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A case study on the historical peninsula of Istanbul based on three-dimensional modeling by using photogrammetry and terrestrial laser scanning

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Abstract Terrestrial laser scanning is a popular methodology that is used frequently in the process of documenting historical buildings and cultural heritage. The historical peninsula region sprawls over an area of approximately 1,500 ha and is one of the main aggregate areas of the historical buildings in Istanbul. In this study, terrestrial laser scanning and close range photogrammetry techniques are integrated into each other to create a 3D city model of this part of Istanbul, including some of the buildings that represent the most brilliant areas of Byzantine and Ottoman Empires. Several terrestrial laser scanners with their different specifications were used to solve various geometric scanning problems for distinct areas of the subject city. Photogrammetric method was used for the documentation of the facades of these historical buildings for architectural purposes. This study differentiates itself from the similar ones by its application process that focuses on the geometry, the building texture, and density of the study area. Nowadays, the largest-scale studies among 3D modeling studies, in terms of the methodology of measurement, are urban modeling studies. Because of this large scale, the application of 3D urban modeling studies is executed in a gradual way. In this study, a modeling method based on the facades of the streets was used. In addition, the complimentary elements for the process of modeling were combined in several ways. A street model was presented as a sample, as being the subject of the applied study. In our application of 3D modeling, the modeling based on close range photogrammetry and the data of combined calibration with the data of terrestrial laser scanner were used in a compatible way. The final work was formed with the pedestal data for 3D visualization.

Keywords 3D modeling · Terrestrial laser scanner · Close range photogrammetry · 3D visualization

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Introduction

Mainly, the aim of this study is to document the historical buildings and the urban pattern in the peninsula of Istanbul by using terrestrial laser scanning techniques. Then, the study integrates

Fig. 1 Historical peninsula of Istanbul

these models with terrestrial photogrammetric techniques in order to create a 3D city model of the mentioned region. The analysis of the study is made by considering the application flow. Two significant properties of the study become prominent when they are compared to the other reference studies. In recent 3D city modeling projects, there is a basic 3D digital terrain model and a similar application flow (Ergün 2007; ShiuanFu and Jie 2004; Destruel and Valorge 2004). These reference works, which benefit from aerial photogrammetry or by remote sensing, are based on digital terrain modeling. However, for this study, a distinctive flow of application was applied and instead of using the digital terrain model, digital facade model was produced. Thus, the study is based on the basic layer of 3D modeling process because of the allocation of the buildings and the streets. The other crucial point of the work is the geodetic network modeling. It is used for the fixation of 3D coordinate system without digital terrain model for digital facade models. Geodetic work can be defined as the basic layer of this study. 3D facade models, street floors, and pavements were scanned simultaneously with terrestrial laser scanners. As an exception, roof models were produced by satellite images. In this area, 80% of buildings have a contiguous allocation, and most of them are classified as “historical”. The historical peninsula region, surrounded by the city walls, covers an area of approximately 1,500 ha. It is an incredibly rich cradle of cultural heritage with the landmarks such as The Topkapı Palace, Hagia Sophia, Suleymaniye Mosque. The region has actually 1,500 years of history (Fig. 1) (Google Earth, http://www.google earth.com).

This paper examines and explains the main line of the workflow of our study. Because this is a laser scanning and photogrammetric study, it benefited from different methods, which causes a complexity. So, in the categorization of the stages of the study, a methodology-focused approach is used. As a result, the paper is formed of four stages, which are necessary for clarification in the study.

These are:

1. Geodetic study
2. Laser scanner study
3. Photogrammetric modeling and the documentation process
4. 3D urban modeling study

Geodetic study

The main aim of the geodetic study, which is based on the maps using the scale of 1/5,000, is to collect an accurate data structure in the scale of 1/1 and locate it to their real coordinates. Therefore, it is necessary to integrate the laser point clouds of building facades with their real coordinates and the locations on the base maps (Fig. 2). It is necessary to generate extra points for the triangulation network based on the maps with the scale of 1/5,000 and UTM coordinate system. Twenty-three ground control points in UTM coordinate system were determined and coordinated

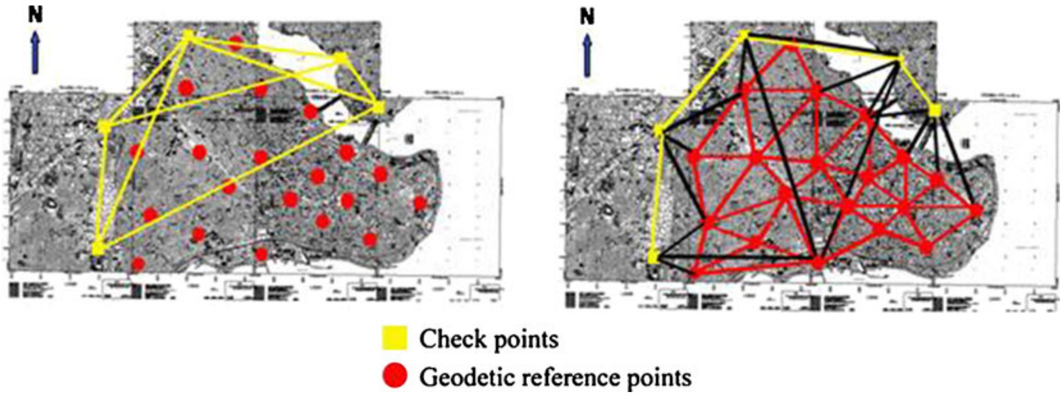

Fig. 2 Control point and check point geometry in the area

by using DGPS methodology (Fig. 2). Then, a precision polygon network research was done, and the main triangulation points were connected to each other by precision polygon lines. The target points, which were used to combine point clouds on the scanned facades, were also used to geo-register the point clouds. Therefore, density of the network points on the main precision polygon series was increased by supplementary precision polygon series for the streets wider than 10 m. Open traverse lines were determined to make the coordination of the targets located on streets narrower than 10 m.

All the measurements were made for the network, which includes precision polygon lines. They were adjusted according to the conditional measures adjustment techniques. For conditional measures adjustment, main precision polygon series were measured as three full series horizontally and two full series vertically, while supplementary precision polygon series were measured as two full series horizontally and one full series vertically. Additionally, elevation points were moved from RS points to the main triangulation network to increase the precision on the Z direction with the help of geometric leveling.

Laser scanner study

In the study, nine units of terrestrial laser scanners (four from Optech and five from Leica companies) and their Cyclone and Polyworks software were used (Optech Inc., http://www.optech.ca/; Leica Geosystems, http://www.leica-geosystems.com/hds/en/lgs_5210.htm). The processes of acquiring laser point cloud of the building facades in the study area and clearing the noises in the point clouds were the main part of this study. Then a simplification process was applied to the data. Thus, the drawing of the 3D surface models of the buildings was achieved. The facades of designated buildings were scanned by various point densities, changing between 5 and 50 mm due to the structural formation and the historical background of the area.

The regulation of the densities of scanning was made by professional architects. The point clouds belonging to the facades of buildings were simplified by the operators to help the generation process of solid models. In the next step, the solid models were visually processed by CAD operators who used Polyworks and Cloudworks software. 3D models of the buildings' facades include, among other things, ornaments, details of windows, and balconies. A detailed drawing was made so that they became suitable to be used in order to recreate the facade plans for restoration studies (Fig. 3).

In addition to the 3D modelings of the facades, floors of the streets and the pavements were also scanned with the terrestrial laser scanners. Point clouds of all the details were oriented and scaled with geodetic and leveling measurements. Then, all the data was translated into 3D coordinate system. In this case, scanning intensity of the grounds and pavements were less time consuming than the scanning intensity of the facades.

Fig. 3 Point cloud model sample

Control points were generated on the surface of the scanned facade in order to combine point clouds, derived from terrestrial scanners. Then, the control points were geo-registered by geodetic method in the UTM coordinate system. Considering the accuracy of the study, the geo-registering was used to combine the point clouds throughout the lab works after field works. In this manner, combined point clouds were viable for being located by their original positions on digital real-time maps.

Photogrammetric modeling and the documentation process

Terrestrial photogrammetric process is certainly one of the building blocks in the study. It was simply realized by the help of ground coordinates, derived from laser scanner data without any additional ground survey.

The methodologies that were used for 3D modeling included entirely professional and conventional studies of orientation, evolution, and drawing, in which geodetic and photogrammetric techniques were benefited. After the geodetic geo-registering studies, the process, which was based on taking terrestrial and aerial photogrammetric images of objects or providing satellite images, was initiated and then it was finalized by generating the base maps that were used for creating 3D surface models, 3D geo-referencing of their details, and generating 3D urban models.

Olympus E300 model was the professional digital camera that functioned in the process of the production of data, after photogrammetric modeling. Each laser scanning team consisted of two personnel. One of them was responsible for taking

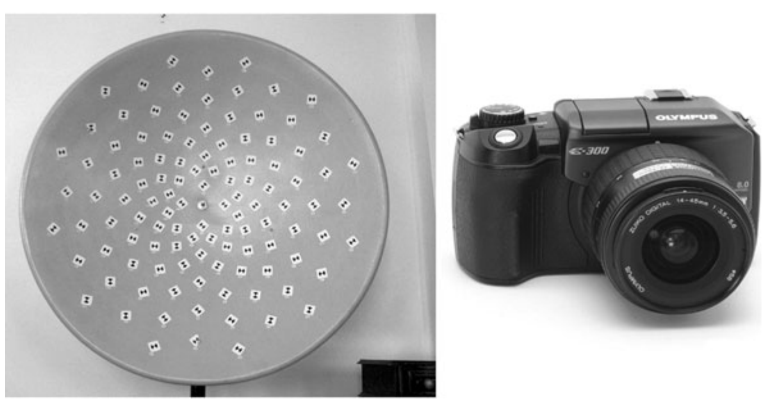

Fig. 4 Geometric calibration field and Olympus E300 camera

Table 1 Olympus E300 and 14 mm lens geometric calibration parameters

Camera	Focal length	Resolution	Sensor size	x_0	y_0	Calibrated focal length
Olympus E300	14 mm	3,200 × 2,400 pixels	17.3 × 13.0 mm	0.025 mm	0.017 mm	14.1389 mm

the photogrammetric photos of the area of scan. Geometric calibration of the E300 Olympus camera was done in 3D calibration zone by GIT—Department of Geodetic and Photogrammetric Engineering (Fig. 4). Table 1 shows the calculated parameters. These projects demonstrate that a commercial digital SLR camera is suitable for a detailed 3D evaluation and reconstruction of large, complex historical buildings. Due to the digital data flow, architectural photogrammetry has now become an efficient alternative to the classical building measurement and reconstruction methods (Kersten 2004).

Using the calibrated 14 mm Olympus lenses, an effective color interval was obtained.

Photogrammetric PI 3000 and Z-Map software was the tool used to generate the texture of 3D CAD models, which were the end products of laser scanning and photogram, taken in the area by field operators, processed in the software, and finally rectified facade images were generated (Topcon A.S.M., http://www.topcon.com.sg/survey/asm.html; Menci Software, http://www.menci.com/laser-scanner/2.html). Then, these images were textured into facades, using point clouds of the related facades. Lastly, facade relief lines were completed on the final textured model in AutoCAD environment (Fig. 5).

3D urban modeling study

The designated streets, including textured 3D models of the buildings, which were generated in CAD format, could be modeled by using AutoCAD software. It was crucial to measure some of the details such as photogrammetrically oriented roofs, eaves, and wall and roof heights, in order to transform the solid models into textured models. Currently, acquisition of 3D city models is difficult and time consuming. Existing large-scale models typically take months to create and usually require significant manual intervention. This process is not only prohibitively expensive but also is unsuitable in applications where a 3D snapshot of a city is needed within a short time, such as for disaster management or for monitoring changes over time (Früh and Zakhor 2004).

One of the most significant issues while generating 3D urban models was obtaining digital elevation models (DEM) of the study areas. In addition to the generation process of DEM

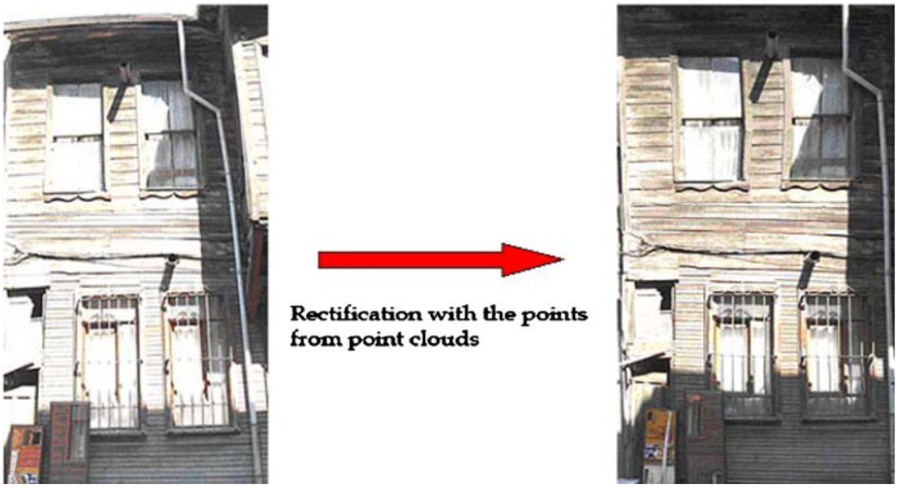

Fig. 5 Textured model of a 3D building facade with image rectification

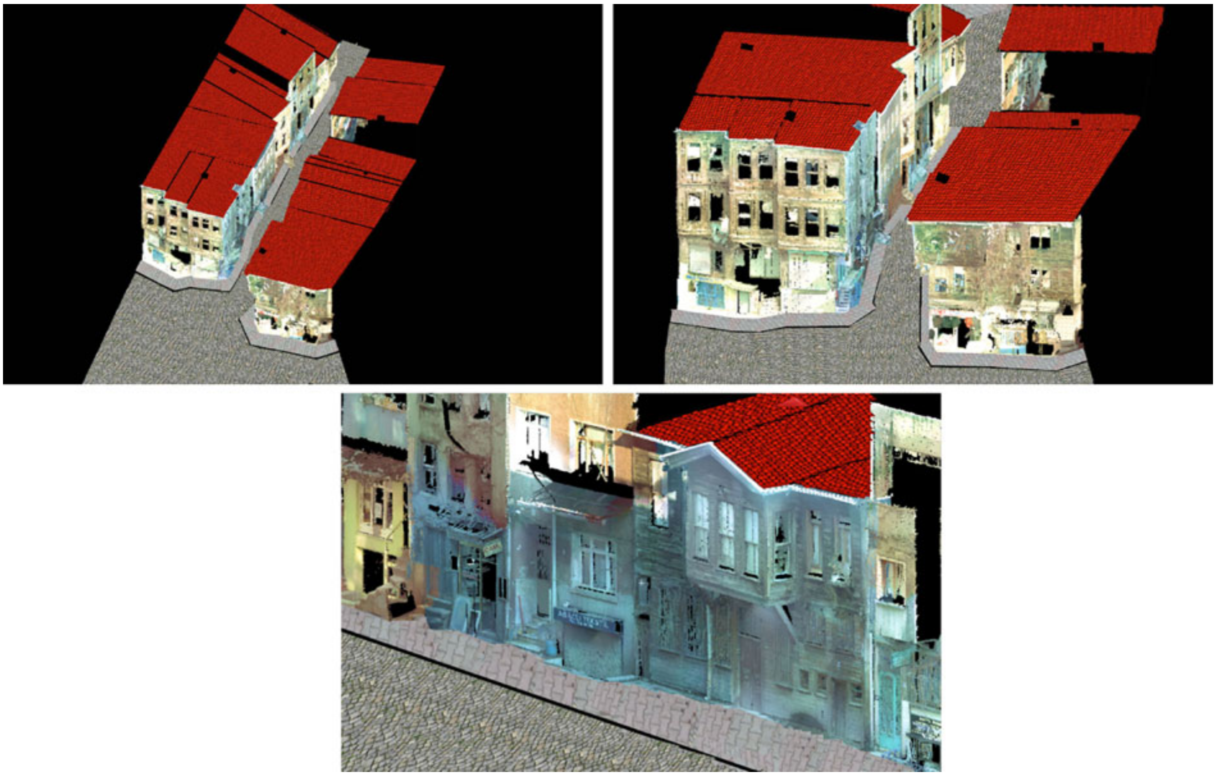

Fig. 6 A sample textured street model generated from the historical peninsula region

by photogrammetric techniques, it was possible to generate DEM automatically or semi-automatically by using a specific software in the market. At the end of this study, 3D textured models of the ground surface, which was visualized from the aerial photos, are attached to the models of the streets. In this case, DEM of the ground surface and the texture models of the ground were combined entirely (Fig. 6). Digital 3D models would allow more accurate quantifications as well as comparisons by direct 3D models superpositions or animations of the modifications (Andreetto et al. 2003).

The laser scanner takes just a few minutes time to scan millions of points with arbitrary resolution. These can be compared to results achieved from measurements done using photogrammetric standard, although photogrammetric methods produce both geometric and color information while a scanner cannot, up to now, capture color. Furthermore, one can easily interpret and analyze photos, thus being able to extract details such as the material of the objects or supplementing the geometry of areas in shadow of the objects (Kern 2001).

Conclusion

Consequently, Kirazlı Mescit Street, which was modeled digitally as an outcome of this study, covers an area of nearly 10 ha. This is the duration of application, including the production process of the data. During the application level, the most challenging problem was to accomplish both the terrestrial laser scanning and the photographing in the very narrow streets of the region of the historical peninsula. Automatic methods for detailed generation of virtual castle or historical buildings are not available in the market. In the future, terrestrial 3D laser scanning could offer automatic acquisition and evaluation methods in combination with digital photogrammetry (Kersten 2004).

The result was presented and simulated as a reality-based product in a virtual environment within original geographic coordinates. Therefore, all the modeled and scanned data, as suitable to the present day maps, were also suitable to mean squared errors derived from the geodetic network generated in the 3D digital surface model. In the frame of the results of the whole network adjustment, some ignorable errors were found. The sources of these errors were generally the direction and scale determination methodology differentiations among the laser scanning data, which included digital terrain model (DTM) and texture model of streets and roof images. A standard technique for creating large-scale city models in an automated or semi-automated way is to apply stereo vision techniques on aerial or satellite imagery (Früh and Zakhor 2003). In the near future, virtual 3D city models may be able to reflect the real world exactly in digital platforms. At the end of these types of studies, the whole world may be simulated by 3D city models in a digital environment in centimeter detail and all of the geodetic and photogrammetric engineering studies and direction-finding applications may be realized for every part of the world from any place of the world. Today, complete and detailed 3D object reconstruction is performed increasingly by methods of digital architectural photogrammetry. The demand for 3D building models has increased from new application fields: facility management and building information systems supporting, among others, operational planning of emergency services and for building security as well as for forwarding agencies and 3D city maps for tourism (Google Earth). After reaching this level of technology, geographic information system (GIS) might be an appropriate and incredible technology for human lives with its analyzing, querying, and visualizing capabilities.

As a positive aspect of the study, since the data of the laser scanning and photogrammetric study were both street based, all the data sets shared the same scale factor homogeneously. This homogeneity appeared depending on the network geometry that is related to the street-based geodesic study. Consequently, optimal scale differences occurred when combining the data collected from all of the regions. These scale differences were in such a level that they could be solved by calculation techniques. However, in such a grand-scale study, the collection and the combination of data would mean a waste of time in this street-based method. When the intended 3D model is considered, creating the whole by adding up the parts taken from aerial photographs and satellite images would be impractical.

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