FIRST EXPERIENCES WITH TERRESTRIAL LASER SCANNING FOR INDOOR CULTURAL HERITAGE APPLICATIONS USING TWO DIFFERENT SCANNING SYSTEMS

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ABSTRACT:

In this paper the comparative application of two terrestrial 3D laser scanning systems for recording and modelling of two historical halls in the City Hall Hamburg is presented. The two halls (Kaisersaal and Großer Festsaal) were scanned in approximately three hours with the Mensi GS100 from Trimble and with the IMAGER 5003 of Zoller & Fröhlich from five (GS100) and 22 stations (IMAGER 5003), in order to generate different cuttings, 2D plans and 3D models from each entire point cloud. For the geo-referencing of the point clouds into a local coordinate system a precision of approx. 5 mm (GS100) and 8 mm (IMAGER) was achieved using specific targets. The quality of the digital CAD data modelled from the laser scanner data is controlled by reference distances, while the efficiency of the recording and data processing was compared to each other and finally evaluated.

1. INTRODUCTION

Since the end of the nineteen nineties when the first terrestrial 3D laser scanner came on the market, the systems carried out an enormous technical advancement, so that they are established as 3D metrology beside and also in addition to well-known technologies such as photogrammetry and tacheometry. Due to the improvements in hardware and software the systems are today able to record and accordingly evaluate complex forms and objects with a dense 3D point grid. Nevertheless, investigations into precision and efficient project implementation are very important for understanding and improvement, and for a broad market acceptance of such measuring systems. The Department of Geomatics of the Hamburg University of Applied Sciences tested comparatively in a pilot project, how suitable two terrestrial 3D laser scanning systems - Mensi GS100 from Trimble and IMAGER 5003 of Zoller & Fröhlich - are for indoor cultural heritage applications of two historical halls in the city hall of Hamburg. The quality of the digital CAD data modelled from the laser scan data was compared with reference distances.

Accuracy tests and practical experiences using the Mensi GS100 at HAW Hamburg are already published by KERSTEN et al. 2004 and STERNBERG et al. 2005. As examples of the use of terrestrial laser scanners for recording of historical inner rooms the scanning of castle Neuschwanstein with the IMAGER 5003 was reported by STRACKENBROCK (2004) and the scanning of the small mosque Hagia Sophia in Istanbul with the 3dLMS (a prototype from TU Darmstadt) is described in DÜPPE & KLEIN (2005). LORRA & JÄGER (2004) report on the efficient use of the IMAGER 5003 for forensic applications.

In this paper the two historical halls and the two 3D laser scanning systems are introduced briefly in chapter 2. The data acquisition, registration and geo-referencing with the laser systems is presented in chapter 3, while the results of the data processing and evaluation of the two different data sets are discussed in chapter 4. Finally, the systems are compared to each other and evaluated in chapter 5.

2. OBJECTS TO BE SCANNED AND LASER SCANNING SYSTEMS

The historical halls selected as objects to be scanned are characterised by a large measurement area with up to 17 m x 41 m x 16 m and by detailed ornamentation. In order to take these two aspects into consideration two laser scanning systems, working with different measurement methods, were used for the recording.

2.1 Kaisersaal and Großer Festsaal in the City Hall of Hamburg

The City Hall of Hamburg, which is the seat of senate and citizenry today, was built by a group of architects under the leadership of Martin Haller in 1886-1897 as a magnificent sandstone building in the style of the Neo Renaissance. The City Hall is 111 meters long and has a tower of 112 m height. In the City Hall 647 rooms are located, of which the splendid rooms or halls are the Kaisersaal and the Großer Festsaal (Fig. 1). Both halls are equipped with much marble, many gold ornaments and precious paintings. They are still used today for receptions and social meetings. The Kaisersaal received its names after a visit of the German Emperor Wilhelm II. on the occasion of the opening of the Kiel-Canal. It has a remarkable ceiling painting, which symbolizes merchant shipping under the German flag. The walls, on which portraits of important mayors of Hamburg hang, are covered with a wallpaper of raised cattle leather, which is the largest 19th century example in Germany. In the richly decorated Großer Festsaal receptions for domestic and foreign politicians are still given today. The golden State emblem shines over the wooden seats of the mayors. Directly over this State emblem a huge wall painting is located, that shows Hamburg´s harbour at the beginning of the 20th century. Furthermore, large wall paintings, which were painted by Hugo Vogel before 1909, illustrate the history of Hamburg from 800 to 1900. These paintings are surrounded by 62 city emblems of the old Hanseatic league (13m height). Three enormous candelabra with 240 bulbs and a weight of 1.7 tons each illuminate the hall.

Fig. 1: Impressions of the Kaisersaal (left) and the Großer Festsaal in the City Hall of Hamburg (right)

2.2 Laser scanning systems Mensi GS100 and IMAGER 5003

The 3D laser scanning system GS100 is manufactured by Mensi S.A., France and the IMAGER 5003 is produced by Zoller & Fröhlich in Wangen im Allgäu, Germany. The most important technical specifications of the two used systems are summarised in Table 1. The substantial differences between GS100 and IMAGER 5003 are specified as follows: The impulse time-of-flight method of the GS100 (wavelength 532 nm) permits the measurement of longer scan distances than the IMAGER 5003 (780 nm), whereas the scanning speed of the GS100 is clearly slower due to the measuring method. The field of view is substantially larger with the IMAGER 5003 than with the GS100, thus it permits a higher flexibility of the system when used indoors. On the other hand the GS100 offers a higher angular resolution and a significantly smaller spot size of the laser beam at the object. The laser point of the GS100 is imaged as 3mm spot size at the object at 25m distance, while the laser point of the IMAGER 5003 can cover a size of 11 mm at the same distance. Due to the integrated video camera the GS100 offers the possibility for colour coding of the point clouds with RGB values.

	Mensi GS100	**IMAGER 5003**
Metrology method	pulsed time of flight	phase differences
Field of view	360° horizon., 60° vertical	360^0 horizon., 310^0 vertical
Optimal scan distance	2 – 100 m	1 – 53.5 m
Scanning speed	up to 5000 points/sec	up to 500000 points/sec
Accuracy in distance (25m)	6 mm (single measurement)	~ 6mm
Angular resolution	0.002 gon	0.020 gon
Divergence / Spot size in 25 m	0,06 mrad / 3 mm	0,22 mrad / ca. 11 mm
Calibrated video camera	RGB 768 x 576 Pixel	None

Table 1: Technical specifications of the laser scanners Mensi GS100 and IMAGER 5003

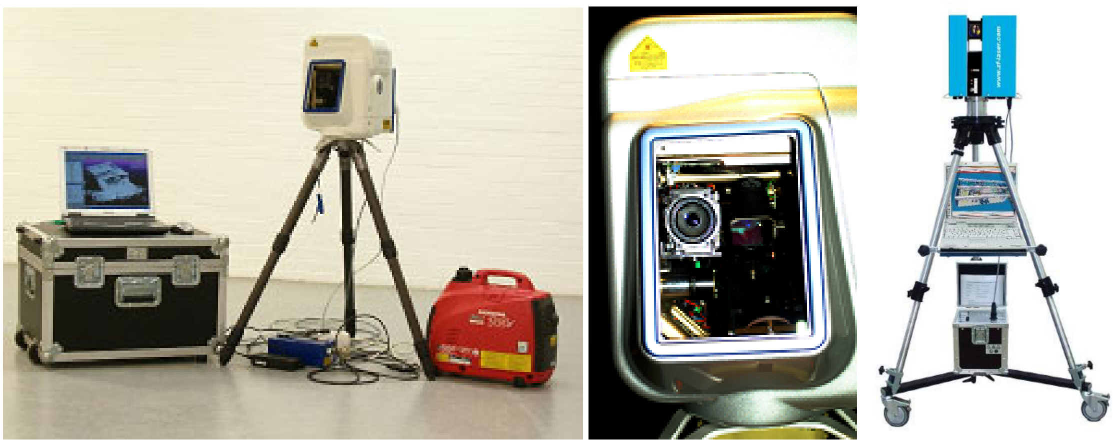

Fig. 2: The 3D laser scanning system Mensi GS100 of HAW Hamburg with accessories (left), GS100-interior with digital camera and mirror (middle), IMAGER 5003 with accessories (right)

Software	Mensi GS100	IMAGER 5003
Scanning	PointScape V1.2	LR Viewer2
Post Processing	Real Works Survey V4.1 for registration and geo-referencing, OfficeSurvey Modules	LFM Modeller V3.64c for registration and geo-referencing, fitting of geometric primitives in point clouds
Post Processing	3Dipsos V3.0 for registr. and geo-referencing, fitting of geometric primitives in point clouds	LFM Server + Generator 3.64i for data processing of huge point clouds

Table 2: Software for the laser scanning systems Mensi GS100 and IMAGER 5003

Fig. 2 shows both 3D laser scanning systems with appropriate accessories. The standard equipment of the GS100 is a solid transportation box and a notebook for controlling the measuring instrument during the data acquisition. A useful addition of the system is an efficient generator (e. g. Honda power generator EU10i, electrical power approx. 1 KW) for use in the field, since electricity is not available everywhere. The IMAGER 5003 is installed on a mobile tripod and is supplied with power by a battery. Likewise, the control system of the scanner is a notebook.

A substantial component of laser scanning systems is the software, which is summarized for both products used in Table 2. The software allows control of the scanner via a notebook during the data acquisition phase, the registration and geo-referencing of point clouds from different stations and a huge number of options for data post processing up to the fitting of geometric primitives into the point cloud for CAD construction.

3. DATA ACQUISITION, REGISTRATION AND GEOREFERENCING

The work procedures necessary, before actual data evaluation of the 3D point clouds, are data acquisition, registration and geo-referencing of point clouds into a superior coordinate system. Therefore, before scanning targets for both systems were attached in a well distributed pattern in both halls to allow a transformation from the scanner into the superior coordinate system during post-processing. The different targets (see Fig. 3 middle), nine for the GS100 and 29 for the IMAGER 5003, were measured with a Leica total station TCRA 1105 in a local 3D network and determined in a network adjustment with an accuracy of approximately 4mm.

For the laser scanning in the two halls a time budget of five hours in total was provided by the City Hall authority. Due to these time constraints the GS100 could only scan from five scanner stations (see Fig. 3 middle), while due to the short scan times of approximately 7 minutes per scan per station the IMAGER 5003 could scan from 22 stations in total. The resolution of the IMAGER was set to 'high', for which a 360° scan yields a size of 10000 pixels x 5967 lines. This setting leads to a grid spacing of 16 mm x 16 mm at 25 m distance. The changes of the scanner stations could be carried out very quickly and flexibly with the IMAGER 5003 using the roll support. However, with the GS100 a set up and dismantling of the system of approximately 10 minutes was necessary in each case. The guidance of the two scanners was controlled by a notebook using the software PointScape V1.2 (GS100) and LRViewer 2 (IMAGER 5003). In order to be able to register the scanned point clouds of different scanner stations automatically, each visible green target was scanned separately with the GS100 before each object scan. The numbered targets for the IMAGER 5003 were scanned in each panorama scan. Unfortunately the scanning of the two halls could not be accomplished in ideal conditions since both groups of visitors in the City Hall and also invited people for the scanner demonstrations sometimes caused a slight vibration of the parquet floor. However, no significant effects of the vibration could be determined in the subsequent data processing of the point clouds. The important scanning statistics are summarized in Table 3. Although, the grid spacing for both systems was selected as approximately the same, a significantly higher number of scanned points, and thus a larger volume of data, were achieved from the many scanner stations and from the larger field of view of the IMAGER 5003.

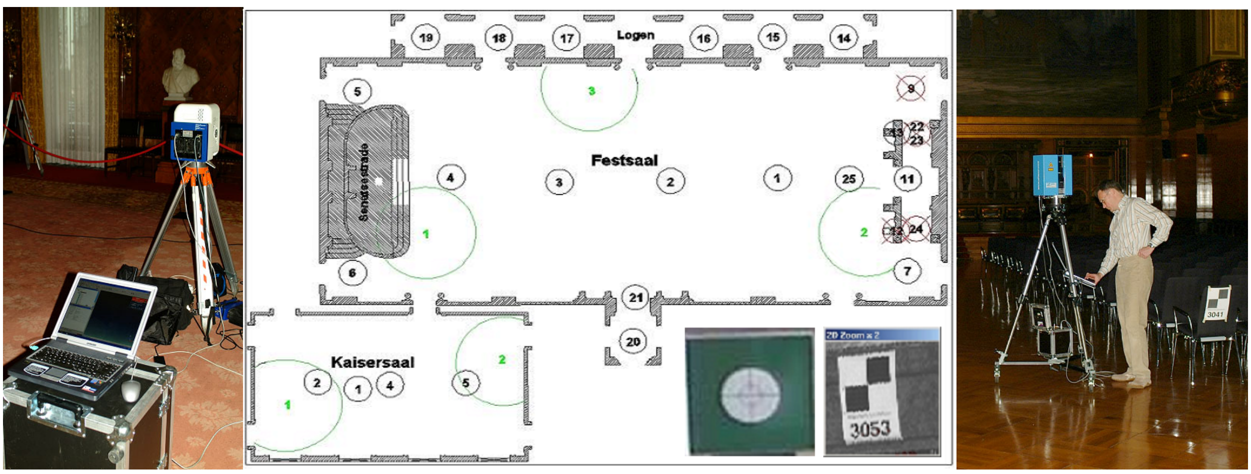

Fig. 3: Left: Mensi GS100 in Kaisersaal, middle: Overview of the Scanner stations: GS100 big circles and IMAGER 5003 small circles, as well as targets for GS100 and IMAGER 5003, right: IMAGER 5003 in Großer Festsaal.

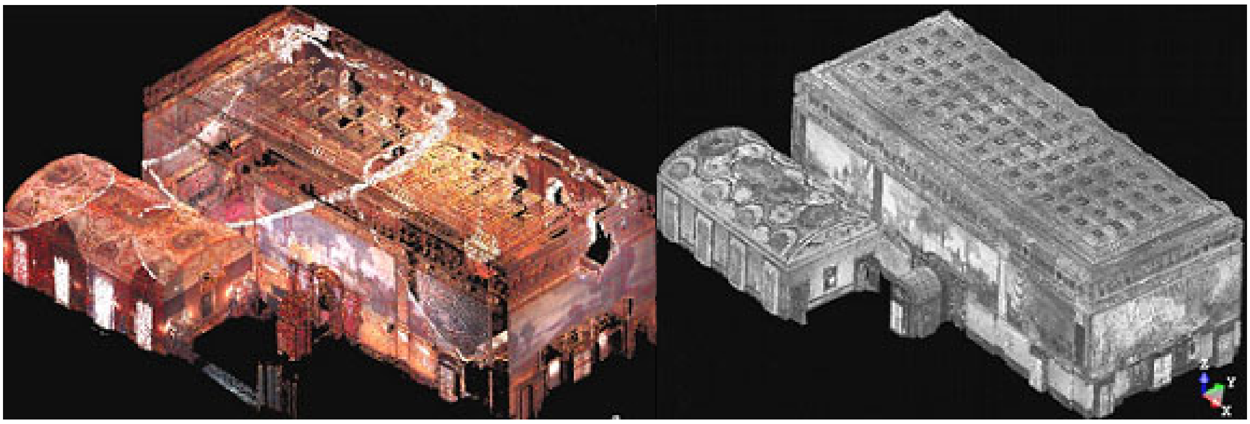

Fig. 4: Geo-referenced point clouds of both halls: Mensi GS100 (left), IMAGER 5003 (right)

Scanning statistics	**Mensi GS100**	**IMAGER 5003**
# of targets	9	29
# of scanning stations	5	22
# of scans	8	22
# of points (in Mio.)	24,5	1076
Volume of data [MB]	500	5400
Grid width in 25 m [cm] / Scan	1.9	1.6
Scaning time/station [min]	50	7
Scaning time in total [min]	190	154

Table 3: Scanning statistics for Mensi GS100 and IMAGER 5003

The subsequent registration and geo-referencing of the eight GS100 point clouds was achieved automatically with Real Works Survey 4.1 using three and five targets with an accuracy of 3 mm (Kaisersaal) and 5 mm (Großer Festsaal), respectively. On the other hand, due to the large volume of data, the point clouds of each IMAGER 5003 scanning station were geo-referenced directly with the software LFM Modeller 3.64 using at least three targets. Some scans could not be geo-referenced at all since there were too few targets were visible (see crossed circles in Fig. 3). The geo-referencing of the individual point clouds could be conducted with 3-6 targets per scan and an accuracy of 8 mm. Fig. 4 shows the registered and geo-referenced point clouds of the Großer Festsaal and Kaisersaal, whereby the GS100 data is RGB coded by the images of the video camera, while the data from the IMAGER 5003 is represented only in grey values.

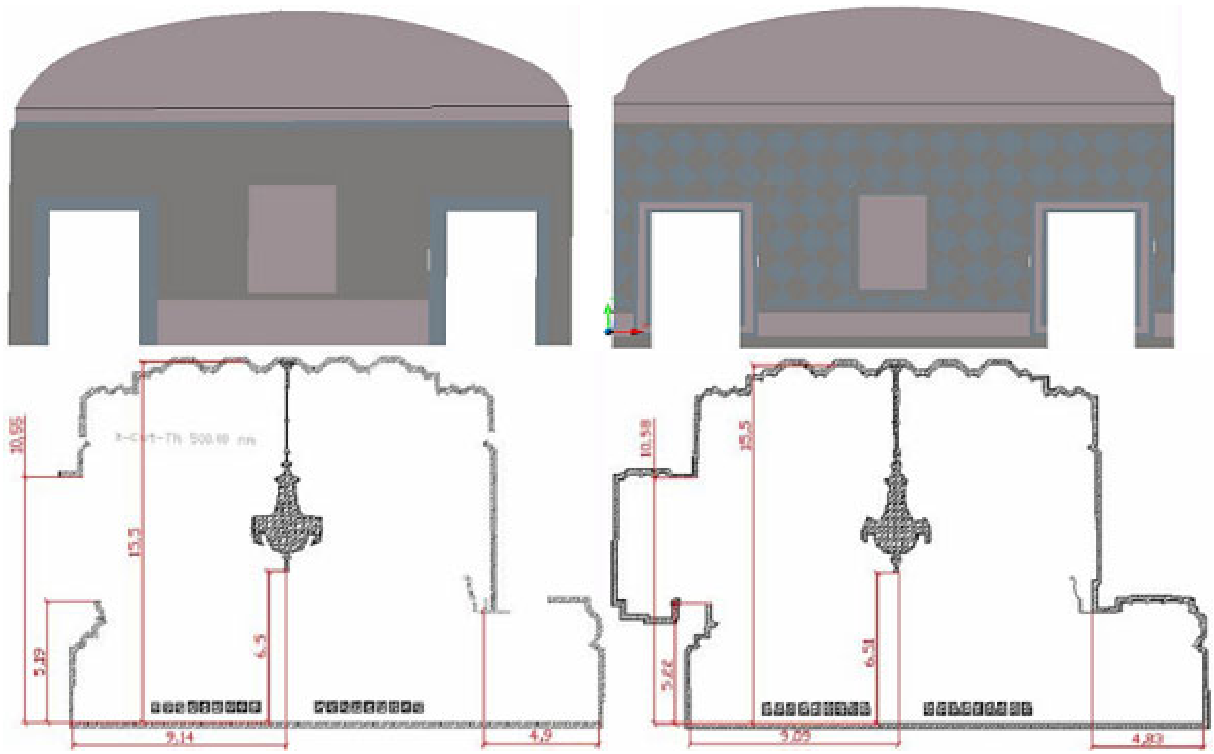

Fig. 5: Level of detail of the 2D construction of one wall in Kaisersaal (top), and one cross section in Großer Festsaal (bottom), constructed each in the point cloud of GS100 (left) and IMAGER 5003 (right)

4. DATA PROCESSING OF THE POINT CLOUDS

The generation of 2D cuttings, ground plans and a 3D model was the main focus of the evaluation of the point clouds. For this data processing the software Real Works Survey 4.1 could be used for the GS100, which allows the manual and automatic generation of cutting planes, the inclusion of polylines into the point cloud of the cuts and the export of the polylines to AutoCAD. These polylines were the basis to construct both ground planes and sketches, as illustrated in Figures 5 and 7, and a 3D model (Fig. 6) in AutoCAD. For example, for the construction of a part of a wall in Großer Festsaal (Fig. 8) 48 cutting planes at a distance of 10 cm with a width of 5 cm were formed and polylines were derived from this.

Fig. 6: Level of detail of the 3D model of one door in Großer Festsaal, constructed in the point cloud of GS100 (left) and IMAGER 5003 (right)

The comparison of distances from the 2D ground plans with reference distances resulted in an average deviation of 17 mm. For checking the accuracy quality of the 3Dmodel of a door (Fig. 6) the comparison between the CAD model and reference distances resulted in an average deviation of 10 mm.

For the evaluation of the point clouds of the IMAGER 5003 and GS100 the LFM Modeller software and 3Dipsos were not used, since both software modules allow only the generation of 3D primitives, e.g. for applications in industrial as-built documentation. Therefore, the software LFM Server of Zoller & Fröhlich was used. With this software it is possible to load parts of the point cloud at full resolution as background information for construction in AutoCAD. For the generation of the 2D ground plans cutting planes were produced manually in LFM server and the thus extracted part of the point cloud was transferred directly to the connected program AutoCAD as background information. Using this software module the large volume of data from the IMAGER 5003 was easily and effectively handled and 2D ground plans and the 3D model were efficiently produced in AutoCAD.

The deviations between reference distances and distances in the 2D ground plans were, on average, 13 mm. In the 3D model deviations of 11 mm were determined.

In Fig. 7 it is clearly visible that the products derived from the point clouds of the IMAGER 5003 are more highly detailed compared to the GS100 products, since the point density in the object space was clearly higher due to the higher number of scans, which yielded fewer gaps due to shadings. Furthermore, the construction work with LFM Server was less time-consuming than with Real Works Survey. Consequently, for the construction of the side wall of Großer Festsaal with Real Works Survey only a 2D plan could be generated, while it was possible to generate a 3D model (Fig. 8) from the IMAGER point cloud in the same processing time with LFM Server and AutoCAD.

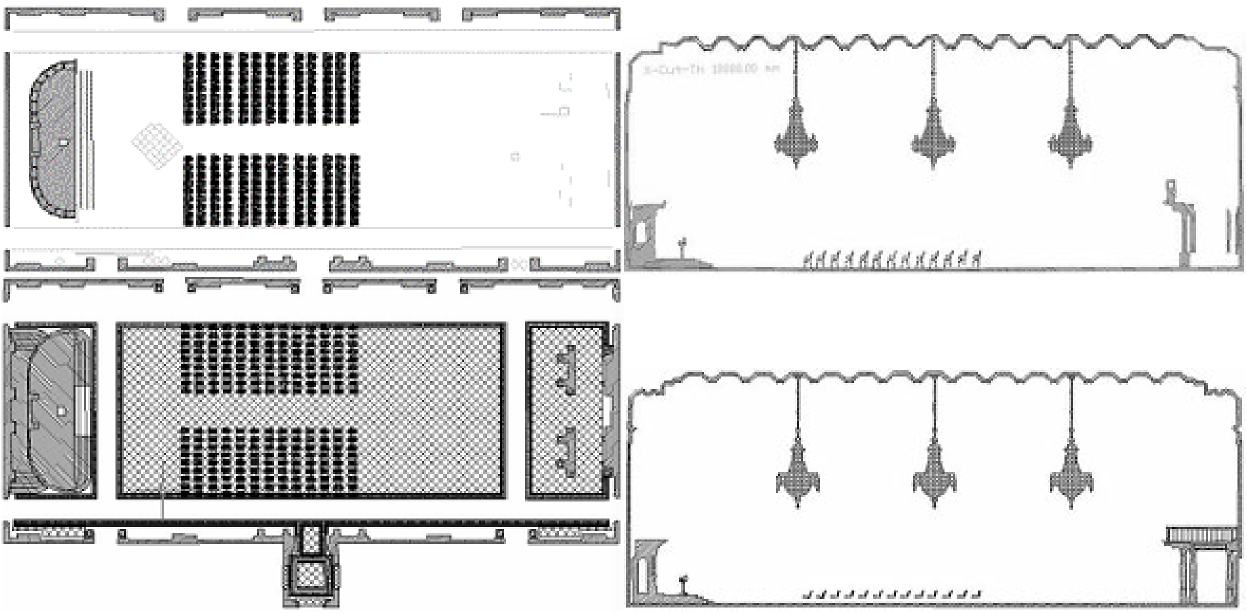

Fig. 7: Level of detail of 2D plans (ground plan and cutting) of Großer Festsaal derived from data of the GS100 (top) and IMAGER 5003 (bottom)

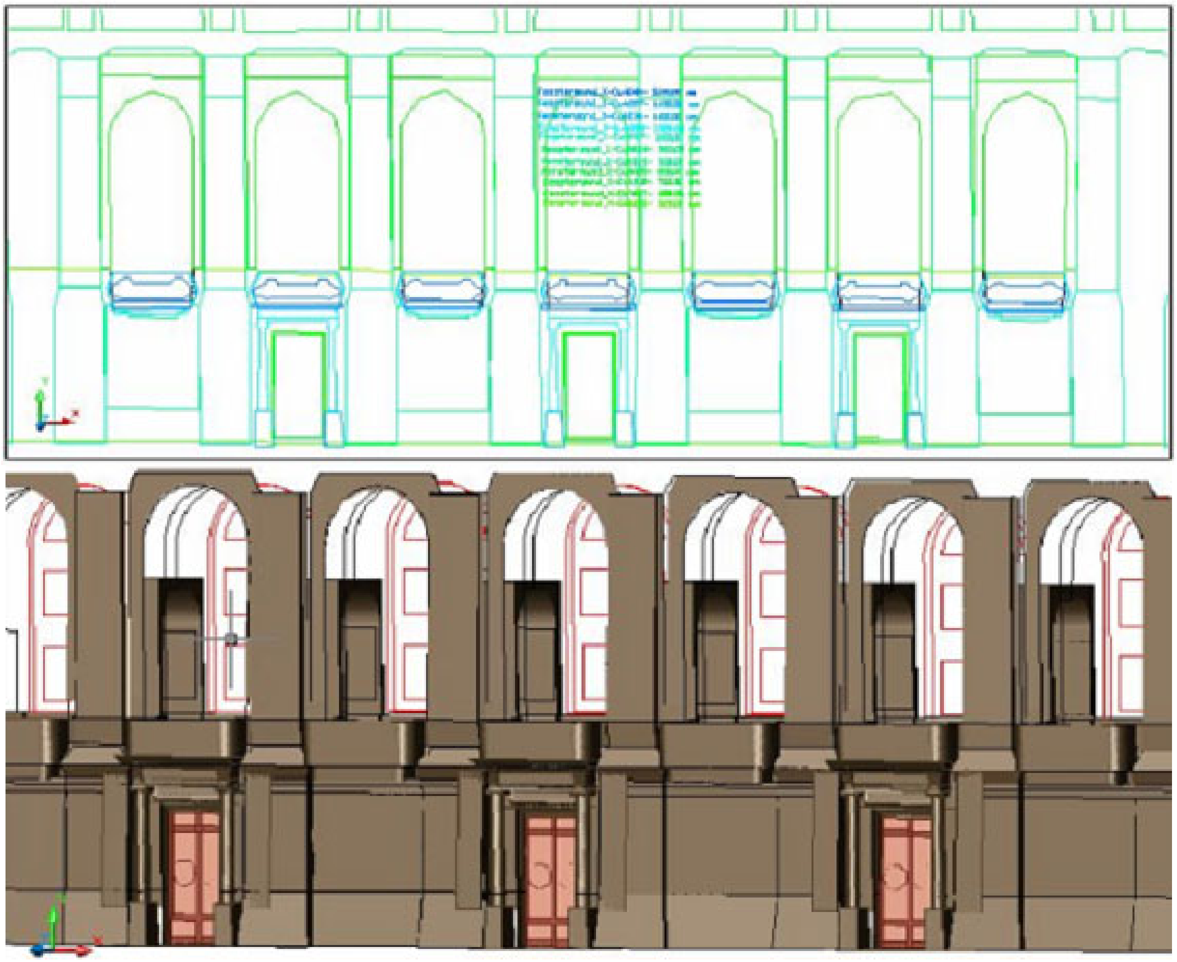

Fig. 8: Construction of one facade of Großer Festsaal: 2D plan derived from Real Works Survey (top) and 3D model derived from LFM Server and AutoCAD (bottom)

5. COMPARISON OF THE LASER SCANNING SYSTEMS

The processing time of all the substantial work procedures of the two projects Kaisersaal and Großer Festsaal are summarized in Table 4 for Mensi GS100 and IMAGER 5003.

It showed up in this project, that the expenditure of time for data acquisition in relation to the data evaluation diverges widely by a ratio of 1: 30. While scanning in the City Hall and the subsequent data preparation (registration/geo-referencing, etc.) is highly automated, much manual work is necessary for the production of 2D cuttings, sketches and 3D models. Due to the higher point density and number of scanning stations (which yielded significant covering) a faster evaluation could be accomplished with the data of the IMAGER 5003. Therefore, the project processing time with the IMAGER is around 15% (two working days) more efficient than with the GS100 (see Table 4).

The use of the two laser scanning systems (hardware and software) was evaluated in comparison after the processing of each project on the basis of different evaluation criteria. The evaluation criteria for the review are specified in Table 5, whereby for each criterion a weighting and a marking were assigned in the form of points (1 = negative, 2 = average and 3 = good). The provided catalogue of criteria is thereby designed to also consider the requirements for recording and data post

Work procedures/Processing time [h]	Mensi GS100	IMAGER 5003
Scanning	3,2	2,6
3D network adjustment	4,0	4,0
Registration/Geo-referencing	2,0	2,0
Data preparation, data conversion	0,5	2,0
Generation of 2D cuttings	44,5	39,0
Generation of 2D plan/3D model	53,0	41,5
Total Time [h]	**107,2**	**91,1**

Table 4: Processing time per work procedure using Mensi GS100 and IMAGER 5003

Assessment criteria/Review	Weighting [%]	Mensi GS100	IMAGER 5003
Field of view of the scanning system	10	2	3
Scanning distance (range)	10	3	2
Scanning speed	10	1	3
Number of scanned points	10	2	3
Volume of data	5	3	2
Flexibility of the systems in inner rooms	5	2	3
Registration/Geo-referencing	5	3	2
Automation in the data post processing	30	1	1
Accuracy	5	2	2
Results/Products	10	2	2
Number of points in total	100	180	205
Meaning of assessment points: 1.....negative, 2.....average, 3.....good			

Table 5: Evaluation criteria for the use of both systems Mensi GS100 and IMAGER 5003

processing of historical inner rooms.

Primarily the level of automation in the data post processing of point clouds with both systems and the scanning speed of the Mensi GS100 are evaluated negatively. All other criteria are judged either with average or good. All in all the IMAGER 5003 is judged better with 205 points, as compared to 180 points for the GS100, for the processing of projects due to its better performance in the scanning of the interiors.

6. CONCLUSION AND OUTLOOK

The two used terrestrial laser scanning systems worked satisfactorily during the data acquisition in the City Hall of Hamburg and during the evaluation of the point clouds for indoor cultural heritage application. Despite the less than ideal conditions during the scanning phase good results could be obtained in form of 2D cuttings, sketches and a 3D model with both systems. Nevertheless, it could be indicated, that the large volume of data of the IMAGER 5003 caused more effort for the data preparation than the GS100 point clouds, but due to the higher point density and minor shading the point cloud of the IMAGER could be evaluated in substantially more detail. The data acquisition is quite simple with both scanners, but the evaluation of the point clouds is very complex and time-consuming (up to a factor of 30 for scanning and evaluation). Thus, it is very important to take both hardware and software of a laser scanning system in consideration for forthcoming applications. Consequently, there is no scanner for all applications, but rather for each application one specific scanner. In this project the IMAGER 5003 proved to be more flexible and more suitable since the point density and the many scanning stations made a better evaluation possible within a shorter processing time than with the GS100. Generally, 3D laser scanning is an innovative technology, whose use offers a high potential in the care of monuments.

In the future increased automation in data post processing will be necessary to achieve increased acceptance of this technology in the market. Additionally, the system will become faster, more precise, more convenient and, hopefully also, less expensive. A data fusion of digital high resolution cameras with 3D point clouds seems to represent a consequent improvement of the systems for visualization and interpretation tasks.

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