3D Scanning and Modelling of the Bismarck Monument by Terrestrial Laser Scanning for Integration into a 3D City Model of Hamburg

Thomas P. Kersten

HafenCity University Hamburg, Photogrammetry & Laser Scanning Lab
Hebebrandstrasse 1, 22297 Hamburg, Germany
Thomas.Kersten@hcu-hamburg.de

Abstract. In the context of an integrated pilot study between the HafenCity University Hamburg, the Jade University of Applied Sciences in Oldenburg and the Agency for Geo-Information and Surveying Hamburg the Bismarck monument in Hamburg has been scanned with the Z+F IMAGER 5006 3D laser scanning system to generate a virtual 3D model of the monument from the laser scanning data using different programs. A substantial aspect for modelling was data reduction, since the generated 3D model has to be integrated into the city model of Hamburg with the smallest possible data volume. Therefore a combination of triangle meshing and CAD turned out to be an optimal solution. Furthermore, the extent to which the modelled data can be reduced by appropriate polygon decimation, in order to derive a geometrically correct and visually attractive result (virtual 3D model), has been investigated. The geometrical quality of the model was evaluated on the basis of reference values. As well as the integration of the virtual model into the city model of Hamburg the generated virtual model was also prepared for interactive visualisations. For the entire processing of the project time management of the individual work procedures has been calculated, in order to derive statements about the economy of the project. Thus conclusions/recommendations for further projects on object recording, modelling and visualization of such historical buildings and monuments using this procedure with this technology could be provided.

Keywords: 3D modelling, 3D triangulation, cultural heritage, meshing, terrestrial laser scanning.

1 Introduction

While these days world-wide computer networking and the self-evident use of the internet is standard as far as possible, presentation in this medium could become important for a city with tourism value such as Hamburg. So the characteristic cityscape of the Hanseatic city, which is also characterised by a vast number of monuments, could be presented multi-medially as a virtual 3D city model. In the listing of the recognised monuments currently 2800 individual architectural monuments, 2100 ensembles as well as 3000 ground monuments are listed. The protection of historical

M. Ioannides (Ed.): EuroMed 2010, LNCS 6436, pp. 179–192, 2010.

buildings and monuments and the preservation of monuments in the Hanseatic city are described by Hamburg's monument protection law, however a detailed documentation of these objects is often missing.

For geometrical 3D object recording of complex objects such as monuments terrestrial laser scanning is now suitable as an efficient survey procedure. With their ability to scan a very large number of 3D points in seconds without signalisation laser scanning offers high application potential, especially in archaeology, architecture and cultural heritage, as has already been illustrated in numerous publications (see among others [1], [2], [3], [4], [5], [6], [7], [8], [9]).

In this paper 3D object recording and modelling of the Bismarck monument in Hamburg by terrestrial laser scanning are presented as a cooperative pilot study of the HafenCity University Hamburg, the Jade University of Applied Sciences in Oldenburg and the Agency for Geo-Information and Surveying Hamburg. For the production of a virtual 3D model the aspect of data reduction is the main focus in order to merge the geometrically and visually correct model with the smallest data volume as possible into the 3D city model of Hamburg.

Fig. 1. Bismarck monument in an aerial photo (left) and statue (right)

2 The Bismarck Monument in Hamburg

Even during his own lifetime Bismarck monuments were constructed in numerous German cities as well as in other countries in honours of the first German Imperial Chancellor Prince Otto von Bismarck. Born on 1 April 1815 in Schönhausen in the district Stendal Otto von Bismarck became increasingly active in politics after completion of his legal studies in Göttingen and Berlin in 1835. In 1862 he was appointed the Prussian Prime Minister; five years later in 1867 he became chancellor of the North German federation and after a four further years he became the first Imperial Chancellor of the German empire. When in 1888 emperor Wilhelm II ascended to the throne, Bismarck came increasingly into conflict with the young emperor, so that „the iron chancellor" resigned in the year 1890. On 30 July 1898 Otto von Bismarck died on his estate Friedrichsruh in the Saxonia forest close to the gates of Hamburg.

One of the most famous statues was built in the Free and Hanseatic City of Hamburg in the former Elbe Park (Fig. 1). This monument is the largest monument in Hamburg and has consequently a special meaning for the Hanseatic city. The building of the monument was controversial at that time. Initially agreement could not be reached on a location and later the historical Elbe pavilion had to yield for the final location of the huge statue. The architect Johann Emil Schaudt and the sculptor and art nouveau artist Hugo Lederer planned the building project and also implemented it. However, with a height of 34.3 meters and a weight of 625 tons its gigantic size required further agreements. The construction costs aggregated to approximately 500,000 Gold marks. The monument shows Bismarck in form of a Roland statue, a so-called statue of a knight, which was considered as a symbol of municipal rights. The eight figures at the foot of the object (base) symbolised the Germanic tribes. The inauguration of the monument took place on 2 June 1906 after a three-year construction period. More than 100 years at the slope of the river Elbe has not passed without effect on the Bismarck statue. Monitoring activities have found that the listed building has stability problems - at present nine centimetres of inclination on the overall height. Therefore, it must inevitably be renovated in the near future.

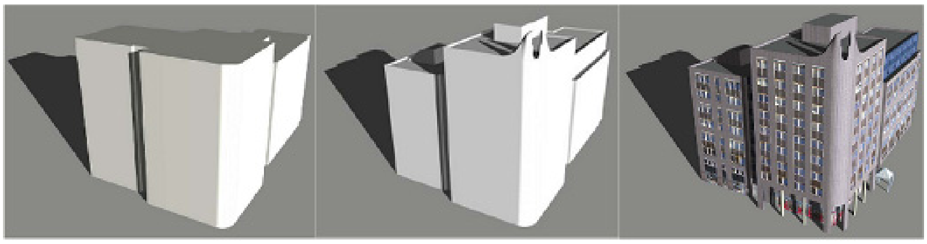

Fig. 2. Building of 3D city model of Hamburg in level of detail 1 to 3 (© LGV Hamburg)

3 The 3D City Model of Hamburg

The 3D city model of Hamburg is available in three different levels of detail (LoD) and quality. The level of detail 1 (block model) was completed in 2001 for the entire area of Hamburg (755 km^2) and consists of 320,000 buildings [10] For the automatic generation of the block models a sketch from the digital basic city map (DSGK) and the respective storey height from the Hamburg official land registers (real estate map and real estate book) for extrusion of the model was used. For LoD 2 the roof landscapes were measured in large-scale aerial photographs in detail and blended with the digital terrain model, so that the model consists of roof and wall surfaces (Boundary Representation). This LoD 2 was finished in 2003 for an area of 250km^2 in the city centre and in Bergedorf and enclosed approx. 130,000 buildings. From LoD 3 (architectural model) texture-mapped buildings are available only in selected areas of the city Hamburg. In Figure 2 the above described levels of detail 1-3 are represented for the city model of Hamburg using the example of one building.

4 Object Recording

Object recording was carried out using the IMAGER 5006 terrestrial laser scanner from Zoller + Fröhlich on 13th August 2008 during very windy weather conditions. Technical specification and accuracy potential of the laser scanner are described in [11]. During scanning GPS measurements were acquired using a Leica GPS system 500 for the geodetic network (five additional points), while the targets were measured by total stations. In total 16 black-and-white targets and four white spheres, which were used as control points for the registration and geo-referencing of the 17 scan stations (Fig. 3 left), were attached to the monument at different heights as well as being set around the viewing platform on tripods. Moreover photographic images with a Nikon D70 were acquired for later possible texture mapping of the 3D model. The object recording was carried out by a three-person team of the cooperation partners involved.

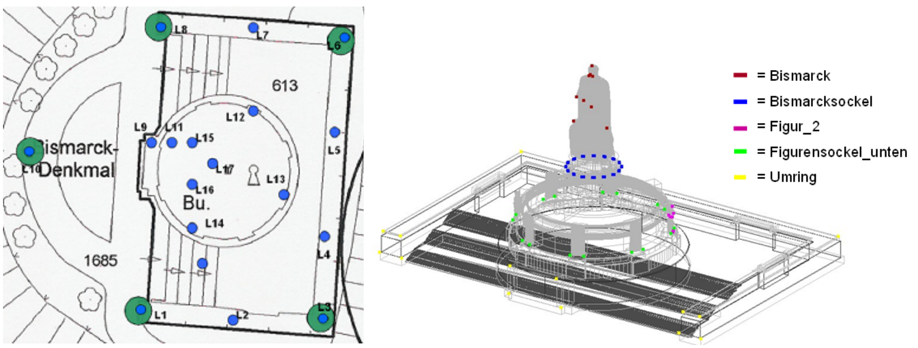

Fig. 3. Scan stations (L1-L17) and five geodetic control points (large circles, left), check points determined by total station (right)

For later quality control of the 3D model 74 check points were determined by total station on three stations around the object during an additional day in the field. The distribution of these check points is represented in Fig. 3 (right). As a check of the heights of the geodetic network distance levelling was carried out on a further field survey day.

5 Data Processing

The data processing was performed in several work procedures, which are described in the following.

5.1 Geo-referencing, Filtering and Segmentation of Scans

In total 180 million points were scanned, which had to be processed efficiently. The registration of 17 scan stations was accomplished with the software LaserControl from Zoller + Fröhlich, in which registration and geo-referencing were accomplished in one processing step. All b/w targets and spheres (127 measurements) were semi-automatically measured in the different scans and later transformed into a common coordinate system using the control point coordinates from a bundle adjustment. The average deviation at the control points was 13mm (standard deviation 6.5mm), whereby 13 measurements of the control points with a deviation over 30mm were excluded from the computation. The poor result can be justified by explaining that the spheres were frequently knocked over by wind causing discrepancies in the geodetic network. However, this result is completely sufficient for this task, although a result better by a factor two was expected.

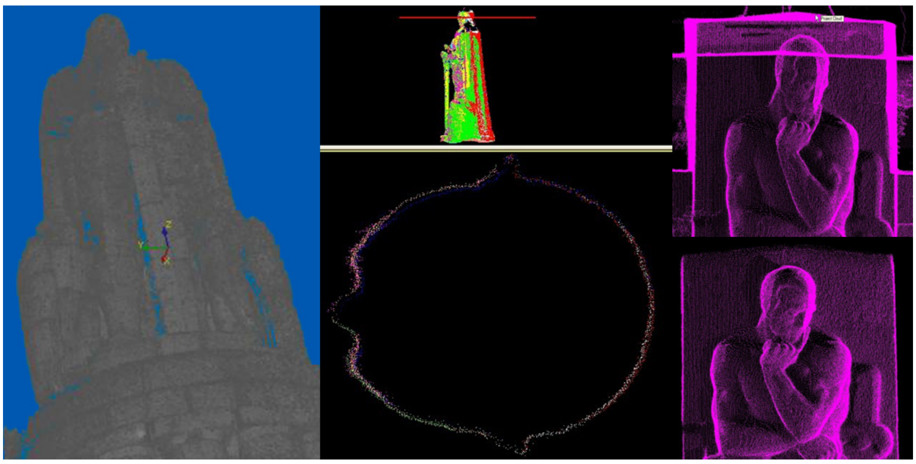

Fig. 4. Single scan of the Bismarck statue (left), quality control of the registration at the head of the statue (centre), segmentation of a figure at the socket (right)

The registration and geo-referencing of the scans was subsequently examined by forming cuts in different levels in the Trimble software RealWorks Survey (e.g. see Fig. 4 centre). The upper scan areas were not evenly supported by control points due to the spatial distribution of the targets. Thus discrepancies of up to 40mm were revealed between the scans but only in the head area of the statue. This difference was not yet critical for the further modelling of the data to meet the requirements of this task. The complete data set was divided into the three areas, platform, socket and statue, segmented and exported accordingly. During export the data were corrected using standard filter parameters in LaserControl and consequently volumes were already reduced (see also [12]). Subsequently, the unnecessary points were eliminated in the segmented point clouds using RealWorks Survey (see Fig. 4 right).

5.2 Modelling

Due to size and complexity of the object a combination of CAD modelling and triangle meshing offers an optimal solution for the 3D modelling of the Bismarck monument. The use of the CAD model is suitable for simple geometrical bodies such as the platform and the socket of the monument, while triangle meshing proves useful for irregular geometry such as the Bismarck statue and the eight figures surrounding the socket. Thus a significant data reduction is already obtained in this stage of the processing by CAD modelling of essential parts of the monument, which also permits more efficient handling of the data for the visualisation of the object at a later stage. Fitting of geometrical primitives such as plane, circle and cylinder into the appropriate positions of the point clouds was not as successful as expected, so that much manual post-processing would have been necessary. Therefore the generation of essential cross-sections in the segmented point clouds (Fig. 5 right top) with the software PointCloud, a plug-in for AutoCAD from the company Kubit, was selected as a successful approach for the creation of a CAD model. However, the manual digitisation in polylines was found to be too labour intensive. Subsequently, the cuts were extruded on their height accordingly, so that one CAD model each has been developed for the socket (Fig. 5 right bottom) and for the platform. Tentative experimentation also showed very quickly that modelling of free form surfaces by cuts is too time-consuming and too inaccurate (see Fig. 6 left).

Fig. 5. Part of the socket of the Bismarck statue (left), generated cross-sections of the geometric object (right top), CAD model of the socket (right bottom)

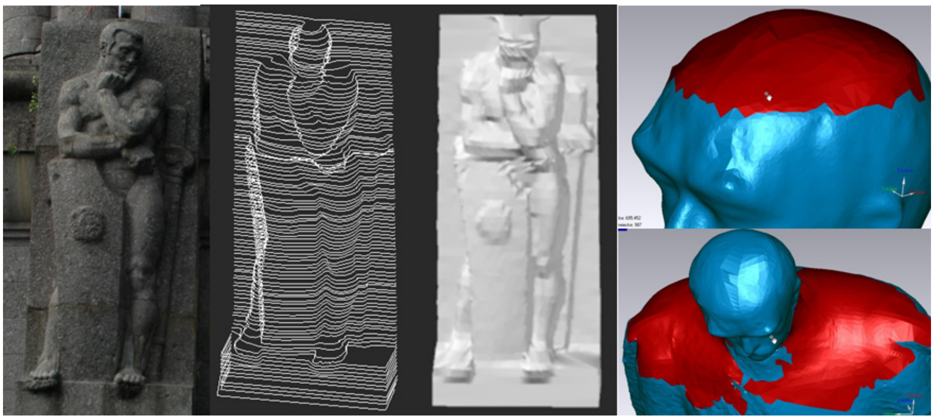

Fig. 6. Modelling of a figure at the socket by cross-sections (left) and curvature-based filling of holes (red) for shoulder and head areas of the Bismarck statue (right)

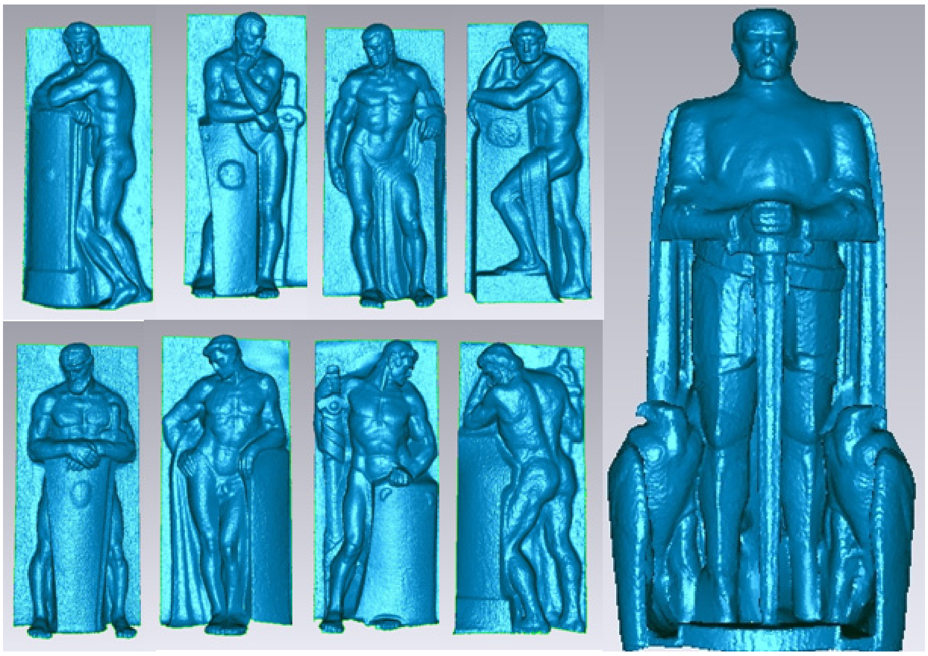

Fig. 7. Eight modelled figures of the monument socket (left) and modelled Bismarck statue (right)

The more complex surfaces of the eight figures around the socket and the Bismarck statue were modelled by 3D triangulation (triangle meshing) in Geomagic (version 10). However, before actual meshing different filter functions were still deployed by Geomagic, in order to eliminate still further outliers and scanning noise from the segmented point clouds (approx. ½ million points of per small figure). The computation of the triangle meshing is performed automatically; however the result can still be optimized afterwards, in which existing holes are filled and the surfaces are smoothed. The large holes within the upper areas of the Bismarck figure, which could not be scanned due to shadowing by the statue height (34.3 meters), were later filled by a curvature-based computation; however bridging points were manually set before due to the size of large holes. The complete result is represented in Fig. 6 (right), while all figures modelled by triangle meshing, are arranged in Fig. 7 (left). During the smoothing of the surfaces one had to proceed very carefully in Geomagic, since important details and intricacies of the surface are quickly lost by over-regulation of the parameter settings. Generally while handling this dataset with Geomagic it was revealed that experience was necessary for optimal parameter control. But a geometrically correct 3D model of the statue (Fig. 7 right) has been generated by processing of the complex object areas (free form surfaces) with Geomagic, which demonstrates a very high visual recognition value.

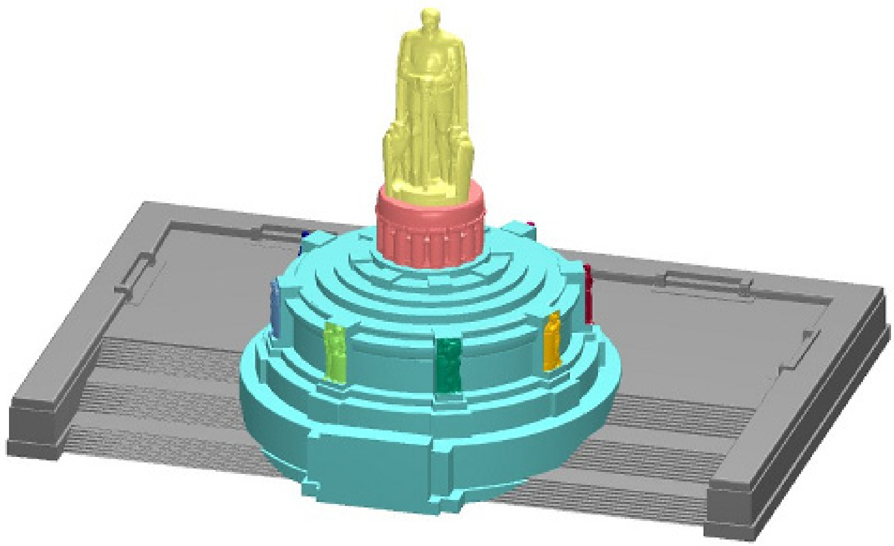

Fig. 8. Colour-coded parts of the Bismarck monument

Finally, all modelled parts of the monument from AutoCAD/PointCloud (CAD) and from Geomagic (triangle meshing) were combined into a entire 3D model using the software MicroStation V8 (Fig. 8). According to the format this entire 3D model has a data volume of 108 MB (DXF), 21 MB (DWG) and 18 MB (DGN), which was transferred into the 3D city model of Hamburg as generated for the integration into the 3D city model of Hamburg, but it is still too large.

5.3 Data Reduction and Accuracy Analysis

In order to be able to reduce the data significantly, a polygon decimation of the meshed object had to be accomplished, which supplies a geometrical and visually correct result. Investigations with Geomagic showed that maximum curvature-based polygon decimation down to 10% supplies a result for the Bismarck figure, which fulfils both mentioned criteria. Thus, the original data volume of the Bismarck figure could be reduced from 800,000 to 80,000 polygons, which corresponds to a reduction of the file size by a factor 10 from 140 MB to 14 MB (DXF). In Fig. 9 differences between the version with 100% and 10% are barely noticeable, while the changes are clearly visible in the figure with the reduction to 3% compared to the full version. The average deviation of 1mm between original and 10% version was calculated in a 3D comparison, while the maximum deviation was 15mm. In the 3D comparison between original and 3% versions the deviations were already higher by a factor of 4 than with the version with 10%. On the other hand polygon decimation down to 5% could be achieved for the figures on the socket without significantly losing geometrical and visual quality.

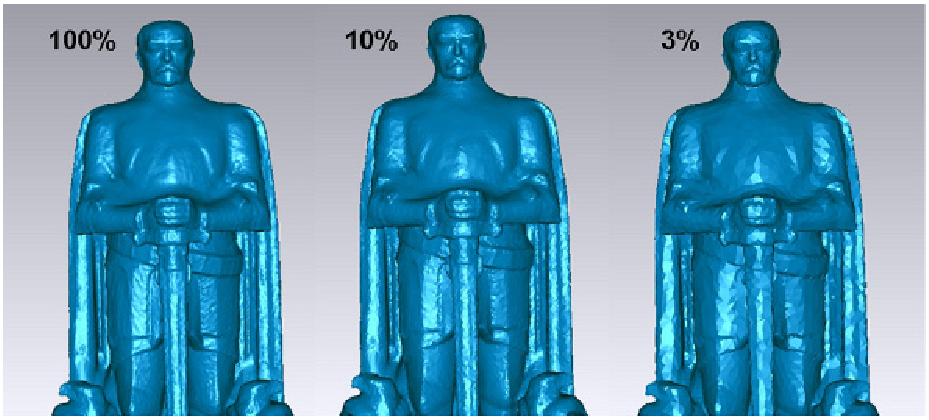

Fig. 9. Visual impression of different levels of polygon decimation in Geomagic for the 3D model of the Bismarck statue

For the accuracy analysis of the modelled 3D monument 74 check points, which were well distributed at the platform, at the socket, at the figures and at the Bismarck statue (see Fig. 3 right), were determined with a total station. The deviations between model and reference were on average between 3-10 cm in XY and in height, which is appropriate for the 3D city model and clearly fulfil the accuracy requirements of 30 cm. The analysis demonstrated the difficulty of identifying and measuring checks points especially on free form surfaces, which could explain larger deviations at several points. However, the re-created geometry of the statue shoulder and head could only be checked visually in the model. A detailed accuracy analysis is documented in [13].

5.4 Visualisation

The generated 3D model of the Bismarck monument was visualized in different formats and with different tools. A simple interactive representation was provided in the VRML format in different resolution stages (including figures at the socket 38 MB, without figures 9 MB) (see Fig. 10). But due to the uniform grey colour of the monument no texture mapping has been carried out. Only Bump Mapping was used as a test, in order to obtain a better depth effect in the model. A further easy-to-use independent viewer is the software AECVIZ from Tornado Technologies Inc., in which the model was imported as DXF (108 MB) and visualised interactively as an executable program (*.exe with 4 MB). In addition the model was converted into the common format 3D PDF (9 MB), which can be represented with each Acrobat Reader starting from version 8 (Fig. 11). The integration of the monument into the 3D city model of Hamburg is shown in Fig. 12. Several video sequences as flights around the virtual monument were generated with the program Cinema 4D (Fig. 13 top). For the integration of the model into Google Earth the quality of this existing geo data could be seen, since situation and height did not fit to the precisely generated virtual monument for a few meters (Fig. 13 bottom). But a Google Earth version of this monument is not planned.

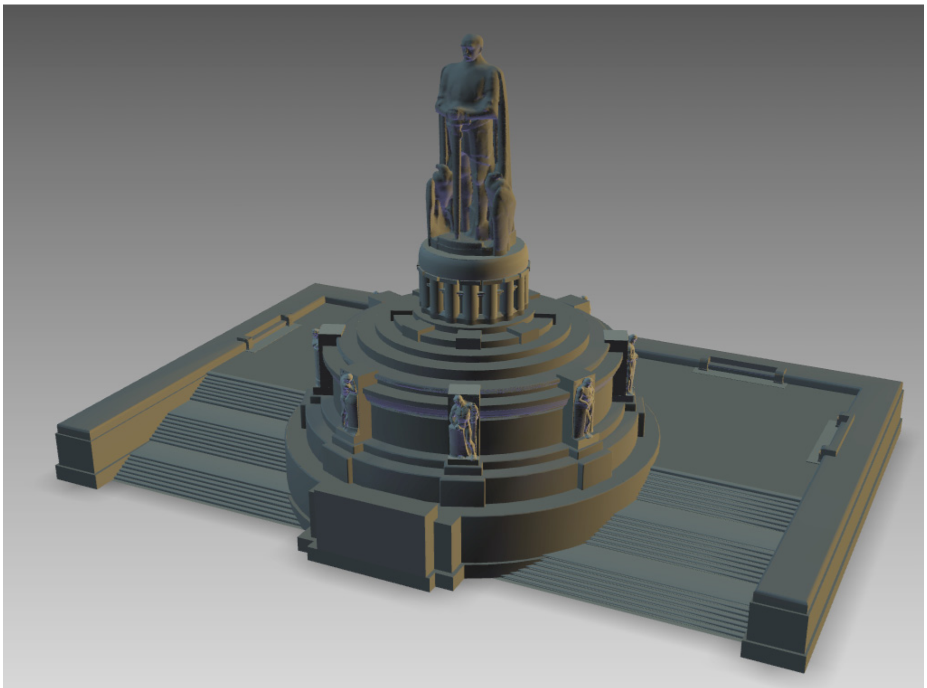

Fig. 10. Presentation of the 3D model in the VRML format

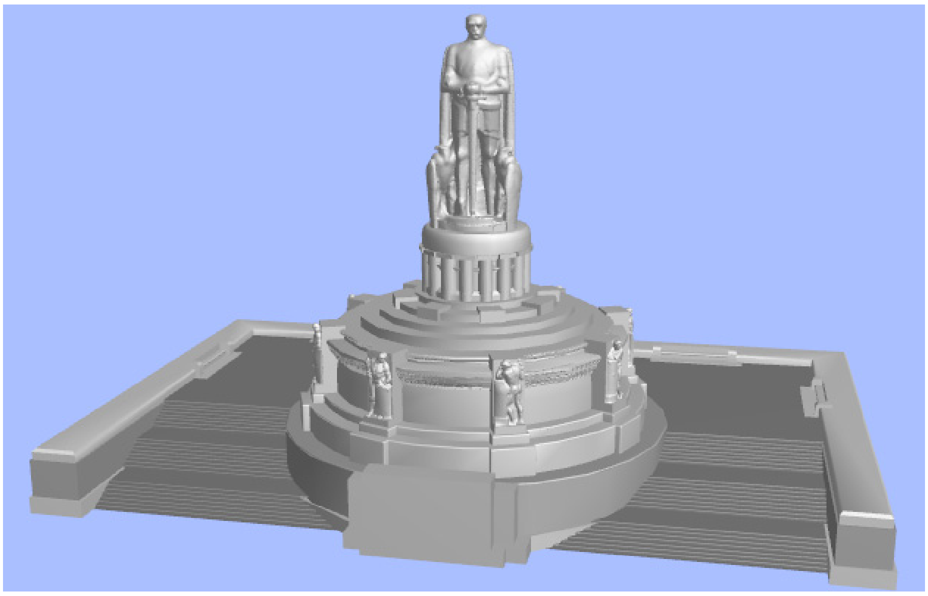

Fig. 11. Visualisation of the Bismarck monument as 3D PDF

Fig. 12. Bismarck monument integrated into the 3D city model of Hamburg (in the background is the St. Michaelis church visible)

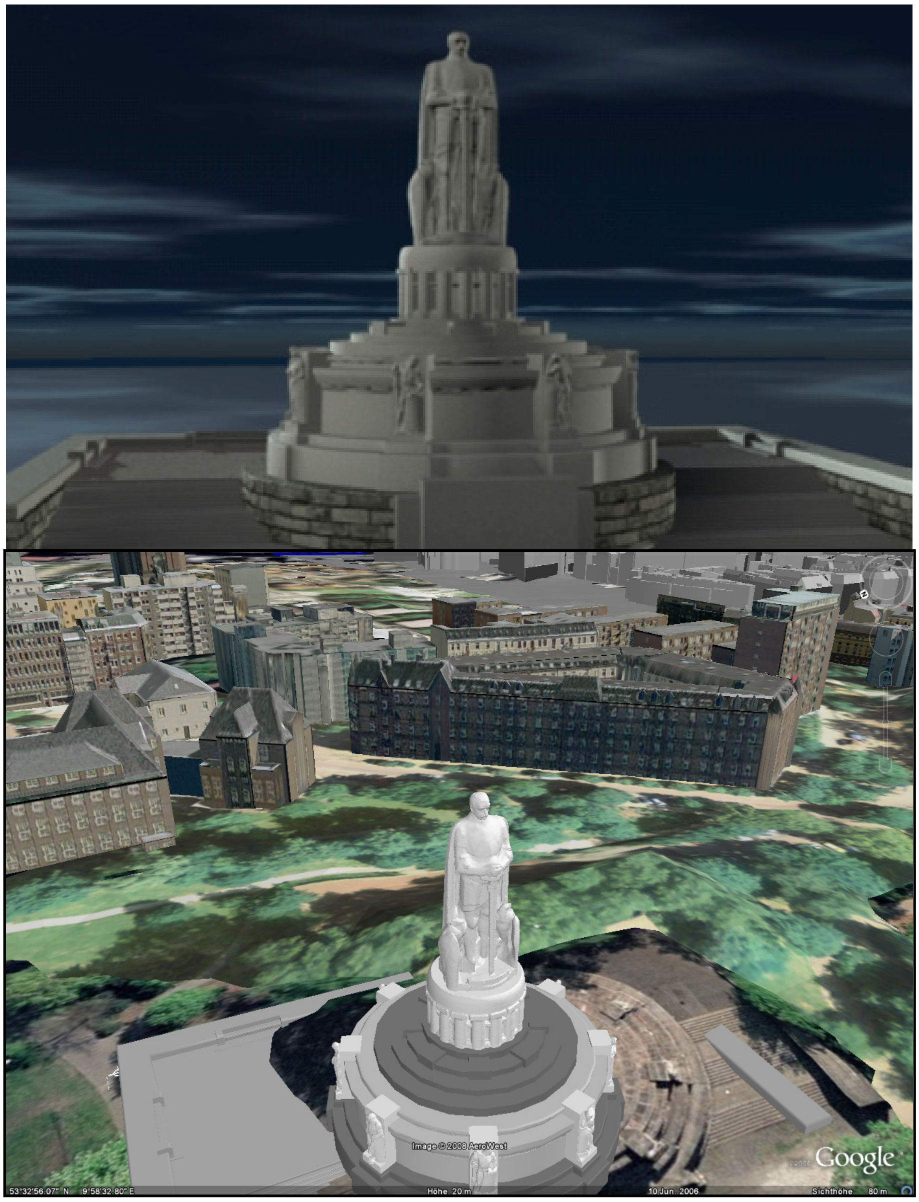

Fig. 13. Visualisation of the Bismarck monument in Cinema 4D (top) and in Google Earth (bottom)

6 Conclusions and Outlook

This integrated pilot study showed that complex objects such as the Bismarck monument can be recorded in detail by terrestrial laser scanning within a short time. However, the 3D modelling has been carried out using mostly manual methods; consequently this is time and cost-intensive. In total 210 hours were estimated for the entire project work, which partitioned themselves on the different work procedures: data acquisition 14h, adjustment geodetic net 16h, processing scanning data 30h, 3D modelling 130h, data reduction 8h, texture mapping 4h and visualization 8h. Since 61% of the entire working time was used for modelling, the biggest potential for optimisation can be achieved there by increasing automation. The ratio of object recording to data processing with 1:14 is slightly higher that other practical projects carried out at HCU Hamburg (1:10 for e.g. Kornhaus bridge Hamburg, Holstentor Lübeck). If one calculates a rate of €50 per hour for an engineer in the whole project, as a result costs of € 10,500 can be estimated for the whole project volume, which appears quite expensive for the object recording and modelling of monuments and which might not correspond to real market conditions. There is still substantial optimisation potential in all work procedures. The obtained accuracy of approx. 3 – 10cm for the 3D model of the Bismarck monument fulfils the requirements for the integration into the 3D city model of Hamburg and even for further visualisation applications without any problems. Thus, despite significant data reduction, which was achieved by curvature-based polygon decimation in triangle meshing of the complex structures (figures) and by CAD modelling with volume bodies for simple objects (platform and basement), a geometrically and visually correct 3D model has been generated. Although shadowing areas could not be scanned due to the statue height, missing parts of the Bismarck statue could be supplemented computationally with appropriate software. However, different software packages (LaserControl, RealWorks Survey, AutoCAD/PointCloud, Geomagic, MicroStation) were in use for the production of the final product, since still today no program can cover all substantial work procedures optimally. The object recording and modelling of further monuments and historical buildings in Hamburg are planned, in order to increase the attractiveness of Hamburg's city models by the integration of such detailed 3D models.

Acknowledgments. The project support of Klaus Mechelke (HCU Hamburg) for scanning, Antje Tilsner (Bachelor student at Jade University of Applied Sciences) for data processing, Walter Sieh (Agency for Geo-Information and Surveying Hamburg) and Ingrid Jaquemotte (Jade University of Applied Sciences) for the additional supervision of the project is gratefully acknowledged.

References

1. Sternberg, H., Kersten, T., Jahn, I., Kinzel, R.: Terrestrial 3D Laser Scanning - Data Acquisition and Object Modelling for Industrial As-built Documentation and Architectural Applications. In: The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 35(7), pp. 942–947 (2004)
2. Ioannidis, C., Demir, N., Soile, S., Tsakiri, M.: Combination of Laser Scanner Data and Simple Photogrammetric Procedures for Surface Reconstruction of Monuments. In: 20th CIPA XX Symposium, Torino, Italy (2005), http://cipa.icomos.org/textfiles/TURIN/372.pdf
3. Neubauer, W., Doneus, M., Studnicka, N., Riegl, J.: Combined High Resolution Laser Scanning and Photogrammetrical Documentation of the Pyramids at Giza. In: 20th CIPA XX Symposium, Torino, Italy (2005), http://cipa.icomos.org/textfiles/TURIN/470.pdf

4. Kersten, T.: Virtual Reality Model of the Northern Sluice of the Ancient Dam in Marib/Yemen by Combination of Digital Photogrammetry and Terrestrial Laser Scanning for Archaeological Applications. International Journal of Architectural Computing, Special Focus on Cultural Heritage 02(05), 339–354 (2007)
5. El-Hakim, S., Beraldin, J.-A., Picard, M., Cournoyer, L.: Surface Reconstruction of large complex Objects from mixed range data – the Erechtheion experience. In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 37(5), pp. 1077–1082 (2008)
6. Kersten, T., Lindstaedt, M., Vogt, B.: Preserve the Past for the Future - Terrestrial Laser Scanning for the Documentation and Deformation Analysis of Easter Island's Moai. PFG - Photogrammetrie - Fernerkundung - Geoinformation (1), 79–90 (2009)
7. Kersten, T., Büyüksalih, G., Baz, I., Jacobsen, K.: Documentation of Istanbul Historic Peninsula by Kinematic Terrestrial Laser Scanning. The Photogrammetric Record 24(126), 122–138 (2009)
8. Remondino, F., Gruen, A., von Schwerin, J., Eisenbeiss, H., Rizzi, A., Girardi, S., Sauerbier, M., Richards-Rissetto, H.: Multi-Sensor 3D Documentation of the Maya site Copan. In: 22nd CIPA Symposium, Kyoto, Japan (2009), `http://cipa.icomos.org/textfiles/KYOTO/131-1.pdf`
9. Toubekis, G., Mayer, I., Doring-Williams, M., Maeda, K., Yamauchi, K., Taniguchi, Y., Morimoto, S., Petzet, M., Jarke, M., Jansen, M.: Preservation and Management of the UNESCO World Heritage Site of Bamiyan: Laser Scan Documentation and Virtual reconstruction of the Destroyed Buddha Figures and the Archaeological Remains. In: 22nd CIPA Symposium, Kyoto, Japan (2009), `http://cipa.icomos.org/textfiles/KYOTO/185-2.pdf`
10. Cieslik, B.: Hamburg in der dritten Dimension. ZfV - Zeitschrift für Geodäsie, Geoinformation und Landmanagement, Heft 4, 254–259 (2003)
11. Kersten, T., Mechelke, K., Lindstaedt, M., Sternberg, H.: Methods for Geometric Accuracy Investigations of Terrestrial Laser Scanning Systems. PFG - Photogrammetrie - Fernerkundung - Geoinformation (4), 301–316 (2009)
12. Kersten, T., Sternberg, H., Mechelke, K., Lindstaedt, M.: Datenfluss im terrestrischen Laserscanning - Von der Datenerfassung bis zur Visualisierung. In: Terrestrisches Laserscanning (TLS 2008), Schriftenreihe des DVW, Band 54, Beiträge zum 79. DVW-Seminar am 6.-7, Fulda, pp. 31–56. Wißner-Verlag, Augsburg (November 2008)
13. Tilsner, A.: 3D-Erfassung und Modellierung des Bismarck-Denkmals in Hamburg durch terrestrisches Laserscanning. Unpublished Bachelor thesis, University of Applied Sciences Ostfriesland, Oldenburg, Wilhelmshaven (November 2008)