Documentation of Istanbul Historic Peninsula by Sensor Integration and Data Fusion

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ABSTRACT: Although the Historic Peninsula of old Istanbul was added to the UNESCO World Heritage List in 1985, no documentation of this important area has yet been carried out. In 2006 the Istanbul Greater Municipality's Directory of the Protection of Historical Environment initiated the "Historical Peninsula project", which comprises a project area of 1500 ha and approximately 48,000 buildings in crowded and frequently narrow streets. Therefore, BIMTAS, a company of the Greater Municipality of Istanbul, started the documentation of all buildings in the area of the Historic Peninsula by terrestrial laser scanning in the same year. It was a challenge to build up a new production environment with new high-end technology to fulfil the requirements of this project in a very short time frame of two years. This paper describes the entire production environment for documentation of all buildings, detailing the frequent adaptation of production required through learning on the job. Although the data acquisition and mapping environment was established on the job during production, it was always essential to optimise the technical solutions in order to meet the quality requirements for the generated data and for the deadlines of data delivery. Only 80ha of 1500ha could be completed by static scanning during six month, requiring the change from static to mobile terrestrial laser scanning due to the increased speed of scanning, whereby the remaining major area could be scanned within three months by the mobile method.

1. INTRODUCTION

The Historic Peninsula of old Istanbul (Fig. 2) is one of the most important tourist locations in Turkey. Due to its importance these "Historic Areas of Istanbul" were added to the UNESCO World Heritage List in 1985. This area is located on the southern shore of the Golden Horn, which separates the old city centre from the northern and younger parts of the European side. The Historic Peninsula ends with the Theodosian land walls in the west. The peninsula is surrounded by the Sea of Marmara on the south and the Bosporus on the east.

2. THE ISTANBUL HISTORIC PENINSULA PROJECT

The inner city wall of Istanbul known as Historical Peninsula is an area that mostly consists of archaeological, urban and historical protected areas. The Historic Peninsula (Fig. 2) comprises a project area of 1500ha and approximately 48,000 buildings in crowded and frequently narrow streets (total length 400km). The facades of the building along the roads and streets cover an area of about 5,500 000m². In 2003, the whole area was declared as a protected area, when urban protection plans at 1:5000 and 1:1000 map scales were completed. The districts Eminönü and Fatih were also included in this area, after sub-regions of Süleymaniye, Zeyrek, Cankurtaran and inns (caravanserai or hostel) and city walls regions of the peninsula had been already declared as protected areas. In these urban protection plans, first, second and third degree protection areas were defined. For the first and second degree protection areas, detailed studies of urban design projects based on 1:500 and 1:200 map scale shall be carried out in the future. In the meantime, all zoning applications in this area were suspended until the urban design project has been completed.

A project contract, briefly named as "Historical Peninsula project" was allocated to BİMTAŞ by the Istanbul Greater Municipality's Directory of the Protection of Historical Environment, which comprises the following phases of the project.

1. Research studies and analysis are to be carried out to determine historical, sociological, economical, urban and architectural factors of the region and logical relations between them.
2. Photographic and geometric determination of existing spatial features, physical factors and functional characteristics related to the cultural assets by analytical studies and technical drawings.
3. Introduction of former cultural assets through historical research and restoration works.
4. Development of proposals for restoration methods, urban design and new building designs compatible with the historical environment, and that are made according to synthesis based on an analysis of existing and historical cultural assets.

Finally, due to the request of many municipality applications and due to an expected earthquake in Istanbul within the next 30 years BIMTAS, a company of the Greater Municipality of Istanbul, started the documentation of all buildings in the area of the Historic Peninsula by terrestrial laser scanning in 2006. The plan is that the Historic Peninsula should be mapped in a time frame of two years, which demonstrates the great ambition of the project.

3. SYSTEMS USED FOR DATA ACQUISITION

For this project a new production organisation was built up at BIMTAS using modern 3D mapping and computer technology. The terrestrial laser scanning group includes 24 staff, which uses the following technical equipment for data acquisition: five Leica scanners (four HDS4500 and one HDS3000), four ILRIS-3D scanners from Optech (Fig. 1), four Topcon total stations for geodetic control point measurements and pre-calibrated SLR cameras Nikon D70 with 14mm and 28mm lenses for digital photogrammetric documentation. The technical specification of the terrestrial laser scanning systems used for this project are summarised in Table 1.

The three scanner types use two different principles of distance measurement: Leica HDS4500 uses phase shift method, while Leica HDS3000 and ILRIS-3D scan with the time-of-flight method. In general it can be stated that phase shift method is fast but the signal to noise ratio depends on distance range and lighting conditions. If one compares scan distance and scanning speed shown in Table 1, it is obvious, that the scanner using the time-of-flight method can measure longer distances but is relatively slow compared to the phase shift scanner.

	Leica HDS4500	Leica HDS3000	Optech ILRIS-3D
Scan method	Phase based	Pulsed	Pulsed
Field of view [°]	360 x 310	360 x 270	40 x 40
Scan distance	< 53.5m	< 100m	< 1500m
Scanning speed	≤500000pts/s	≤ 1800pts/s	≤ 2000pts/s
Angular res. V/H	0.018°	0.0034°	0.001°
3D scan precision	5mm/50m	6mm/50m	8mm/100m
Camera	add-on	integrated	integrated

Table 1. Major specifications of the terrestrial laser scanning systems used

Figure 1. Terrestrial laser scanners used: Leica HDS4500, Leica HDS3000, and Optech ILRIS-3D, target for registration and geo-referencing of scans

The HDS4500 measures distances up to 53m, while the HDS3000 and the ILRIS can measure up to 100m and 1500m, respectively. Due to the limited speed of 1500 or 4000 points per second and due to the limited field of view it quickly became clear that the ILRIS scanners and the HDS 3000 are not useful for the busy and narrow streets of the project area. These scanners are more suitable for the documentation of landmarks. Thus, all buildings were scanned with a scan resolution of ~15mm at the object using four HDS4500. For data processing of the scanned point clouds, which includes registration, geo-referencing and segmentation of the point clouds, five licenses of Cyclone 5.2 and four licenses of Polyworks 4.1 were used in the office.

For the scanning of the buildings, targets were used as control points for registration and geo-referencing of the scans from different scan stations as illustrated in Fig. 1 (right). The targets have black-white quarters of a circle with a diameter of 126mm. To obtain centre positions of the targets, the targets were automatically fitted in the point cloud after manual pre-positioning using algorithms of the Leica Cyclone software.

Figure 2. Area of the Historic Peninsula project in Istanbul

Figure 3. Example of a coloured point cloud of building facades at the Historic Peninsula

4. DATA ACQUISITION BY TERRESTRIAL LASER SCANNING AND PHOTOGRAMMETRY

4.1 Static terrestrial laser scanning

The data acquisition by static terrestrial laser scanning started in September 2006. During application in the Historic Peninsula streets it turned out that only the HDS4500 were able to scan in this special environment. As mentioned before the ILRIS-3D and HDS3000 scanner could not scan efficiently in the narrow streets due to the limitation in the field of view, distances that were too short and insufficient scanning speed. Furthermore, the registration of the point clouds of the ILRIS-3D caused problems with tilted scans from the same scan stations, and required matching with the Iterative Closest Point (ICP) algorithm and needed initial values for its computation. Consequently, the daily laser scanning was carried out with four, or sometimes with three, HDS4500. Fig. 3 shows an example of a coloured point cloud of building facades at the Historic Peninsula.

In general, a satisfying spatial (geometrical) distribution of the targets on the object or around the object was guaranteed for the required description of the detailed object. The coordinates of all targets were determined by geodetic methods using total stations. The target-based registration and geo-referencing of the point clouds, which are acquired by the HDS4500 scanners, worked without any problems using five Cyclone software components as following: (a) registration of all scans and quality control of the result (check of residuals), and (b) geo-referencing using all control points including quality control by checking residuals.

80ha of the project area (of in total 1500ha) could be scanned within the first six months using the existing production capacity, which clearly indicated, that the scanning would need more than eight years for the entire area of the project, if this current scan rate of approximately 0.7ha per day could not be increased. It was obvious that the project deadline could not be met; therefore it was decided to increase the production rate by the integration of a mobile system.

Figure 4. Sensor configuration on the mobile mapping van of VISIMIND AB

4.2. Mobile terrestrial laser scanning

As a consequence the scan progress was significantly increased by the introduction of a mobile mapping van from the Swedish company VISIMIND AB (Fig. 4) in June 2007 using a hybrid sensor system on the vehicle consisting of a terrestrial laser scanning system HDS4500, supported by GPS/IMU and digital cameras. The sensor integration and the calibration of the system in the streets of Istanbul took some weeks, but the data acquisition in the field was working by the end of June 2007. The laser scanner’s orientation was fixed in the horizontal direction, scanning only in the profile perpendicular to the direction of movement of the vehicle. It has been operated with 25 scan profiles/second, later improved to a speed of up to 40 profiles/second (possible maximum by instrument specification: 50 profiles/second). The distance between neighbouring profiles was 2-3cm in the beginning, corresponding to a van speed during scanning of 0.5m/sec up to 0.75m/sec or 1.8 km/h up to 2.7km/h.

Due to problems with the reception of the GPS signal in the narrow streets of the Historic Peninsula control points were marked on the buildings every five meters along each side of the street (Fig. 5). Some targets were removed or destroyed before scanning (Fig. 5 right) and were replaced by natural points such as window corners. Some targets have been destroyed after scanning, but before the geodetic determination of the object coordinates, they also had to be replaced by natural points. The sticking on of the targets was carried out by BIMTAS staff (4-5 people), while the determination of the target coordinates was performed by BIMTAS staff and additional subcontractors. BIMTAS staff measured additional natural ground control points, well distributed on the facades, in order to stabilise the in-house data processing of the mobile mapping system, while the subcontractors only measured the targets. Not all control points have been identified correctly in the point clouds causing geometrical problems for the direct geo-referencing and some geometric deformation of the point clouds (Fig. 6: misfit at block corners, swinging building façade, etc.). Nevertheless, the technical parameters of the hybrid systems were optimised on the job due to these problems with the quality of the pre-processed point clouds.

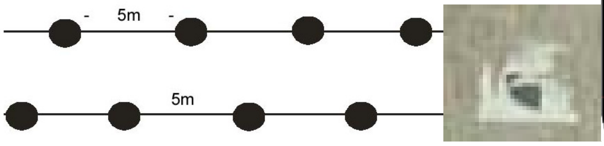


Figure 5. Distribution of control points in the streets for mobile terrestrial laser scanning (left), and destroyed target (right)

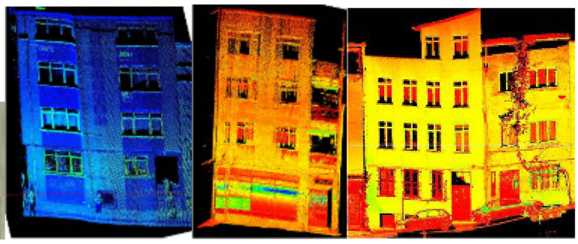


Figure 6. Geometric problems from direct geo-referencing of point clouds (from left to right: swinging façade, misfit at block corner, and deformation of a façade)

For problematic facades where control points were missing, VISIMIND recently developed with the so called 'image tracking tool' an automatic photogrammetric bundle adjustment enabling a bridging of longer distances without control points (Fig. 7).

The speed of data acquisition by terrestrial laser scanning with the mobile mapping system of VISIMIND could be increased significantly. 33 blocks could be scanned in 33 working days until the end of August 2007. Usually, scanning could be carried out five days per week (Mo-Fr, plus Sunday) starting at 6.30 am until 2 pm of each working day. Consequently, the laser scanning of the remaining 50 blocks could be finished with the mobile system by November, 8th, 2007 with the improved total production rate of ~600m per hour, while post processing of the multiple sensor data took until January 2008. The production rate was mainly 1:10, i.e. for one hour scanning 10 hours post processing was needed. In total, 12 operators of the laser scanning group were supporting the data post processing of the mobile mapping system during the major processing phase. Nevertheless, approximately 2% of the area (30ha) could not be scanned by mobile terrestrial laser scanning (TLS) due to traffic restrictions and environmental conditions. This remaining 2% of the total area must be scanned by static TLS at the end of the project in order to complete the data acquisition. At least two months will be needed for scanning by static TLS using all available laser scanning systems.

4.3. Digital photogrammetry

For photogrammetric documentation of the building facades as mentioned before, pre-calibrated SLR cameras Nikon D70 with 14mm and 28mm lenses were used. The acquired images were processed in combination with the static terrestrial laser scanning data. When the mobile system was used for data acquisition, only the images of the integrated oblique and horizontal cameras (Fig. 8) were used for mapping. The upper sideward looking camera is vertically rotated against the lower camera by approximately 34°, enlarging the vertical field of view of the camera system to approximately 86°, so that the camera system starts at an angle looking down to the street.

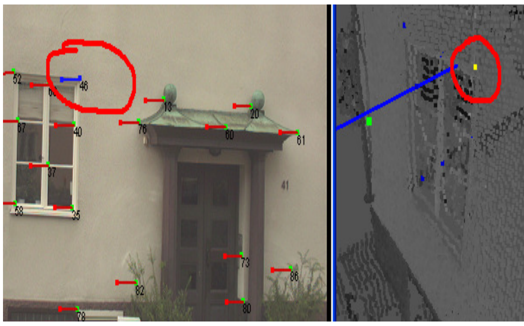


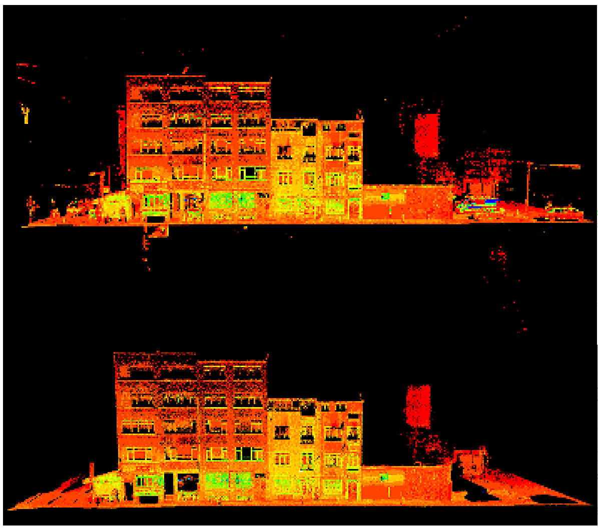
Figure 7. Image tracking tool for "problematic" facades without control points

Figure 8. Oblique and horizontal camera integration in the mobile system (left), image taken by oblique camera (right)

5. MAPPING OF FACADES

The geo-referenced point clouds from the laser scanning group were used for line mapping of the facades in a plot scale 1:200. The point clouds were segmented by two people using Cyclone software before mapping (Fig. 9) to eliminate unnecessary points and to reduce the data volume to the requested minimal portions for the mapping software.

In this project generation of façade maps with 1:200 plot scale is required. This extreme demand corresponds to a standard deviation of the positions with 0.2mm in the map and 4cm in the object space, but this extreme accuracy is required only as relative accuracy; for the absolute accuracy a standard deviation of 0.5mm in the map, corresponding to 10cm in object space should be sufficient. As a tolerance limit three times the standard deviation has been accepted. Therefore, the control point configuration and accuracy must always be checked to obtain this accuracy. While all problems of static and mobile scanning were solved, the delay in the control point determination was a bottleneck in the production.



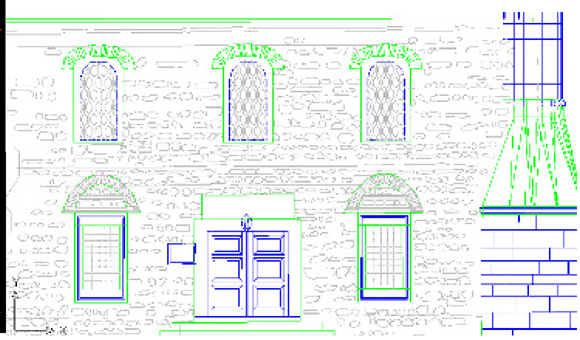


Figure 9. Segmentation of a point cloud

Figure 11. Detailed mapping of a building façade based on laser scanning data and a photogrammetric image

The facade mapping group consists of 34 operators using 34 licences of the Menci-software Z-MAP Laser from Italy, which is able to process laser scan data and rectified photogrammetric images simultaneously for line mapping with limited AutoCAD functionality. It was estimated that approximately 5 million m² of facades have to be mapped. The production rate was similar to the static laser scanning group: 80 ha with 32 operators in approximately 6 months. With regards the facade area, in total 81,000 m² could be finished in 39 days, which corresponds to 65 m² per person per day. The production rate could be increased from 60 m2 of facade/day/operator (March 2007) on average to 140 m2/day (October 2007), which is more than a factor of a 2 time increase. If one assumes in total 5 million m2 façade area for mapping of the Historic Peninsula, it corresponds to an estimated mapping time of approximately five years with 34 operators working on 210 days per year. This estimation indicated that the mapping could not be finished before the deadline of the project.

For data processing in Z-MAP all related data of the segmented part (point cloud, Nikon image(s), camera calibration file) was saved in one directory using the name of the block plus a suffix, e.g. 900_01. This block name is defined in the cadastre map. The HP workstations xw8200 used are equipped with dual XEON Processors (3.6 GHZ), 4 GB RAM and nvidea Graphic Cards with 256 MB RAM. For facade mapping the point cloud and one oriented image of the façade were used. Thus, the orientation of the photogrammetric image (usually recorded with the 14 mm lens) had to be determined by resection in space using at least five well distributed corresponding points (usually corners of windows) in the point cloud and in the image. For the adjustment of the spatial resection the calibration data of the pre-calibrated NIKON D70s are used. Usually the residuals of the control points were in the range of some millimetres, which indicated that sufficient results have been achieved. To carry out mapping with Z-MAP the images had to be rectified to the main plane of the facade. Therefore, the plane was defined by more than three points, which were measured in the point cloud and in the image. Thus, the photos were rectified to the main plane of the facades and shifted to parallel planes based on the point clouds. Based on the dense point clouds from the Leica HDS4500 scanners, the mapping was often possible without support of the photos, using just the grey values of the point cloud. Nevertheless, the colour photos are a significant support particularly for the detailed mapping of bricks and stones (see Fig. 11). One major problem is the very detailed mapping of bricks and stones, which reduced the speed of mapping significantly. Unfortunately, the architects as the major clients could not be convinced to use digital orthophotos of the facades instead of the detailed maps in the scale of 1:200. An example of the final product from façade mapping is depicted in Fig. 11, which is derived from 3D polylines as illustrated in Fig. 12. Currently, the mapping of the building facades is still not finished.

Figure 11. Part of the final product from façade mapping using terrestrial laser scanning data and photogrammetric images

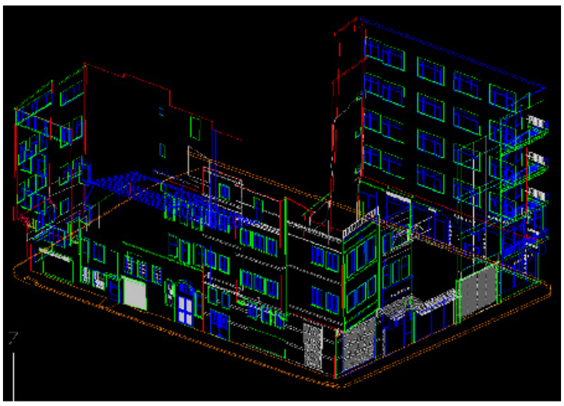


Figure 12. Mapped 3D polylines of facades of a building block

6. ROOF MAPPING

Since early July 2007 a roof mapping group was established, in order to measure and to model the roofs of all buildings in 3D within the perimeter of the Historic Peninsula project. A project team of five operators started the new production line after three days of intensive training in mid July using the Z-MAP Foto software (Fig. 13). In the beginning UltraCamD images with 30cm GSD were used for data acquisition. Due to the limited resolution of the digital imagery it was very difficult for the operators to measure small roofs. As a rule of thumb, mapping is possible up to the map scale 1:3000 with 30cm ground sampling distance (GSD), which could be confirmed by the tests made in this group. Thus, it was decided to use higher resolution imagery for this task, available since mid August as scanned analogue colour aerial images with 9.5cm GSD. The photo flight has been conducted using a JenOptik LC0030 camera (f= 305mm) at a photo scale of 1:4500. The photos were scanned with a resolution of 21 µm using a Zeiss SCAI scanner.

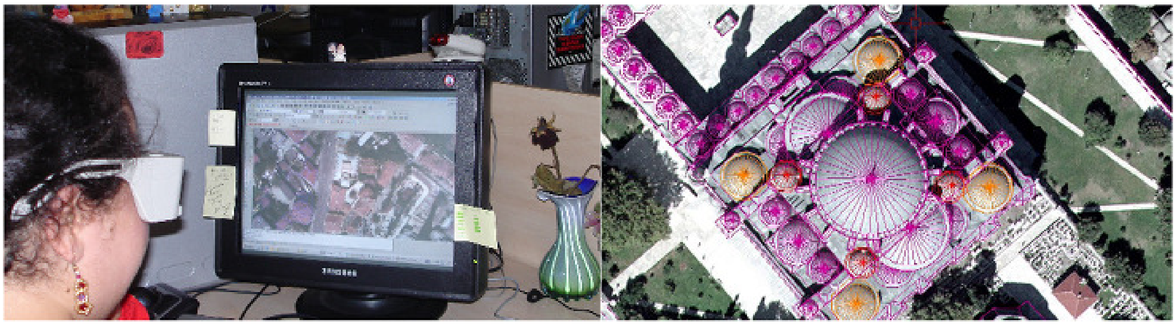


Figure 13. 3D mapping of roofs using Menci-software Z-MAP Foto in stereo mode

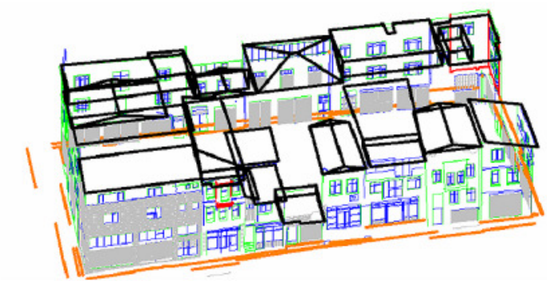


Figure 14. Combination of data from two different sources: 3D polylines of roofs based on aerial images and 3D polylines of facades from terrestrial laser scanning data

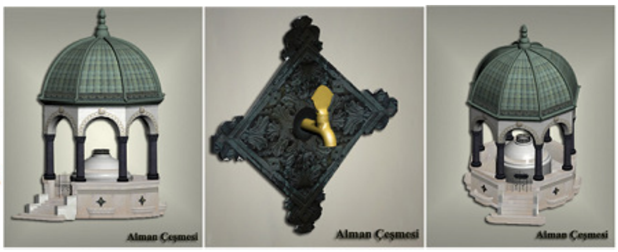


Figure 15. Photo-realistic and detailed 3D model of the "German Fountain" (generated with 3D Studio)

In this part of the project an essential quality-defining task was the combination of the two different data sets, from aerial imagery and mobile TLS, into one common data set in the same coordinate system without any discrepancies caused by the different data acquisition sources. Therefore, the orientation of the aerial images was transformed into the same datum as was used for the laser scanning data, in order to perform the mapping in the same coordinate system. The differences between façade corners and roof corners are mainly in the range of 20-60cm (spatial vector). The differences mainly represent the effect of point definition – the roof extends over the wall. In addition the following error sources exist: effects from datum transformation, accuracy of the orientation data, accuracy of the laser scanning data, identification of the roof corners in the images, definition of the roof corner and facade corner (rain spout), respectively. The two last sources for discrepancies might have the biggest influence on the accuracy of the merged data, which is generated from data of two different sensor systems (terrestrial laser scanning and aerial images). An example of the combination of 3D polylines of roofs from aerial images and 3D polylines of facades from terrestrial laser scanning data is presented in Fig. 13.

7. 3D MODELLING OF CITY MODEL AND LANDMARKS

The modelling group started simultaneously with the facade mapping to model landmarks from laser scanning data. Therefore, the mapping group measured 3D polylines of the landmark, which were used for the 3D modelling with Autodesk® 3ds Max® software.

In December 2007 the group started to generate a 3D city model of the Historic Peninsula as a so called block model (LoD1 = Level of Detail 1) using just cadastre data (Fig. 16), which could be finished after three months. Currently, the modelling group is producing a 3D city model in LoD2 (Fig. 17) by combining the block model with the roofs, mapped by the roof mapping group.

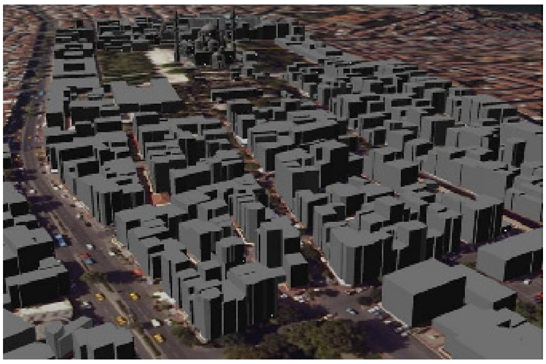


Figure 16. Part of the 3D city model in LoD 1 (block model generated from cadastre data)

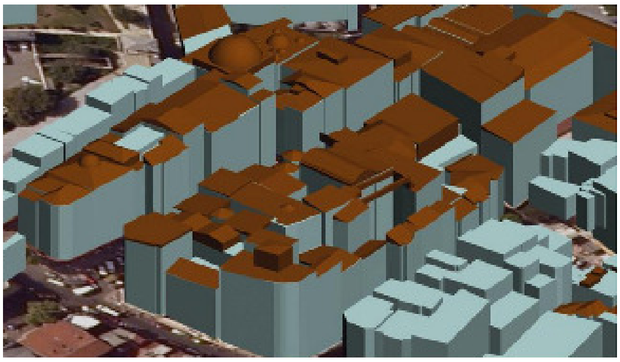


Figure 17. Part of the 3D city model in LoD 2 (roof model generated from the block model)

8. CONCLUSION AND OUTLOOK

With the Historic Peninsula project BIMTAS was able to create a modern production environment with high-end technology and well-trained personnel, which could efficiently perform static and mobile terrestrial laser scanning for the entire area of the Historic Peninsula within 15 months, from which the dominating part has been scanned by the mobile system within three month. In particular, the requirements of the projects with respect to quality and deadlines for data delivery drove the parameters for optimising the production to ensure that a technical solution was always found for the requirement to speed up the data acquisition. Thus, the change from static to mobile terrestrial laser scanning for data acquisition significantly speeded up the scanning.

BIMTAS learned many lessons concerning project management and tuning of technology to manage the requirements, so that the company is able to run similar projects elsewhere. However, the key for successful projects is still the highly educated and trained personnel, who learned their skills by working for such a project as the Historic Peninsula, and efficient project planning.