3D City Modelling of Istanbul Historic Peninsula by Combination of Aerial Images and Terrestrial Laser Scanning Data

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Keywords: aerial, city, cultural heritage, integration, modelling, project, TLS, visualization

ABSTRACT: There is an increasing demand for 3D city models for many applications and users worldwide. Some of this growth in demand has been caused by the increase in public availability of open geospatial viewers (e.g. Google Earth, Virtual Earth). 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 and modelling of all buildings in the area of the Historic Peninsula by terrestrial laser scanning (TLS) and aerial imagery in the same year. Although the data acquisition/recording of the project area could be completed within a time slot of 15 months, the 3D mapping and modelling turned out to be a hugely time-consuming challenge. The entire production environment from data acquisition to 3D mapping and modelling of the buildings is described in this paper, whereby the focus is emphasized on the latter. The combination of terrestrial laser scanning data and aerial imagery for deriving new products of 3D city models at different levels of detail is presented.

1. INTRODUCTION

Several disciplines like urban planning, architecture, telecommunication, tourism, environmental protection and many others have an increasing demand for digital 3D city models, in order to use such complex data for planning, analyses, visualization and simulation in different applications. Additionally, the open geospatial viewers (e.g. Google Earth, Virtual Earth) increase the demand on 3D city models. To satisfy this increasing demand for such data, the city models must be acquired quickly, precisely, in detail, and with full completeness and in an economic manner. The Historic Peninsula of old Istanbul (Fig. 1) is one of the most important tourism locations in Turkey and is a challenge for 3D city modelling due to its complex building and roof structures.

Due to its importance these "Historic Areas of Istanbul" were added to the UNESCO World Heritage List in 1985. It 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.

A brief introduction into the Historic Peninsula project is given. The production environment for roof mapping using aerial imagery, façade mapping with terrestrial laser scanning data and 3D modelling with the combination of both data is described.

Figure 1. Istanbul Historic Peninsula

Figure 2. Sensor configuration on the mobile mapping van of VISIMIND AB

2. THE ISTANBUL HISTORIC PENINSULA PROJECT

The inner city wall area of Istanbul known as Historical Peninsula consists mostly of archaeological, urban and historical protected areas. The Historic Peninsula (Fig. 1) comprises an area of 1500ha with approximately 48,000 buildings in crowded and frequently narrow streets (total length 400 km). The facades of the building along the roads and streets cover an area of about 5,500 000 m². In 2003 it was completely declared as a protected area, when urban protection plans at 1:5000 and 1:1000 map scales were completed. For these protected areas detailed studies of urban design projects based on 1:500 and 1:200 map scales shall be carried out in the future.

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. 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 Historic Peninsula area by terrestrial laser scanning in 2006. It has been planned that the Historic Peninsula should be mapped in a time frame of two years, which demonstrates the great ambition of the project.

The data acquisition of the Historic peninsula was carried out by terrestrial laser scanning for the building facades in the streets and for the building roofs by aerial photo flights with an analogue and a digital camera.

3. DATA ACQUISITION BY TERRESTRIAL LASER SCANNING

The data acquisition by terrestrial laser scanning started in September 2006 mainly using four Leica HDS4500. Figure 3 shows an example of a coloured point cloud of building facades in the

Historic Peninsula. 80ha of the project area (of 1500ha in total) was 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 project area, if this current scan rate of approximately 0.7ha per day could not be increased.

Figure 3. Coloured point cloud of building facades in the Historic Peninsula

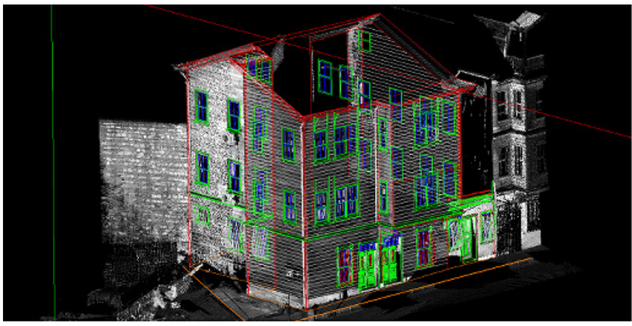
As a consequence the static scanning was replaced by mobile mapping through the Swedish company VISIMIND AB (Fig. 2) in June 2007 using a hybrid sensor system on the vehicle consisting of a terrestrial laser scanning system HDS4500, supported by GPS/IMU and digital cameras. This increased the scan rate dramatically. The sensor integration and the calibration of the system in the streets of Istanbul took some weeks, but the data acquisition in the field has been working since the end of June 2007. The laser scanner was fixed with its orientation in the horizontal direction, scanning only in the profile perpendicular to the moving direction and operating with a speed of up to 40 profiles/sec. The distance between neighbouring profiles was 2-3 cm at the beginning, corresponding to a speed of the van during scanning of 0.5m/sec up to 0.75m/sec or 1.8 km/h up to 2.7km/h.

Thus, the speed of data acquisition by terrestrial laser scanning was significantly increased through use of this mobile mapping system. Consequently, the laser scanning with the mobile system was finished 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 of the data was needed. However, approximately 2% of the area (30ha) could not be scanned by mobile TLS due to traffic restrictions and environmental conditions. For the scanning of this remaining part static TLS is required. A more detailed description of the data acquisition by terrestrial laser scanning for the Historic Peninsula project is summarised in Baz et al. (2008).

4. MAPPING OF FACADES

The geo-referenced point clouds from laser scanning were used for line mapping of the facades at a scale of 1:200. The required positional standard deviation of 0.2mm on the map corresponds to 4cm in the object space as relative accuracy. The facade mapping was carried out by 34 operators using 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. An example for the mapping of building facades with Z-MAP Laser is shown in Fig. 4.

The production rate varied between 60 m^2 facade/day/operator (March 2007) and 140 m^2/day/operator (October 2007), which is an increase of production speed by a factor of more than 2. If one assumes in total 5 Mio m^2 façade areas 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.



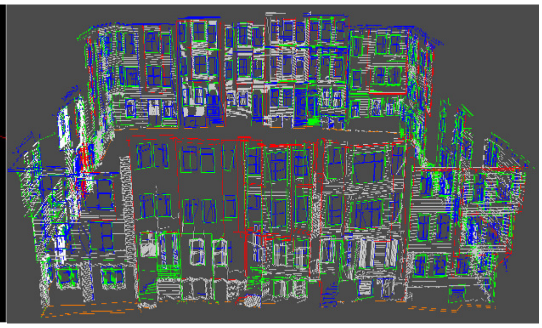


Figure 4. 3D polylines map of building facades based on Z-MAP Laser

Figure 5. Mapped 3D polylines of building block façades derived from terrestrial laser scanning data

An example of the final product from façade mapping is depicted in figure 6, which is derived from 3D polylines as illustrated in figure 5. The mapping of the facades is described in more detail in Baz et al. (2008).

Figure 6. Detailed map of building façades using laser scanning data - laser scanning data (top) and façade plan (bottom)

Figure 7. Part of an aerial image from the Historic Peninsula used for roof mapping

5. ROOF MAPPING WITH AERIAL IMAGERY

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 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. In the beginning available UltraCamD images with 30cm ground sample distance (GSD) were used for data acquisition. The synthetic UltraCamD image has 7500 x 11500 pixels with a pixel size of 9µm*9µm corresponding to an image format of 67.5mm in the flight direction and 103.5mm across flight direction and a focal length of 101.4mm. Each image covered 2.3km x 3.5km.

The photo coordinates have been determined by automatic aerotriangulation with an Intergraph workstation, while the orientation elements of the digital images were adjusted by bundle block adjustment with BLUH. The results of the bundle block adjustment with self-calibration of the UltraCamD data are summarised in (Büyüksalih and Jacobsen, 2006). A horizontal accuracy of up to a factor 0.6 of the GSD could be achieved at independent check points, which corresponds to

18cm in object space. This is a limited result for a digital camera. The sigma0 from the bundle block adjustment is in the range of 0.4 pixels, indicating that the accuracy potential is better. The main reason for this is the limited control point definition and accuracy. Nevertheless the achieved geometric quality is sufficient for the roof mapping, which is more limited by the object definition. The vertical accuracy is two times better than the horizontal accuracy due to good connections between the images in the block and due to measurements of each control point in 4.5 images (on average).

However, due to the limited resolution of the UltraCamD imagery it was very difficult for the operators to measure small roofs and to identify clearly the roof points. As a rule of thumb, mapping is possible up to 0.1mm GSD in the map scale, corresponding to a map scale of 1:3000 with 30cm GSD, which was confirmed by the tests made by this group. Thus, it was decided to use higher resolution imagery for this task, available since mid of August as scanned analogue colour aerial images with 9.5cm GSD. The aerial flight has been conducted using a JenOptik LC0030 camera (f = 305mm) in July 2006 at a photo scale of 1:4500 covering almost 1 km^2 per photo. The photo orientation was determined by automatic aerial triangulation and bundle block adjustment. The expected standard deviation is Sxy = 10cm and Sz = 14cm for topographic points, which is much better than from the triangulation of the UltraCamD images. The analogue photos were scanned at a resolution of 21µm using a Zeiss SCAI scanner. As an example a part of an aerial image taken by the analogue camera illustrates the configuration of roofs in the Historic Peninsula (Fig. 7).

The advantage of the analogue imagery is the high resolution of approximately 10cm GSD in comparison to the limited 30cm GSD of the UltraCamD images, which enables clear identification of the roof points by the operator. In contrast, measurement in shadow areas of the scanned analogue images is not possible due to limited dynamic range of the photos. In comparison to images from digital cameras the contrast and brightness adjustment in analogue images does not provide satisfying results in shadow areas for measurement tasks.

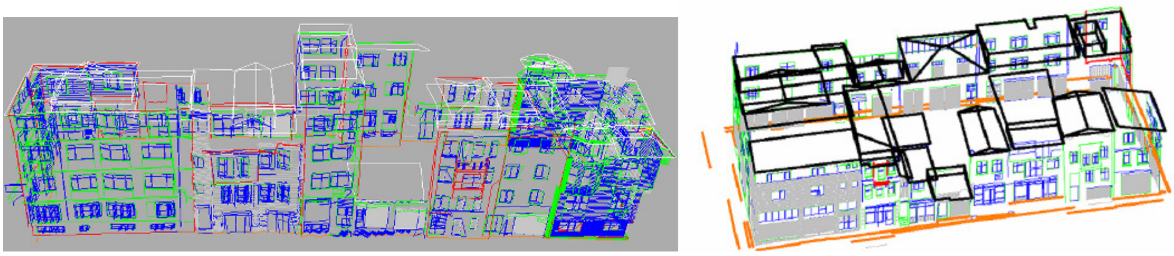


Figure 8. Combination of data from two different sources: 3D polylines of roofs based on aerial images and 3D polylines of facades from terrestrial laser scanning data

In this part of the project to ensure the quality of the data it was an essential task to combine the two different data sets from aerial imagery and mobile TLS into one common data set in the same coordinate system without any discrepancies from the different data acquisition sources. Therefore, the orientation of the aerial images has been transformed to the same datum as 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 represent mainly 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). Two examples of the combination of 3D polylines of roofs from aerial images and 3D polylines of facades from terrestrial laser scanning data are presented in Fig. 8.

The production rate is approximately 100ha of mapped rooftops within 30 days (status August 2007) with five operators. It is estimated that the area of the Historic Peninsula project (1500 ha) will be mapped within one year.

6. 3D MODELLING OF CITY MODELS AND LANDMARKS

Digital photogrammetry and laser scanning, both airborne and terrestrial, are efficient modern techniques for 3D data acquisition as a base for 3D modelling. Image-based 3D modelling has been reviewed by Remondino and El-Hakim (2006). The 3D modelling for specific products using different data sources is the most time-consuming task. Therefore, it was decided to generate different products with different level of detail (LoD) and quality for the city model and the landmarks. The definition of the level of detail is taken from the 3D city model of Hamburg: LoD1 = block model as an extruded foot print of vector data, LoD2 = roof model with detailed roof structures, and LoD3 = architectural model with detailed roofs and facades. LoD4 would include a detailed exterior and interior model. For 3D modelling of all products Autodesk® 3ds Max® software was used. This software is a powerful, integrated 3D modelling, animation, and rendering application to efficiently create parametric shapes and objects and to quickly begin modelling. 3ds Max offers also various import/export functions for several formats, which provides a huge flexibility for the requirements of the clients.

Figure 9. 3D city model of Istanbul Historic Peninsula as LoD1

6.1 3D city model in level of detail 2 (LoD1)

In December 2007 BIMTAS started to generate a 3D city model of the Historic Peninsula as a so-called block model (LoD1) using just cadastre data. This model was completed for all 50,000 buildings after only three months of production with two operators. LoD1 product (Fig. 9) has been generated from the building outlines available in the vector map of the Historic Peninsula, while the building heights were extracted from known information about the number of storeys above the horizontal surface plane. Currently the data is available in 3ds-format in 1km²- tiles.

6.2 3D city model in level of detail 2 (LoD2)

Currently, the modelling group is producing a 3D city model in LoD2 (Fig. 10) by combining the block model with the roofs, which are measured as 3D polylines by the roof mapping group.

Therefore, the measured polylines of the roofs will be converted to 3D planes and thereafter the roof corners can be connected perpendicularly to the corresponding roof points of the block model. In this modelling process the building heights of each block model will be matched with the height of the measured roof. It was quickly realised that there were some discrepancies between the block model and the roof model, i.e. the vector data from cadastre did not fit very well with the photogrammetrically determined roofs. Therefore, it was decided to change the method of production by using measured height points on the ground to generate the facades, i.e. the roof corners can be connected perpendicularly to the measured ground points. Currently, the Suleymaniye region could be almost finished as LoD2 product as illustrated in Fig. 10.

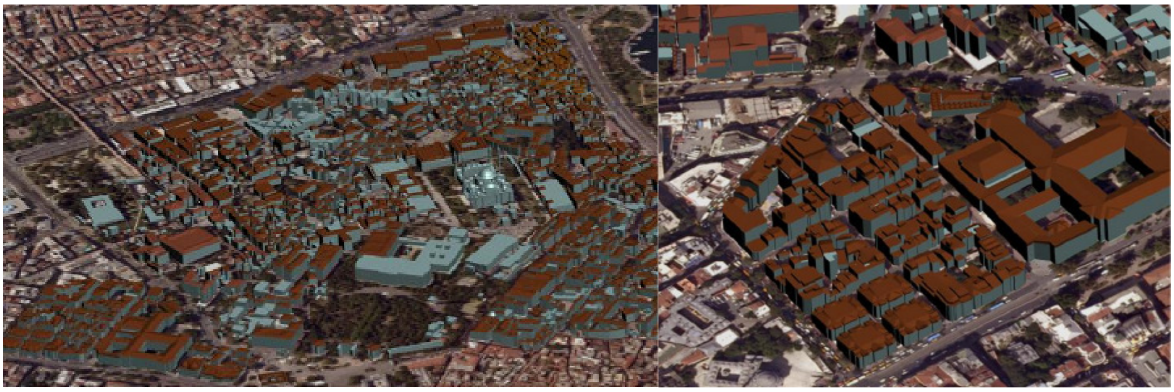


Figure 10. 3D city model of Istanbul Historic Peninsula as LoD2 in the Suleymaniye area superimposed on an orthophoto as an overview (left) and detailed view (right)

6.3. 3D city model in level of detail 3 (LoD3)

The LoD3 is a high quality product, which is generated from the detailed roof-mapping and from building facades including photo-realistic texture mapping of the each building. Similar detailed models of north German castles were generated by digital photogrammetry (Kersten et al., 2004) or archaeological 3D objects in the Republic of Yemen by a combination of photogrammetry and terrestrial laser scanning (Kersten, 2007). Due to the very time-consuming generation of such products only one project part, as pilot project, has been completed thus far. For an architectural comparison of an existing and planned situation two 3D models (old/new) of the same block (511) in Suleymaniye Bölgesi were generated. The modelling of the planned situation was based on 2D drawings, while the existing situation could be modelled using the facade drawing data, which was generated from laser scanning data. For the existing buildings photo realistic textures were available, while for the planned situation textures from the library of ArchiCAD were used. Following a request from the project architects a video sequence (4:47min, 640 x 480 pixel, 46 MB as wmv format) was generated for a visual comparison of the existing and the planned situation of a block in Suleymaniye Bölgesi.

6.4. 3D modelling of landmarks

The 3D modelling group generated photo-realistic 3D models of landmarks, such as the "German Fountain" shown in figure 11, with data from façade mapping using 3ds max. Additionally, the group was able to perform 3D modelling using existing ground and façade plans from different sources (e.g. Sultan Ahmet Mosque, see Fig. 12). The details and the precision of these models are more than sufficient for visualisation purposes. Finally, video sequences can be generated from any modelled object using 3ds max.

Thus far the following landmarks have been modelled in 3D: German Fountain and the Sultan Ahmet Mosque (Blue Mosque), a historic grave located in the garden of the Suleymaniye Mosque (Fig. 13), and the fountain of the Yildiz palace. Currently, the 3D modelling is focussed on the Suleymaniye Mosque (Fig. 14).

Figure 11. Photo-realistic and detailed 3D model of the "German Fountain" (3ds max)

Figure 12. Perspective Scene of the "German Fountain" and the Sultan Ahmet Mosque (3ds max)

However, one major problem in modelling and visualisation is still not solved sufficiently: The data volume of the CAD data for the 3D models (e.g. 60 MB DWG file for the German Fountain) is far too large for many visualisation applications due to the high level of detail. This problem might be solved in the future by better computer performance. For (interactive) visualisation of the 3D models on the internet an export of photo-realistic models from 3ds max to standard file formats (e.g. VRML) is required. Hence, 3D models with reduced data volumes for better visualisation performance on the internet must be generated. Which is the most appropriate file formats for visualisation of the 3D models and for data exchange? There is still potential for the optimisation of the CAD data by using geometric features instead of poly-meshes.

Figure 13. Photo-realistic and detailed 3D model of a historic grave located in the garden of the Suleymaniye Mosque

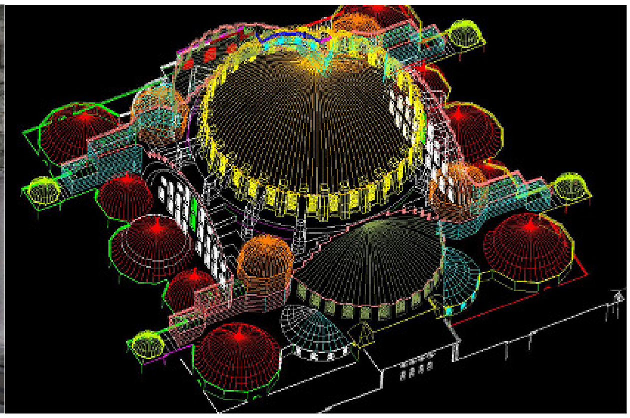


Figure 14. Wireframe of the Suleymaniye Mosque 3D model

7. CONCLUSION AND OUTLOOK

Since 2006 BIMTAS has been tackling a large project on the architectural documentation of Istanbul's Historic Peninsula including almost 50,000 buildings (11,000 of these buildings are historic) with an area of 1500ha. In the frame of this project, the company established different production groups (e.g. laser scanning and geodesy group, and groups for façade mapping, roof mapping and 3D modelling) with highly educated and trained staff (geodesists and architects), who were able to tune and to optimise the production lines for efficient cultural heritage documentation. In order to run such a huge project, modern technologies (hardware and software) were required. With the Historic Peninsula project BIMTAS was able to build up a modern production environment with high-end technology and sophisticated personnel, which could efficiently perform 3D mapping of building facades and roofs as a data base for the subsequent 3D modelling. The data acquisition of all the building facades in the streets of the Historic Peninsula was finished in less than three months by mobile terrestrial laser scanning. However, processing and 3D mapping of the laser scanning data are still continuing. A similar project is reported by Frueh and Zahkor (2003), who also used ground-based data from mobile laser scanning system and cameras in addition to airborne laser scanning data and aerial imagery.

With 3D city models in LOD1, LOD2 and LOD3 BIMTAS is going to derive new products from laser scanning data and aerial imagery, which will fulfil the requirements of many applications and users due to the different levels of detail. The dominating parts of the production lines for the generation of such 3D city models are still manual work, i.e. there is huge potential for optimisation and automation of the production to complete such projects as the Historic Peninsula in reasonable time frames. In the meantime the 3D mapping and modelling of landmarks will be continued in order to generate the most important landmarks as interactive textured 3D models

Istanbul is selected as one of European Cultural Capitals in 2010. Thus, many other projects will come in the near future. There is already a request to create the LoD1 and LoD2 products of the area comprising the two sides of the lower part of the Bosporus including approximately 15,000 buildings. BIMTAS learned many lessons concerning project management and tuning of technology to manage the requirements, so that the company is well positioned to run similar projects in the future.

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