Presented paper at the XXth ISPRS Congress, Istanbul, July 2004, *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXV, Commission V, Part B2, pp. 126-132.*

3D ACQUISITION, MODELLING AND VISUALIZATION OF NORTH GERMAN CASTLES BY DIGITAL ARCHITECTURAL PHOTOGRAMMETRY

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ISPRS WG V/2 Scene Modelling and Virtual Reality

KEY WORDS: Architecture, CAD, Cultural Heritage, Digital, Modelling, Photogrammetry, Virtual Reality, Visualization

ABSTRACT:

In order to create virtual realities, three-dimensional scenes must be generated digitally. Frequently such scenes are freely invented in computer games and have little or nothing to do with reality. The Department of Geomatics of the Hamburg University of Applied Sciences (HAW Hamburg) records historical buildings and castles for detailed virtual reality applications, which can be used in visualizations, simulation and planning for tourism, navigation, facility management, architecture, cultural heritage and city planning. A condition of such modelling and visualization is a complete 3D acquisition of the objects, e.g. with geodetic measuring techniques, terrestrial laser scanners or with digital architectural photogrammetry.

Three north German castles in Celle (Lower Saxony), Ahrensburg and Glücksburg (both in Schleswig-Holstein) were recorded photogrammetrically using a digital SLR Camera (Fujifilm FinePix S1 Pro) and later modelled and visualized. The data processing steps from data recording, determination of photo orientation, camera calibration and CAD modelling to visualization are described in the paper. The results of the photogrammetric 3D data acquisition and CAD object reconstruction are summarized and the visualization of the virtual castles is presented. Some economic aspects of the project work are finally discussed.

1. INTRODUCTION

Due to new developments in semi-conductor and sensor technology and due to increasingly economical and efficient computer performance, architectural photogrammetry has developed into a fully digital technology in the last years. Since the beginning of the 1990's digital cameras with resolutions that are comparable with film-based Medium Format cameras have been available. During the 1980's and the 1990's detailed facade drawings were still produced at a scale of 1:50 to 1:100 using photographs from film-based cameras and by analogue and analytical photogrammetry. These elevations were used by architects and for the preservation of historical monuments. However, today complete and detailed 3D object reconstruction is increasingly performed by methods of digital architectural photogrammetry. The demand for 3D building models has increased from new application fields: facility management; building information systems supporting among others operational planning of emergency services (fire-brigade, emergency doctors, police, etc.); for building security as well as for forwarding agencies and 3D city maps for tourism (as an internet application or on CD-ROM). Both, the accuracy and the level of detail required depend on the particular application.

2. RECORDED OBJECTS: HISTORICAL NORTH GERMAN CASTLES

In order to test the potential of the procedures and the digital technology of architectural photogrammetry at the Hamburg University of Applied Sciences, three north German castles in Celle (Lower Saxony), Ahrensburg and Glücksburg (both in Schleswig-Holstein) were photogrammetrically recorded and reconstructed in 3D in three diploma theses in the years 2001, 2002 and 2003.

The castle in Ahrensburg (see Fig. 1 left), which is located 20 kilometres east of Hamburg, was selected in April 2001 as the first object for photogrammetric recording. The water castle was built during the late Renaissance between 1580 and 1596. Since 1938 the castle has been used as a museum for the manor-house culture of Schleswig-Holstein exhibiting original furniture from the 18th and 19th century, painting and porcelains.

The 700 years old castle of Celle (Fig. 1 centre), which is located 50 kilometres north-east of Hanover, is a landmark of the city Celle and unites several architectural styles: the Renaissance and the Baroque as well as some Gothic elements. Today a museum and the oldest Baroque theatre of Europe are accommodated in the castle. In addition, the castle contains a castle chapel, which was consecrated in 1485. This is the only

Fig. 1: Front view of the water castle Ahrensburg (left), Celle castle (centre), and helicopter view of Glücksburg castle (right)

Camera	Digital SLR camera
Image sensor	23.3 x 15.6 mm Super-CCD chip
Pixel	3.4 Mio pixel (effective), 6 Mio. Pixel (int.)
Frame size	3040x2016, 2304x1536, 1440x960
Format	TIFF-RGB (ca. max. 17 MB/image)
Storage device	Microdrive 1GB (max. 58 photos)
Lens mount	All types of Nikkor lenses
Burst rate	approx. 1.5 frames/s, up to 5 frames
ISO sensitivity	ISO 320, 400, 800, 1600
Interface	USB, Video Out
Weight	ca. 820g (without batteries and lens)

Table 1. Technical specifications of the digital SLR camera Fujifilm FinePix S1 Pro

surviving early protestant court chapel in Germany and provides essential proof of the north German Renaissance.

Another major building in the style of Renaissance architecture in Schleswig-Holstein is the water castle of Glücksburg (Fig. 1 right), which is the centre of a park-like recovery landscape 10 kilometres east of the city of Flensburg close to the Danish-German border. The castle was built between 1583 and 1587 and is today maintained by a foundation as a museum and a cultural meetings venue.

3. DIGITAL SLR CAMERA FUJIFILM FINEPIX S1 PRO

The photogrammetric photographs of the north German castles were taken with the commercial digital single-lens reflex camera Fujifilm FinePix S1 Pro (see Tab. 1). Such a modern digital camera offers the possibility of photogrammetric recording of architectural buildings for preservation and restoration, for art-historical analysis and for documentation. It also facilitates the production of visualizations due to its high resolution and its ease to handle. The camera's chassis is based on an older version of a Nikon camera, the N60 SLR. However, in contrast to the film-based version the camera uses a Super-CCD chip with a focal plane of 23.3mm x 15.6mm, which corresponds to an effective resolution of 3.4 million pixels and an interpolated resolution of 6 million pixels. The used storage device, the Type II card IBM Microdrive (1 Gbyte) is able to store up to 58 colour photos (18 MB each) with full resolution in TIFF format. The relatively light and handy camera can be used with all commercial Nikkor lenses. For these projects three different lenses were used: 18mm (Celle), 28mm (Ahrensburg) and 80mm (Glücksburg).

4. PHOTOGRAMMETRIC IMAGE ACQUISITION AND DATA PROCESSING

4.1 Photogrammetric Image Acquisition

For the 3D evaluation and reconstruction of the three castles images were taken at an approximate photo scale of 1:1000 using the hand-held Fuji S1 from different positions (Fig. 2): ground positions (Ahrensburg, Celle, Glücksburg), mobile lifting platform with maximum work height of 18m (Celle), helicopter and boat (Glücksburg). The objects were recorded photogrammetrically by multi image triangulation mode, i.e. images were taken around the objects and for the Celle castle also in the courtyard. As an example Fig. 2 right shows the 37 photo positions at Ahrensburg castle for the base (green) and for the wall and roof areas (red). The photogrammetric image recording also contained photographs that were tilted and rotated in different camera positions to guarantee a reliable simultaneous calibration of the camera and the lens at a later stage. To ensure stable interior orientation parameters of the camera during the image acquisition phase, auto focus was switched off, the lens was focussed infinitely and a fixed aperture was used to obtain an appropriate exposure time.

Varying numbers of photos were taken from different camera positions around each castle (Ahrensburg 58, Celle 274, Glücksburg 374). However, not all acquired photos were used for the three-dimensional evaluation. All digital images were stored on the internal 1 GB IBM Microdrive of the camera. The image data were transferred to a notebook by connecting the Microdrive to a PCMCIA card adapter. The data transfer took approximately 20 minutes per Gbyte.

Signalised control points were placed on the objects for the

Fig. 2: Platforms for photogrammetric castle recording, helicopter (left) and mobile lift (centre), configuration of the camera positions at Ahrensburg castle (right)

determination of the orientation of each used photo. The approx. 10cm large signals (see Fig. 3) were self constructed and printed on white paper. Each castle was supplied with several targets (Ahrensburg 22, Celle 47, Glücksburg 28), which were well distributed over the object and fixed mainly on windows.

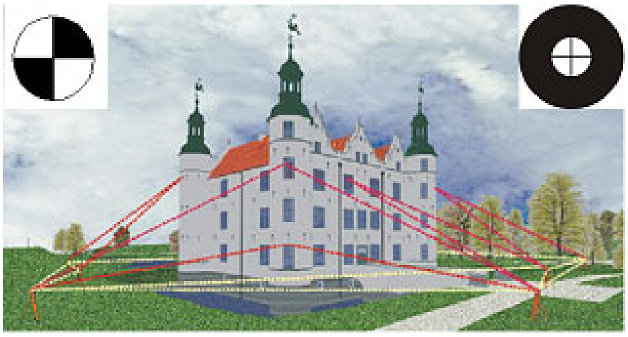

Fig. 3: Geodetic control point determination and signalisation of control points (upper left and right corner)

For the determination of the coordinates of the signalised control points a local geodetic 3D network (see Fig. 3) was designed and measured with a Leica total station. All control points were measured in the geodetic network. The coordinates of the control points were determined in a geodetic 3D network adjustment using the software PANDA from GeoTec, Laatzen, Germany. At Ahrensburg castle 10 natural points, clearly identified and well distributed over the four facades, were measured as additional control points. A standard deviation of better than 5mm was achieved for the coordinates of all control points.

4.2 Photogrammetric Data Processing

The determination of the orientations of each photo was performed by multi image triangulation. To connect all photos in an overall triangulation photo block, all control points and selected natural tie points were measured manually in the digital images. 37 images of block Ahrensburg, 254 images of block Celle and 188 images of block Glücksburg were used for photo triangulation. In Fig. 4 the image point measurements for tie and control points are illustrated exemplarily using the software PICTRAN D (Release 3 and 4) from Technet GmbH, Berlin, Germany.

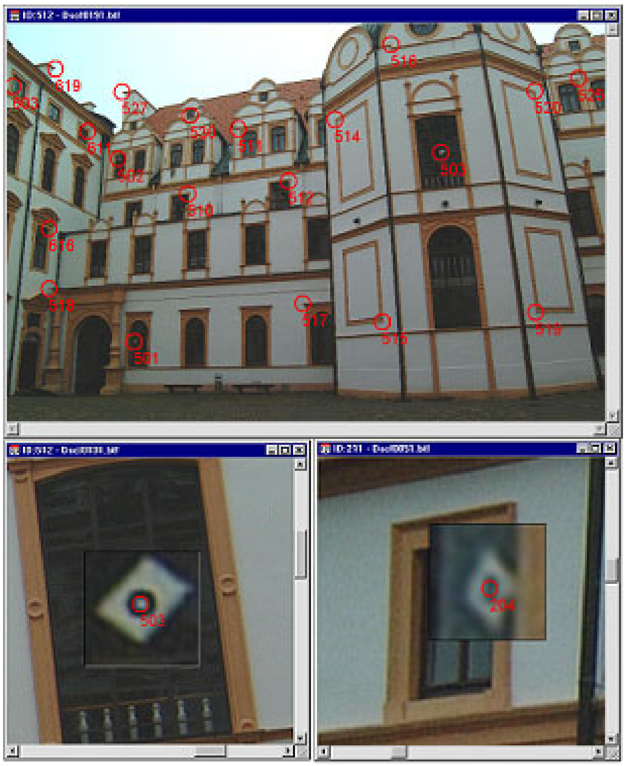

Fig. 4: Image point measurements of tie points (upper) and control points (lower) in one image of Celle castle

In all three photo triangulation blocks more than 10 well-distributed points per image were measured in order to model the lens distortion as one of the camera calibration parameters by bundle block adjustment. This also guaranteed a well-controlled connection of all images in the block. The digital SLR camera Fuji S1 is a non-metric camera; therefore the interior orientation parameters must be determined in a bundle block adjustment, which could be performed simultaneously in PICTRAN B with the determination of the photo orientation parameters. The interior orientation parameters include the location of the principle point, the camera constant, the radial distortion, the decentering distortion, the shear and the affinity parameters. The results of the bundle block adjustment for each castle project are summarized in table 2. The σ_0 of each project was 4.5micron or even better, which is correspondent to approx. half a pixel in image space. The RMS of the control points in XYZ was better than 5mm for each project; while for Ahrensburg and Celle the RMS was better than 2mm. Each triangulation block was sufficiently fixed using a large number

Castle	# Ph	# CP	# OP	# IP	# Rays per pt	# IP/ Ph	σ_0 [µm]	RMS CP XYZ [mm]	# ChP	empirical accuracy			maximum values		
										μ_X [mm]	μ_Y [mm]	μ_Z [mm]	μ_X [mm]	μ_Y [mm]	μ_Z [mm]
Ahrensburg	37	22	155	780	5	21	2.8	1.6							
Celle	254	47	247	3530	14	14	4.1	1.6	27	4.8	2.7	2.4	15.6	8.0	7.8
Glücksburg	188	28	543	4793	9	25	4.5	4.6							

Ph .... Number of photos
CP............ Number of control points
OP............ Number of object points
IP .... Number of image points
σ_0 .... Sigma aposteriori from the adjustment
RMS .... Root Mean Square of the control points
ChP .... Number of check points

Table 2. Results of the bundle block adiustment

of image point measurements (minimum 14 points per image in the average) and each object point was measured in at least 5 images on average guaranteeing high reliability in the overall connection of the images. As an example, the empirical accuracy of the signalised points (comparison of photogrammetrically and geodetically determined points) in project Celle is summarized in table 2. The accuracy was better than 5mm on average, while the maximum value was 16mm. Such results are more than sufficient for 3D building reconstruction. However, it is not assumed that the same results could be achieved with poorly-defined object points as would be usual for historical buildings.

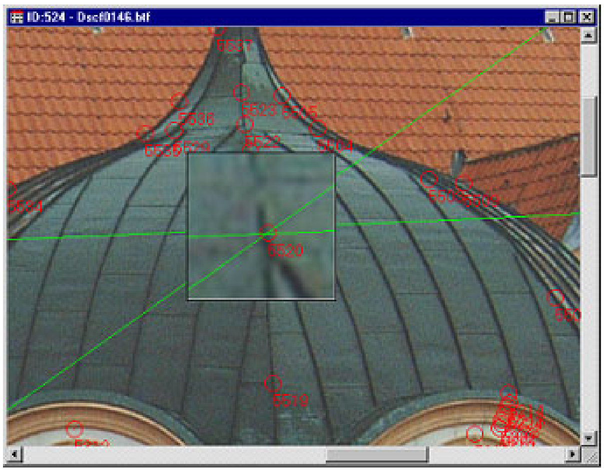

Fig. 5: Manual image point measurements supported by epipolar lines for improved point finding in PICTRAN D

After the update of the camera file using the adjusted calibration parameters and the exterior orientation parameters, the 3D evaluation could be conducted by digitisation (manual image point measurement) of all necessary points for the reconstruction of the building. For reasons of reliability all points were measured in at least three different images, which were acquired from different positions to ensure optimal intersection geometry. All manual measurements were performed in PICTRAN D as points, lines or polygons. The superimposition of the epipolar lines in the images after measurement of each point (Fig. 5) offers significant support to the operator in finding the points quickly and in avoiding point mistakes. The 3D point coordinates of each measured point were determined by spatial intersection and the standard deviation of each point was shown in the user interface for online quality control. Similar parts of the buildings, e.g. windows, were measured only once in detail, while for all varied details the position of this building part was measured using only three points for the later fitting in the constructed model. Due to the complexity of historical buildings some parts of the building, e.g. bent walls or ornate entrance doors (Fig. 6) were generalized.

The digitised 3D points were then transferred for further CAD processing to AutoCAD via the DXF interface. As a strategy the entire building was divided into certain object parts, which were measured in PICTRAN and transferred afterwards to AutoCAD for reconstruction.

5. CAD RECONSTRUCTION AND VISUALIZATION

5.1 CAD reconstruction of the castles

The detailed 3D reconstruction of all three castles in their entirety was performed stepwise in AutoCAD: i.e. each building was constructed in the following sequence: ground plan, walls, towers, roofs, windows, entrances (doors), and finally the assembling of all objects to one complete volume model. Additionally, the immediate terrain environs of each castle, which were measured by geodetic methods, were modelled with AutoCAD Land Development as a digital elevation model (DEM). The corresponding DEM was later integrated into the entire virtual 3D model of the castle to produce a better visualization of the adjacent site. The result of the construction is a 3D volume model of each castle. Fig. 7 shows a wire frame and rendered model of Celle castle. All information in the 3D AutoCAD file is structured in layers; i.e. the same type of object, e.g. walls, windows, frames or glasses, etc., was saved in a special defined layer. The 3D model of Ahrensburg consists of 78 different layers, while the CAD file of Celle and Glücksburg consists of 114 and 39 different layers, respectively.

Some perspective scenes from different viewing positions were computed in AutoCAD for each castle, in order to check the quality of the 3D model by rendering the volume model. The DWG file size (AutoCAD 2002) of the 3D models amounted to 243 Mbyte for Ahrensburg, 260 Mbyte for Celle, and 71 MB for Glücksburg. Using the new software release AutoCAD 2004, the file size can be significantly reduced by a factor of three to five. Nevertheless, this amount of data caused problems for the visualization due to the computer performance of a typical workstation (two parallel processors of 2.4 GHz, an internal 1 GB RAM, and a fast graphic card nVidia Quadro4 700 XGL), compared to the file sizes. The computation of one perspective scene with 3D Studio VIZ took approx. 15 minutes,

Fig. 6: Measurement, reconstruction and rendering of a window of Celle castle (from left to right), ornate doorway as a photo and as a generalized reconstructed doorway (right)

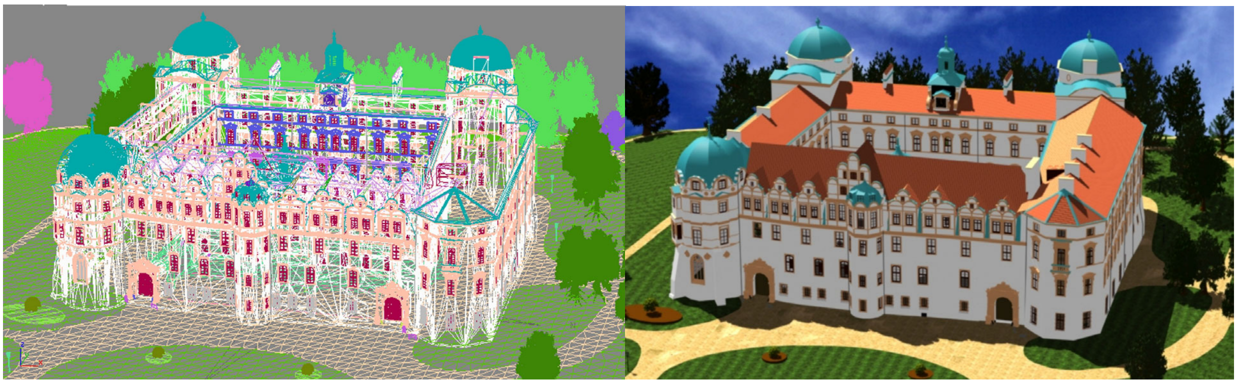

Fig. 7: Volume model illustrated as a wire frame (left) and as a rendered visualization (right) of Celle castle

depending on the amount of features.

AutoCAD offers the functionality for file export to several visualization software packages, e.g. 3D Studio VIZ/MAX. The 3D volume models were transferred to 3D Studio VIZ using the file format 3ds. Unfortunately, pre-defined texture mapping from AutoCAD cannot be supported by 3D Studio. The data export from AutoCAD to 3ds files must be carried out in several steps due to the complexity of the volume models. This characteristic effects that new layers have to be created with a reduced number of 3D objects and /or 3D areas in order to manage the complete data transfer. Thus, for each new layer one new 3ds file is generated.

5.2 Visualization of the castles

Although the generation of perspective scenes of the 3D models is possible with AutoCAD including texture mapping, the major work for visualization of the three virtual 3D models was performed in 3D Studio VIZ (release 3i), a light version of 3D Studio Max. For photo-realistic visualization of the three castles several video sequences and perspective scenes were generated. As an example one perspective scene of each castle is illustrated in Fig. 9. The following processing steps have to be performed in 3D Studio VIZ to achieve such results: a) import and merging of all 3ds files; b) grouping of objects regarding the later texture mapping; c) definition of materials including import of the related texture files; d) manual texture mapping for all objects, specially regarding the inclination and rotation of each object element; e) illumination (e.g. sunlight) of the 3D models; f) definition of special effects (e.g. radiosity, atmospheric weather); g) definition of the camera and its path for the video sequence; h) preview and final generation of a video sequence.

The production of video sequences requires necessarily high computer performance. For example, the computation of the first video sequence of one minute (AVI format) for Ahrensburg castle, which consisted only of the building (28MB 3D Studio file), in the resolution of 800 x 600 pixels took approx. 22 hours processing time on a standard PC from the year 2002 (PIII, 800 MHz, 256 MB RAM). In total 1800 frames (30 frames/s) were generated, which corresponds to a processing time of 1.3 minutes per frame on average. The generated file size is 71MB. In comparison, processing took 7.7 minutes per frame (800 x 600 pixel) on average for a 3D Studio VIZ file of 410MB, which includes the castle of Ahrensburg and the park with photo-realistic texture mapping for the building, the trees and the immediate terrain environs. Therefore, the processing time was 102 hours in total on the PC mentioned in chapter 5.1 for a video sequence of 60 seconds (AVI 196 MB).

6. ECONOMICAL ASPECTS

Although it is fascinating to look at the projects from the technical and realisation point of view, it is absolutely necessary to analyse the projects from an economic perspective. Therefore, the total processing time needed for the project Celle was approx. 1350 hours, which corresponds to €54,000 in total (calculated with an average wage of hour of €40). For the analysis of the project the whole workflow was divided in several working steps and the processing time needed was estimated. The results are presented in Fig. 8 as a percentage of each processing step. It could clearly be shown, that more than 65% of the time needed was used for the time-consuming CAD reconstruction and visualization, while the geodetic and photogrammetric project work amounts to just 35%. In this estimation only the visualization with AutoCAD is included. This result presented here can be confirmed by the analysis of similar projects conducted at the HAW Hamburg.

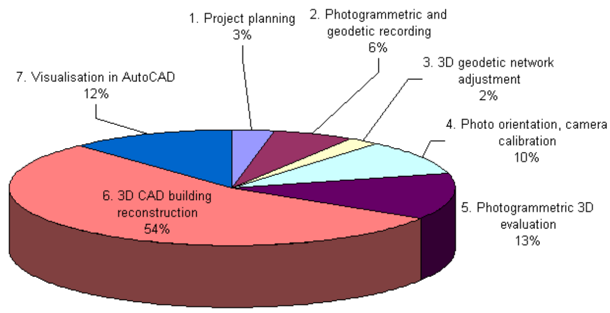

Fig. 8: Estimated time needed to complete project Celle castle

7. CONCLUSIONS AND FUTURE

These three projects demonstrate that commercial digital SLR cameras are suitable for a detailed 3D evaluation and reconstruction of large complex historical buildings. Due to the digital data flow architectural photogrammetry has now become an efficient alternative to the classical building measurement and reconstruction methods. In each project an accuracy was achieved in the range of 1-2 centimetres, which is sufficient for most building applications. However, an important condition for such accuracies is the on-the-job calibration of the non-metric camera, which can be performed simultaneously with the determination of the photo orientation in the bundle block adjustment. The detailed project processing of the Celle castle is described in Kersten et al. 2003, while the project of Ahrensburg castle is summarized in Kersten & Acevedo Pardo 2003. Additionally, further projects of some manor houses in the area of Hamburg, e.g. Landdrostei Pinneberg, Jenisch house and Gossler house in Hamburg, could demonstrate the high potential of digital architectural photogrammetry for exact and detailed 3D building reconstruction (Kersten & Acevedo Pardo, 2002). Such projects are also suitable for the education of Geomatics students, where a complete project can be conducted as a practical course or as a diploma thesis including some further investigations and testing.

The major time-consuming and cost-intensive factors for such projects are the manual 3D building reconstruction in CAD and the degree of visualization, which could easily result in a never-ending-story - if the requirements are not well defined. The estimated costs of the presented projects are obviously much too expensive for use purely in Internet visualization of the castles. Therefore, it is essential to find synergy effects with other interested applications to finance such projects. On the other hand, automatic methods for detailed generation of virtual castles or historical buildings are not available on the market. In future the terrestrial 3D laser scanning could offer automatic acquisition and evaluation methods in combination with digital photogrammetry.

Due to the modern and efficient methods of detailed 3D building reconstruction and the appropriate possibilities for their visualization, especially on the Internet, the interest in the collection of virtual historical buildings will increase. Today a combination of internal and external 3D building modelling can allow virtual fly- and/or walk-throughs (e.g. VRML) in historical buildings.

8. REFERENCES

Kersten, Th. & Acevedo Pardo, C., 2002: *3D-Objektaufnahme von historischen Gebäuden durch digitale Architekturphotogrammetrie für Visualisierungsaufgaben und Facility Management.* Photogrammetrie und Laserscanning: Anwendung für As-Built-Dokumentation und Facility Management, Th. Luhmann (Ed.), Wichmann Verlag, Heidelberg, pp. 42-56.

Kersten, Th. & Acevedo Pardo, C., 2003: *Wie kommt das Ahrensburger Schloss in den Computer? 3D-Gebäudeerfassung und Visualisierung durch digitale Photogrammetrie.* DenkMal! Schleswig-Holstein, Zeitschrift für Denkmalpflege in Schleswig-Holstein, Jahrgang 10, Westholsteinische Verlagsanstalt Boyens & Co., Heide.

Kersten, Th., Eilmus, B., Lindstaedt, M., Acevedo Pardo, C., 2003. *3D-Erfassung und Visualisierung des Celler Schlosses durch digitale Architekturphotogrammetrie.* Photogrammetrie, Laserscanning, Optische 3D-Messtechnik - Proceedings of Oldenburger 3D-Tage 2003, Th. Luhmann (Ed.), Wichmann Verlag, Heidelberg, pp. 213-222.

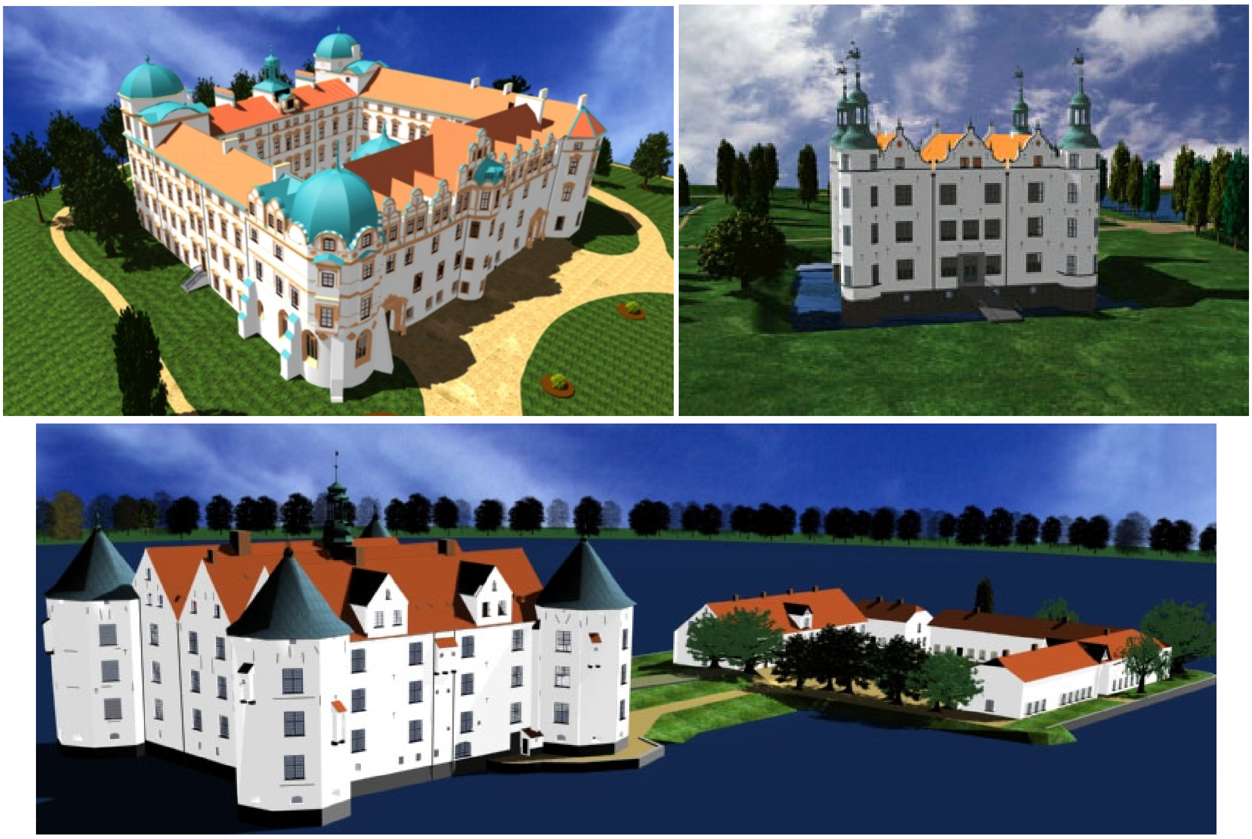

Fig. 9: Perspective visualization in 3D Studio VIZ of the three north German castles: Celle (upper left), Ahrensburg (upper right), and Glücksburg (below)