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Full Length Research Paper

Analyzing the geometric accuracy of simple shaped reference object models created by terrestrial laser scanners

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There has been a tremendous amount of research on accuracy, precision and sensitivity of terrestrial laser scanning (TLS) technology from the day it has been first used till today. In this article, geometric and nominal measurements of 3-dimensional (3D) models gathered by scanning object surfaces using TLS were compared to the measurements of real reference models. For this purpose, in order to determine the suitability of models obtained by TLS to the real ones, reference models of concrete samples with simple geometric shapes, such as cubes, rectangular prisms and cylinders were used. These reference models were scanned with Trimble-Mensi GS 100 laser scanner to create 3D models. As a result of the comparison of the length measurements obtained from the reference objects and the models, it was determined that these models are fairly close to reality.

Key words: Terrestrial laser scanners, 3D modeling, accuracy, comparison, reference object.

INTRODUCTION

The recent development in micro-electromechanical and computer technologies provides important contributions to the accuracy and reliability of terrestrial laser scanning (TLS) technology. Therefore, terrestrial laser scanners are used in many applications. The working principle of terrestrial laser scanners is similar to reflectorless total stations. Terrestrial laser scanner is a device that can quickly measure the 3-dimensional point cloud of an image that is scanned in the form of x, y and z points. With the help of these operations, the realistic 3D models of scanned objects are generated. Terrestrial laser scanners also have significant advantages that distinguish them from traditional measurement methods. These advantages are the ability to capture 3D geometry of the object directly, quickly and in detail, significant reduction in the expenses in terms of cost, capability to take measurements in inaccessible, dangerous areas and ability to scan in the night as well as gathering all the details at once (Reshetyuk, 2006). With the increasing use of TLS, new developments are needed to increase the accuracy and reliability of TLS data and end-products.

In the literature, the accuracy of scanners was studied (Kweon et al., 1991; Hebert and Krotkov, 1992; Lichti et al., 2000; Gordon et al., 2000, 2001). Koskinen et al. (1991), Kostamovaara et al. (1991) and Matta et al. (1993) conducted research on the sources of errors in laser length measuring and scanning technologies. A study on factors affecting the accuracy of laser scanner instru-ments was performed (Hancock, 1999). Extensive calibration tests were conducted by National Institute of Standards and Technology (NIST) (Cheok et al., 2002). The effects of length, angular accuracy, resolution, edge effects and surface reflectance were investigated by the Institute for Spatial Information and Surveying Technology at University of Mainz. In addition, a survey of TLSs (Preifer and Lichti, 2004); a classification of these scanners was done (Fröhlich and Mettenleiter 2004); a comparison of commercially available TLS systems was presented (Lemmens, 2004); the accuracy analysis of points obtained by laser scanners was conducted (Boehm et al., 2003). Also, Reshetyuk (2006) investigated the scanner length measurements, the sensitivity of coordinate accuracy, TLS calibration, sccanner

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Measuring principle: delay time measuring
Opening angle: 360° x 360°
Measuring area: 2 - 100 m
Scanning speed: up to 5000 points/s
Angle resolution: 0.00180
Measuring precision: 6 mm (Single shot)~4 mm
All-mains or storage battery operation

Figure 1. Technical specifications of Mensi GS 100.

performance and accuracy of the product results obtained by scanning. Gottwald (2008) developed and proposed test procedures for TLS to ISO standards. Altuntas et al. (2010) carried out cross section works of generated 3D models by TLS scanner and obtained wall thickness in their model.

In this study, the important points to consider when choosing reference objects were highlighted. The steps by step processing the point clouds collected by scanning, regularizing these points and modeling in 3 dimensions was presented visually. In order to test the geometric correctness of the models obtained by terrestrial laser scanners, sample objects with simple geometric shapes such as cubes, rectangular prisms and cylinders that are made of concrete were used as reference models. Three dimensional models were generated by scanning these reference models with Trimble-Mensi GS 100 (Figure 1). The dimensions of the 3D model that is created from point clouds was compared with the precisely measured dimensions of the reference objects. For this purpose, horizontal and vertical cross-sections were taken from the reference objects and generated 3D models, and the proximity of these models to the real objects were determined by measuring the lengths of these cross-sections. The aims of this study are to test the performance of the laser scanner used in the test, and the size and shape of the scanned objects as compared to reference objects determined with high precision.

MATERIALS AND METHODS

Terrestrial laser scanners and reference objects

Terrestrial laser scanner is a device that can rapidly measure the 3-dimensional data of an image that is scanned in the form of x, y and z points. The distance from the scanner to a point on the object is determined by measuring the time elapsed from the dissemination of the laser signal to collection of the signal that is reflected back from the object surface with high precision. With these scanners, thousands of points that cover the object surface can be obtained in horizontal and vertical directions to obtain 3-dimensional point clouds that cover the entire object. For each point, 3-dimensional coordinates (x, y, z) and RGB (red, blue, green) values, in other words the intensity of the reflected laser signal, are recorded in the coordinate system that is fixed with respect to the scanner.

Scans for objects with complex and large structures are performed at different points that can cover (overlap) each other in order to capture the entirety of the object geometry. To provide a representation that covers the whole object, these scans are integrated and the combined data is transformed into a particular geodetic coordinate system. 3-dimensional model of the scanned object is created and visualization is provided. These created models are exported in numerous CAD software packages and are used for varying purposes.

In TLS applications, it is necessary to take into consideration the conditions that affect the scanning process, especially the general characteristics of the laser scanner, geometric properties of the scanned object (shape, size, etc.), and its spatial location in the environment. Three dimensional models obtained with TLS, allow determination of the geometric features and relevant magnitudes of the scanned object in an indirect way. As also mentioned in Zamecnikova and Kopacik (2004), in order to test the geometric accuracy of these models, objects with simple geometric shapes (spheres, cones, cylinders, cubes or objects that are characterized by nominal measurements) that have no visible alterations, that do not change dimensions or measurements and that are resistant to elastic deformation, must be selected for testing. These reference objects must be made of solid and stable materials, such as metal, brick, concrete and wood. Scan parameters must be selected to reach the most appropriate configuration. In order to compare the spatial location and geometric accuracy of the 3-dimensional model created by terrestrial laser scanning, it is necessary to use measurement tools that give more precise results than TLS. Geometric comparisons are performed by analyzing the differences between the distances, the angles between surfaces and the measured values taken from cross-sections between the data from the 3-dimensional model created with TLS and the values measured by other measurement devices.

Evaluation of TLS data and 3D modeling

Boehler et al. (2002) mentioned all the processing steps of terrestrial laser scanning technology starting from data collection to production of end-product. During scanning phase, points that do not represent object surface are also recorded. The recording of these redundant and irregular points can be prevented by entering distance limits into the software. With the help of the used software, by performing visualization on the point clouds, the redundant points can be detected and deleted. Even after this deletion

Figure 2. Visualizations of targets (Sphere) and reference objects.

process, the remaining points are still irregular. Through a filtering process, these irregular points are attempted to be regularized. When the object surface is smooth and flawless, it is not necessary to process the dense point cloud that reflects the object surface as it causes the software to run slowly. In order to prevent this, reduction is applied on the point set.

Scans can be made from a single point as well as many different points depending on the location and size of the object. Integration of scans made from different points is carried out using marks and targets, such as connection, control points and distinctive window corners of the object. The point cloud obtained as a result of the scan is typically in the same coordinate system as the scanner. To transform these coordinates in the national coordinate system, target points that are predetermined by geodetic and photogrammetric methods are used. In order to do the combination and positioning of scans from different points, at least 3 target points are placed at each intersecting scan area. These target points must be scanned with high sensitivity at each scan area.

The next stage is the creation of an identical and realistic 3-dimensional model using the point clouds that reflect the scanned object or the surface area. If the scanned object consists of simple geometric shapes, simple drawings are performed over the point cloud with CAD software. If the object's surface is very complex and drawings using basic geometric shapes cannot be achieved, surface net models are created. A surface net is created by triangulation done by the software. When this triangulation is made automatically by the software, no triangles may be formed for some sections of the object, unnecessary triangles or gaps may be formed or some errors may occur in the obtained triangles. Regulization of these triangles and filling gaps can be done by the user utilizing software modules. Making use of the surface models, solid models of the scanned object or the area can be created. Additional information, such as textures for object surface visualization, images, etc., can be added on top of the surface nets. Realistic 3-dimensional model of the scanned object can be achieved after all these processes. The measurement obtained from the model, which is the end-product, are generally found to be very close to reality. Through the generated model, point location information, object size, surface, area and volume information can be reached.

Data description

For this study, concrete samples with basic geometric shapes, a cube approximately 15 × 15 × 15 cm in size, a rectangular prism 4 × 4 × 15 cm in size, a cylinder that has a diameter of 10 cm and a height of 20 cm, were used. These objects were obtained by pouring concrete into molds with the specified sizes. These objects had cavities and roughness after being removed from the concrete mold. In this study, identical and realistic 3-dimensional models of these reference objects were created with laser scanning. The gaps and roughness on the reference object surfaces were attempted to be determined. In addition, by extracting cross-sections, it was examined whether there are differences between the reference objects and the created models in terms of the measured lengths.

Scanning of these objects with simple geometric shapes with terrestrial laser scanners was performed by the Calibration Laboratory in Department of Geomatic Engineering at Yildiz Technical University. Trimble-Mensi GS 100 laser scanner was used for scanning (Figure 1), Point Scape was used as the scanning software, Realworks software was used for a more precise integration of point clouds with the help of spheres, Geomagic Studio 5 software was used to organize the obtained point clouds, to create the 3-dimensional model and to extract cross-sections from the generated model (Figure 2).

As a result of a measurement design, it was decided to scan these objects from two different points. Targets were placed in appropriate places, such that at least 3 target (sphere) were located in each scan area (in overlapping areas). Scan parameters were determined to allow capturing the details of the scanned object with the best resolution. The scans made at different points were transformed into a whole by automatic defragmentation with the help of spheres. During the scans, unnecessary and irregular point clouds in the foreground and the background were obtained as well (Figure 3). It was necessary to delete these unwanted points from the merged point sets.

The aim of the overall process was to organize the point clouds that can reflect the object surface as close as possible to reality. After organizing these points, solid models of the scanned object or the surface can be created by benefiting from the surface models. These models were obtained by generating surface net models via point clouds. This surface net was obtained by generating triangles between points with the used software. The realistic 3-dimensional models (Figure 4) of the scanned objects were acquired as a result of this process.

Due to the triangulation gaps and the errors originating from the triangles, these models showed irregularities. In order to regularize these generated models, corrections were made on each object (cylinder, cube and rectangular prism) (Figure 5). The same processing steps were applied to a rectangular prism and a cylinder, and the 3-dimensional models were created (Figure 6).

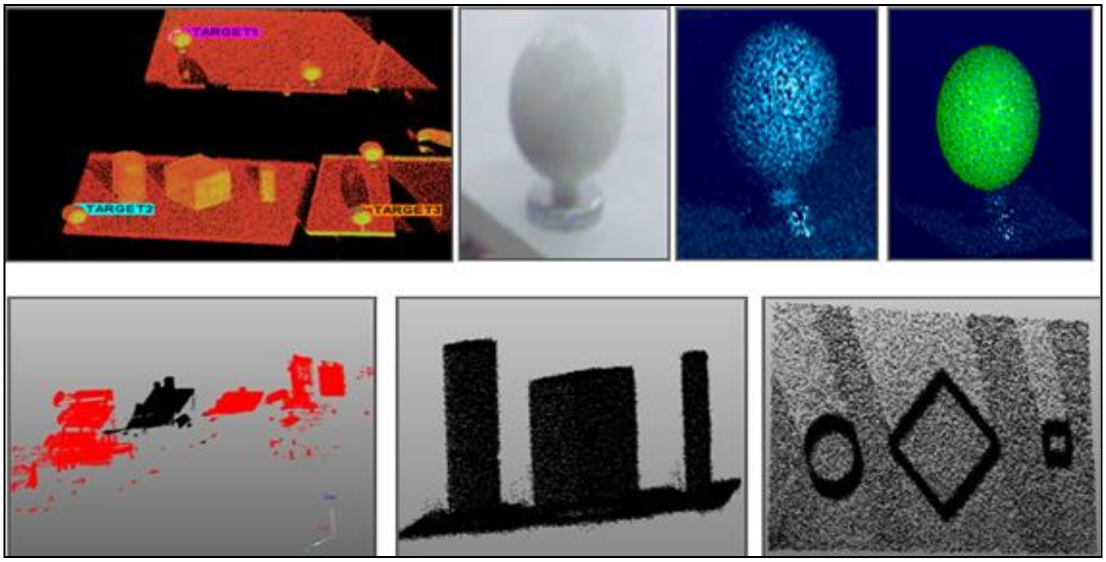

Figure 3. Point clouds of the scanned objects and targets.

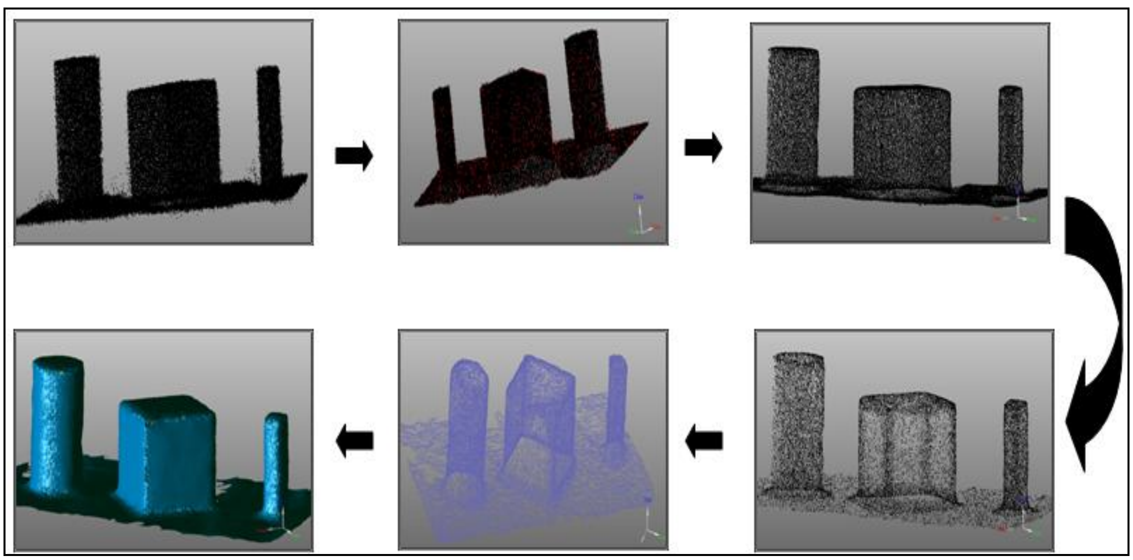

Figure 4. Created irregular 3D model.

RESULTS AND DISCUSSION

Here, the accuracy of the created models was analyzed in terms of their similarity to reality. For this purpose, cross-sections in the horizontal and vertical directions were taken from both the reference objects and the created 3D models, and the lengths of the cross-sections were measured. The lengths on the reference models were measured using a caliper (Figure 7) with 0.01 mm precision for all cross-sections.

On both the created 3D model of the cylinder and the reference object, 6 cross-sections on the vertical with intervals of 3 cm from the horizontal plane obtained from the top surface of the object and 8 cross-sections on the horizontal that pass through the center of the object and divide the surface into 8 equal parts were taken. Lengths (cylinder diameter) measurements were taken for each vertical cross-section that is at an intersection of a horizontal and a vertical cross-section (Figure 8).

Making use of these horizontal and vertical cross-sections, on each vertical cross-section, the diameter values of the cylinder that is between a horizontal cross-section and each vertical cross-section intersecting the horizontal axis were determined by the length measurement module of the used software.

All the cross-section extraction processes described

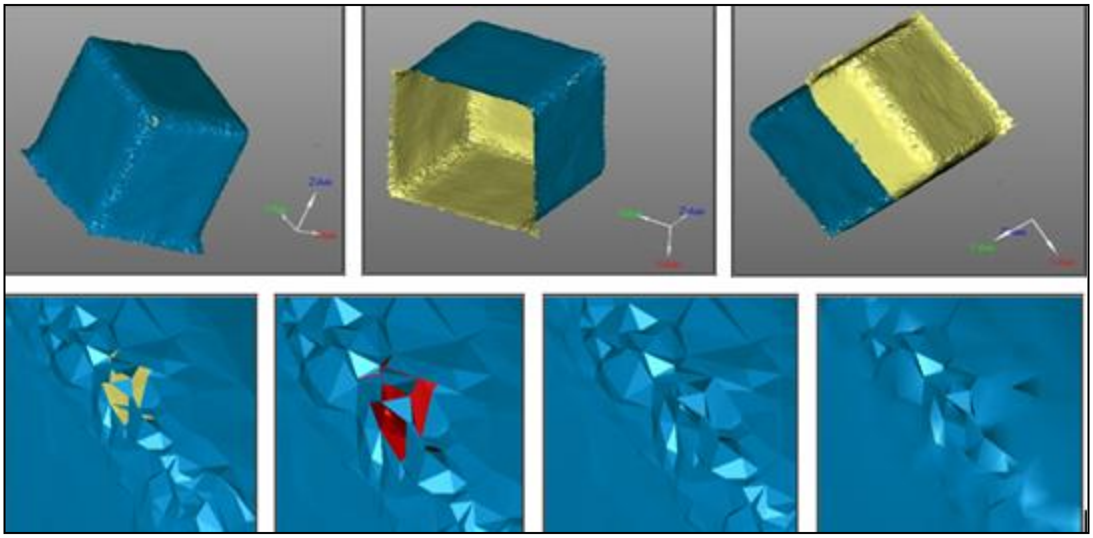

Figure 5. Filling of triangles gaps and softening of the 3D model.

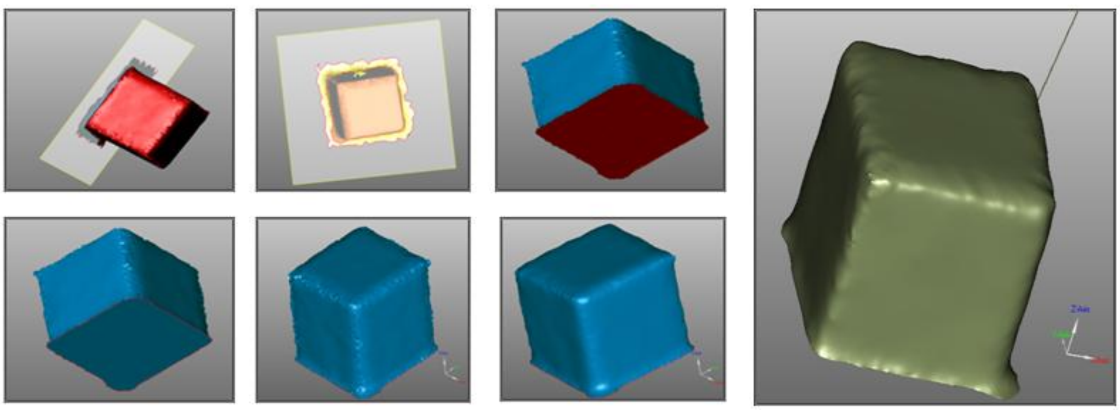

Figure 6. Visualization of the 3D model that is the result of the process (cube).

Figure 7. Caliper used for length measurements of the real model.

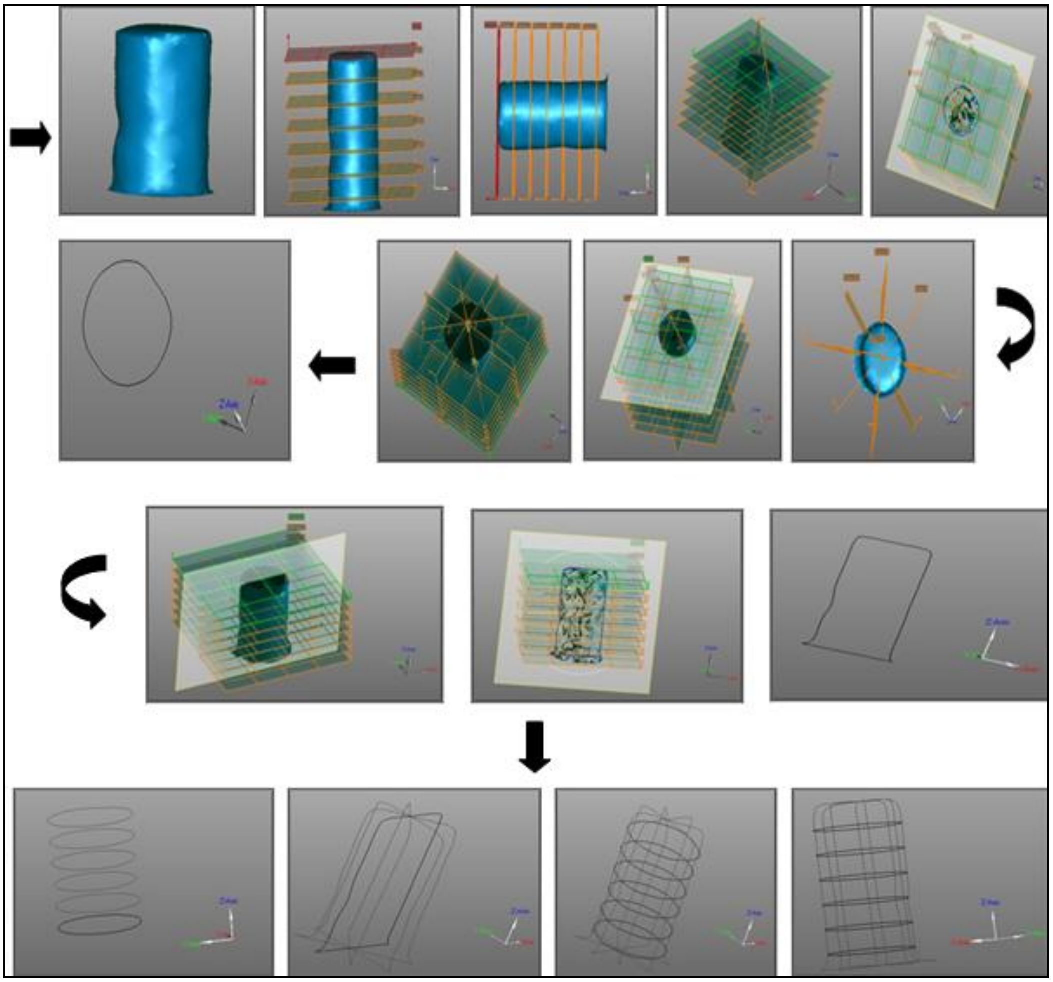

Figure 8. Generated unified sections in the horizontal and vertical directions.

earlier for the cylinder were also applied to the cube and the rectangular prism. 2 vertical and 4 horizontal cross-sections were extracted for the cube and the prism. The lengths between the cross-sections were measured for the object and the model (Figure 9).

Lengths were measured at every cross-section for both the reference objects and 3D models created by scan-ing after dividing them into horizontal and vertical cross-sections. Assuming these average values ($d_{referance}$, d_{model}) are the exact values, standard deviations (s_r, s_m) were calculated for the measured lengths at each vertical cross-section. Standard deviations of the measured lengths at each vertical cross-section were identified to be for the reference model and created model of the cube, rectangular prism and cylinder (Table 1).

For the magnitudes obtained from the object and the model, the differences (f) and the standard deviations (s_f) of these differences were determined by the measured values. Calculation of the standard deviation of the difference was obtained by applying the law of propaga-tion of variance. Therefore, it is possible to use the t-test to determine whether these differences were significant. For a degree of freedom (f = n-1) and with an error tolerance of α = 0.05, the t-test value was compared with border value of the t-test table. It is expected that if the t-test value is greater than the value obtained from the statistical table, this means that the measured lengths from the object and the model are not consistent with each other. If it is smaller, it is concluded that these measured lengths were consistent. For all the tests carried out in this study passed the test and this means that measured lengths were consistent with each other. The results obtained in this study are compatible with results of these studies (Kersten et al., 2008; Hiremagalur et al., 2009; Nutteans et al., 2011). Kersten et al. (2008) carried out tests for determining the geometrical accuracy of "latest" TLS and found the distance depended results ranging from mm to cm. The study of Hiremagalur et al. (2009) aimed at determining the performance of TLS and they tested for range precision, target recognition precision, incidence angle and resolution. They obtained close range measurements with standard deviations ranging from 2 mm to 2 cm. Nutteans et al. (2011) obtained mm level accuracy for point positioning in

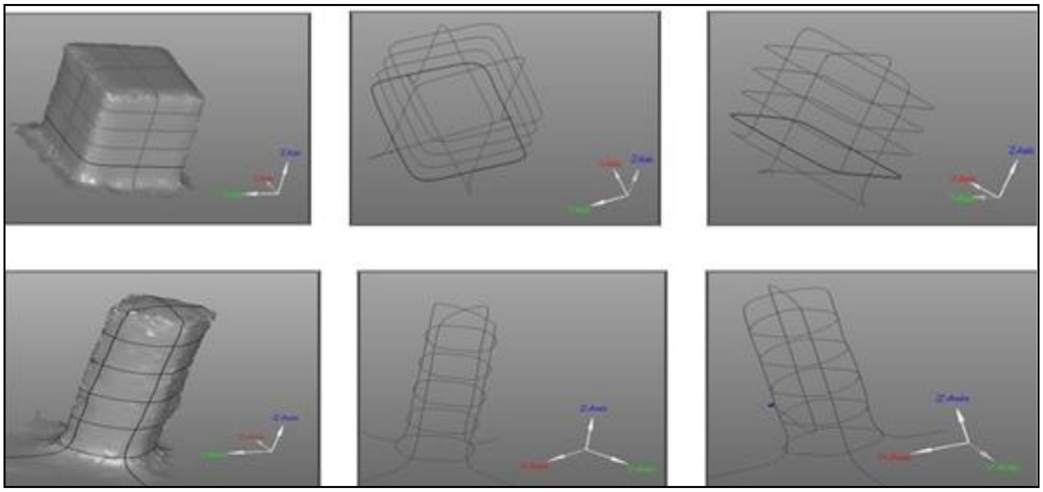

Figure 9. Generated horizontal and vertical sections for other reference objects.

Table 1. Standard deviations of the measured lengths at each vertical cross-section.

	Cube minimum to maximum value (mm)	Rectangular prism minimum to maximum value (mm)	Cylinder minimum to maximum value (mm)
Reference models	± (0.07 - 0.22)	± (0.64 - 1.56)	± (0.19 - 0.391)
Created models	± (2.66 - 3.02)	± (2.44 - 2.94)	± (0.98 - 2.04)

comparisons of coordinates, acquired by total stations, TLS and digital photogrammetric method. They used reference points instead of reference model as in the case of this study.

Conclusion

In TLS applications, it is necessary to take into consideration the conditions that affect the scanning process, especially the general characteristics of the laser scanner, geometric properties of the scanned object (shape, size, etc.), and its spatial location in the environment. In order to test the geometric accuracy of these models, objects with simple geometric shapes (spheres, cones, cylinders, cubes or objects that are characterized by nominal measurements) that have no visible alterations, that do not change dimensions or measurements and that are resistant to elastic deformation must be selected for testing. Scan parameters must be selected to reach the most appropriate configuration. In order to compare the spatial location and geometric accuracy of the created 3-dimensional model, it is necessary to use measurement tools that give more precise results than TLS. In this study, it is analyzed whether there were significant differences between the reference objects and created 3D models in terms of the lengths of cross-sections that were generated in horizontal and vertical directions by using the statistical t-test. As a result of the investigations, for each of the three reference objects, it was observed that the length values gathered from the reference objects and the models were consistent within the limits of the measurement accuracies of the used tools. According to the results of the studies to date and the results obtained by this study, the values that are gathered through the model which is the end-product were fairly close to reality.

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