigenvectors (v_1, v_2, v_3) derived from the covariance matrix of any point p of the point cloud (Atik et al., 2021, Kuçak, 2022).

Table 2. Surface parameters derived from eigenvalues

Sum of eigenvalues	$\lambda_1 + \lambda_2 + \lambda_3$
Omnivariance	$(\lambda_1.\lambda_2.\lambda_3)$^1\3
Anisotropy	$(\lambda_1 - \lambda_3)/\lambda_1$
Planarity	$(\lambda_2 - \lambda_3)/\lambda_1$
Linearity	$(\lambda_1 - \lambda_2)/\lambda_1$
Surface variation	$\lambda_3/(\lambda_1 + \lambda_2 + \lambda_3)$
Sphericity	λ_3/λ_1
Verticality	$\lambda_1.\text{In } \lambda_1 + \lambda_2.\text{In } \lambda_2 + \lambda_3.\text{In } \lambda_3$
First-order moment	see Eq. (1)
1st Eigenvalue	λ_1
2nd Eigenvalue	λ_2
3rd Eigenvalue	λ_3

Eigenvalues are used to calculate many values (Table 2). These parameters (eigenvalue sum, omnivariance, roughness, anisotropy, planarity, linearity, surface variation, Sphericity, first-order moments (1) and curvatures, etc.) are derived solely from 3D coordinates.

$$m \uparrow = \sum_{n \in P_n} (p_n - p_i).,v_2 \qquad (1)$$

where P_n indicates the set comprising the "N" nearest neighbours of each individual point p_i , (.,) indicates the scalar product, v_2 is eigenvector, $m \uparrow$ is the first-order moment of p_i.

4. APPLICATION

4.1. NURBS surfaces and Mesh Models

TLS is a well-known technique for collecting 3D survey data. As a result, we concentrated on processing and developing the raw data from the survey. The only way to create an accurate and comprehensive 3D model is to support documentation and analysis of a cultural heritage object. In this capture, we only focused mesh models and NURBS surfaces. Terrestrial laser scanning data can be altered in various CAD programs for architectural projects. In this study, a building scanned using 3D terrestrial laser scanning technology will be subjected to a 3D analysis and mesh model. Z+F 5006i laser scanner was used to extract the features of the objects (Fig. 6). Also, the RANSAC algorithm and mesh methods by open-source software (Cloud Compare) was then applied to create 3D mesh models and 3D NURBS surfaces from the 3D point clouds. In conclusion, the advantages and disadvantages of open-source software are also being evaluated for obtaining 3D surfaces and performing different surface analyses using an open-source program.

Figure 6. Z+F 5006i laser scanner

To create a mesh is used a triangulation. In this study, 2.5 D Delaunay triangulation was used by Cloud Compare Open Source Program. This technique computes a Delaunay 2.5 D triangulation using a point cloud. Simple 2D projection of the point cloud onto the (XY) plane. Following the triangulation of the appropriate 2D points, the mesh structure is applied to the 3D points (Fig. 7). The cloud convex hull is the default used for the 2D Delaunay triangulation.

Therefore, Cloud Compare will demand that the user enter a maximum length for the triangle edges. This enables the removal of the largest, potentially meaningless triangles, typically on the boundary. All the triangles produced by the Delaunay triangulation will be maintained if this value is left at zero. In this case study, maximum edge length was tried these values (0, 2, 4 meters) and the surface differences between the two mesh models were examined. Average differences of 0.0005 m were obtained with a standard deviation of 0.0003 m. Shortly, similar results were gained as mesh models. The same results were obtained with the model below, the only difference being that the large triangles on the boundary edges were observed.

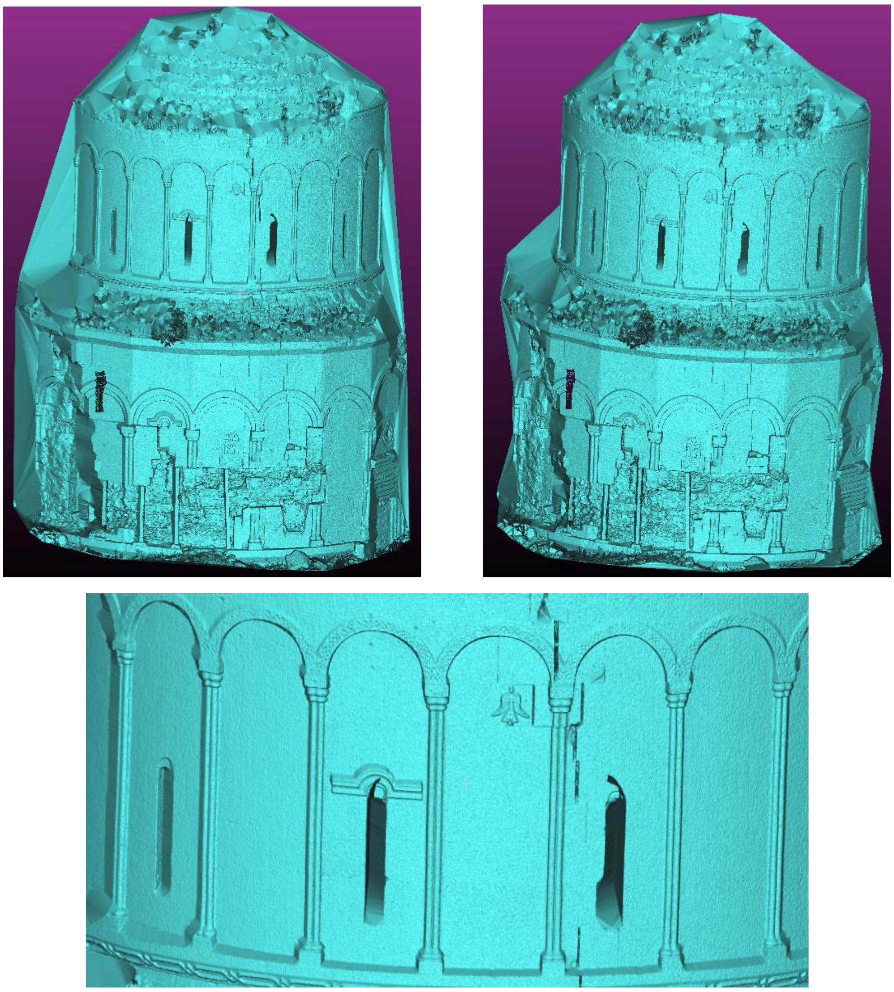

Figure 7. Mesh models (Bottom) and Triangulations (Edge limit = 0, Left Top; Edge limit = 4 m, Right Top) of the church with Cloud Compare Program

The RANSAC algorithm searches for simple shapes in a 3D point cloud (plane, sphere, and cylinder). It recovers primitive shapes from point cloud data by selecting minimal groupings of points at random and fitting primitive shapes. The RANSAC algorithm determines the characteristics of a basic shape by drawing at random the most miniature set of points (a minimum set) that could define it. The algorithm then searches the point cloud for more points and determines whether or not they match the fitted primitive shape. The number of data points that the possible primitive forms can accurately mimic is determined by comparing them to all of the data points. In each iteration, the RANSAC algorithm compares the primitive shape of the detected candidate to the last saved one. In this case study, plane, sphere, and cylinder NURBS surfaces were gained by RANSAC Algorithm. NURBS surfaces (plane, sphere, and cylinder) were determined by using Cloud compare program according to these parameters:

- Max distane to primitive = 0.025 m
- Sampling Resolution = 0.051 m
- Max normal deviation = 25º
- Overlooking probability = 0.01

On the other hand, Cloud compare presents the users other advance parameters "Sphere and Cylinder Advanced Parameters (min and max radiuses). But, they weren't prefered in this case study. Because Default parameters are enough for this NURBS surfaces. Also, Default parameters were tested by increasing and decreasing them at specific intervals. However, the best results were obtained with the values given above. As seen in Fig. 8, the church's columns (green and yellow cylinders) can be obtained clearly in the form of cylinders with the RANSAC Algorithm. The church's arches (blue, brown, purple and yellow arches) could be obtained as part of a spherical surface. The walls of the church were obtained correctly as plane surfaces (deep green and dark brown) (Fig. 8). The desired NURBS surfaces are obtained by defining with this way. Thanks to this study, it has been shown that the desired surface in cultural heritage studies can be produced as a CAD model thanks to the RANSAC algorithm.

4.2. *The inscription of the Church*

The only way to create an accurate and comprehensive 3D model is to support documentation and analysis of a cultural heritage object. So, we computed the geometric features of a surface (Table 2). The data was filtered and segmented based on optimal values. We could quickly obtain vertices, boundary lines, and 3D corners from 3D point clouds in this manner (Fig. 9). Eigenvalues are used to calculate many values (Eigenvalue sum, Omnivariance, roughness, anisotropy, planarity, linearity, verticality, surface variation, Sphericity, first-order moment, and curvatures, and so on.). Because the datasets used only contained geometric information from 3D coordinates.

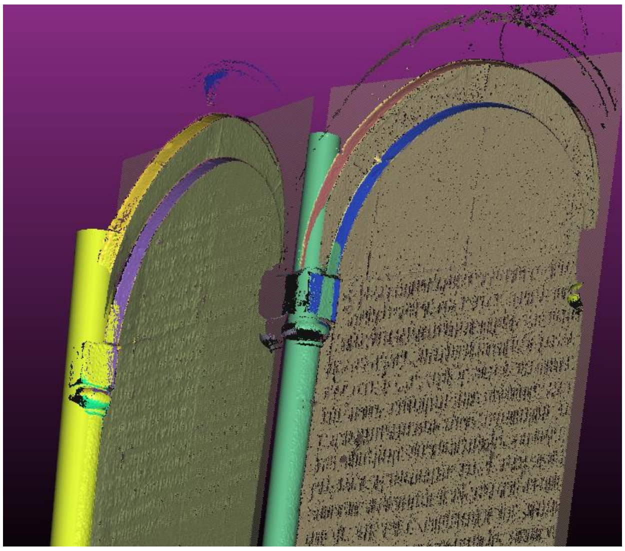

Figure 8. NURBS Surfaces of the church extracted automaticly with RANSAC Algorithm

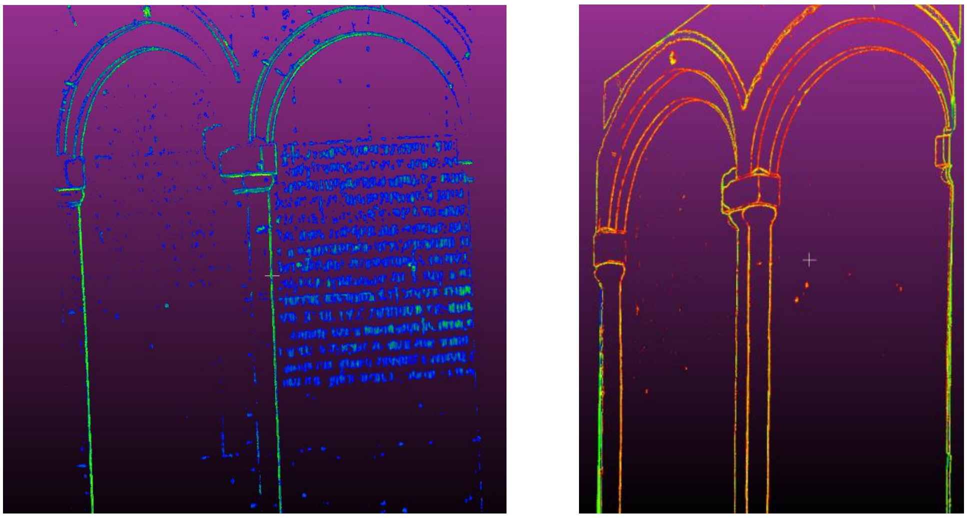

Figure 9. Boundary lines according to Omnivariance (Left) and 2nd Eigenvalue (Right)

As seen above, the boundary points and corner points can be obtained by surface parameters, which can be preferred in many studies (Fig. 9). The corner boundaries were obtained in the filtering study according to the Omnivariance seen in Fig. 9. Therefore, the object shown in the figure 9 can be directly converted to CAD format and used in the line data format in survey and restoration projects. In this study, boundary lines (columns and arches' lines) were obtained automatically from the filtered points. However, we focused on the inscription on the walls of the church in this case study. So, TLS Data according to 3rd Eigenvalue and Omnivariance was segmented. Therefore, the inscriptions in the church were obtained automatically (Fig. 10).

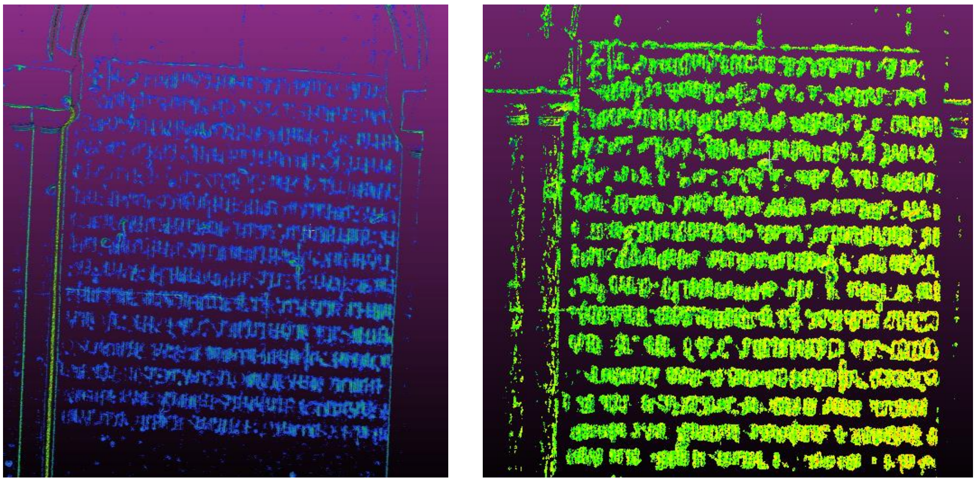

Figure 10. TLS (Z+F 5006i) Data According to 3rd Eigenvalue (Left) and Omnivariance (Right)

When calculating the surface parameters, the most critical parameter is the "local neighbor radius." This entered value plays a significant role in filtering the required information. In this study, while the boundaries are automatically generated with the 2nd eigenvalue parameter, this local neighbor radius value is chosen as 0.0298. While generating the omnivariance value for the inscriptions on the wall, the inscriptions on the wall could be obtained automatically by selecting this value of 0.0198 (Fig. 10).

On the other hand, when the inscriptions of the church obtaining automatically, a new approach was applied. This approach is the cross of surface parameters (2). In this case study, the MatLab programming language multiplied two surface parameters (omnivariance and 3rd Eigenvalue). Then, the new values obtained were filtered in the Cloud Compare Program, and the inscriptions on the wall could be obtained more clearly. Therefore, the inscriptions in the church were obtained automatically (Fig. 11)

New value = omnivariance * 3rd Eigenvalue (2)

Figure 11. TLS (Z+F 5006i) Data according to new approach values (Left) and original point clod (Right, URL 3)

The Redeemer Church is one of the architectural monuments of the medieval city of Ani. its long and elegantly carved inscriptions on the walls tell a lot about its history. It is written in part of an inscription on the walls of the church " *In the year 480 (A.D. 1035), I, Ablgharib marzpan (general) took an edict on behalf of Smbat shahanshah (king of kings) to Michael, Emperor of the Greeks, at Constantinople, and with great effort and great expense I bought a fragment of the Holy Cross, and when I returned, completed this temple....* ") (URL 3). As can be seen in Fig. 11, the inscriptions in the 3rd arcade west of the church's entrance were automatically obtained easily with this proposed new approach. Many inscriptions are written on the walls of the church. The inscriptions seen in Fig. 11 is that "*In the year 791 (A.D. 1342), by the grace and mercy of God, the benefactor and friend of men, I. at'abek Vahram, son of Ivane. son of the great and strong Zak'aria, again restored the dome of this St. P'rkitch, for my long life and in memory for us and for our ancestors. I, therefore, Asil, son of Grigor.*

was sent with the order of the patron at'abek Vahram and, when come, I did, with great effort and fatigue, what had been ordered of me" (Uluhogian 1984). In the article published with the new approach, it is understood from Figures 10 and 11 that Uluhogian 1984 resembles the characters he published. However, the words in the scripts seen in Fig. 11 could not be fully extracted by the texture determination algorithms. Nevertheless, this proposed approach is very efficient and convenient for many cultural heritages. Obtaining letters and words automatically and presenting them as a meaningful whole constitutes the subject of a different project and research. This study has been a study that supports and guides this aim.

In this study was aimed to be a 3D mesh model, and 3D analysis (the inscriptions and the NURBS surfaces) of the Church of the Redeemer located in the medieval city of Ani. The Church's 3D mesh model was reproduced, and the surfaces based on NURBS were reproduced. The findings demonstrate that terrestrial laser scanning can be used to acquire the Church's precise and comprehensive three-dimensional geometric structure. In terms of cultural heritage, it is quite important. A Heritage Building Information Management (HBIM) platform can control cultural heritage assets when they are surveyed accurately enough. Therefore, before being used directly on Building information management (BIM) platforms, NURBS models must be parametrized. As seen in this study, a selected surface of the church can be obtained with the desired accuracy as a NURBS-based or mesh model. This study is an excellent example of accurate architecture and HBIM studies models. On the other hand, CAD line models that can be used in architectural applications are obtained automatically by analyzing the surface parameters. This approach will provide an excellent convenience for restoration work in many architectural applications. Also, the new approach presented for the cultural heritage inscriptions has been successfully implemented. After that, it has been confirmed that it is a preferred practice for such detailed studies in cultural heritage and HBIM studies. In conclusion, when the study is examined in general, studies such as producing CAD models from many surface parameters, NURBS surfaces, and mesh models that can be done with commercial software have been obtained successfully using open-source programs. Moreover, Thanks to these applications, it was emphasized that it is an original study proposing new approaches.

5. CONCLUSION

The Church of the Redeemer, which is located in the medieval city of Ani, was the subject of a 3D mesh model and 3D analysis for this project. Reproductions of the NURBS-based surfaces and the 3D mesh model of the Church were made. Also, the inscriptions on the church were automatically obtained with this proposed new approach. This new approach can be applied easily for many cultural heritages. In conclusion, when the study is considered generally, studies like making CAD models from a variety of surface characteristics, NURBS surfaces, and mesh models that are possible with commercial software have been effectively acquired using open-source applications.

Working with high-accuracy points to model point clouds is critical, as is having enough data. Understanding the precision or resolution required for modeling in point cloud investigations is also critical. The registration or modeling processes can complete if the point clouds are sufficient for the desired work. If the required surface data is missing or insufficient precision and resolution in the existing point cloud, creating a more accurate point cloud from the existing point cloud and integrating it into the reference data for interpolation or modeling will be a more accurate technique.

The resolution and accuracy of point clouds are critical for creating 3D precise mesh models and surface characteristics. As a result, the foundation of point cloud research is working with high resolution and accuracy point clouds rather than different point clouds in 3D modeling. As a result, it is critical to use a large number of high-precision point clouds for data modeling. Various filtering algorithms can use for modeling, interpolation, and surface fitting operations; however, modeling or interpolating data that is missing or incorrectly measured is always tricky. The results show that the RANSAC Algorithm can generate high-precision and complete three-dimensional geometric models, resulting in reliable 3D data for restoration and other engineering projects.

The trials carried out for this study demonstrate that a single unique technique or geometric characteristic cannot be advised for the 3D Surface parameters, the inscriptions or 3D models of the 3D point cloud. As can be seen in Fig. 11, the inscriptions in the 3rd arcade west of the church's entrance were automatically obtained easily with this proposed new approach. Nevertheless, the definition of letters and words as texture could not be done precisely. Letters such as "զ", "փե", "յում" could be obtained with several different algorithms. So, exactly what the texts seen in Fig. 11 are will be tried again with algorithms that can read letters and words in detail over a point cloud obtained with a different laser scanner or photogrammetric method. Such a study could be done with the existing open heritage laser scanning data. Shortly, according to what the user's needs and data type, the correct algorithm and surface parameters must be chosen. Therefore, obtaining letters and words automatically and presenting them as a meaningful whole constitutes the subject of a different project and research. Also, random Sample Consensus (RANSAC) is commonly preferred in surface reconstruction. Vertices and boundary lines from 3D point clouds can be obtained using geometric features of point clouds produced at many scales.

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