COMBINATION OF TERRESTRIAL RECORDING TECHNIQUES FOR 3D OBJECT MODELLING REGARDING TOPOGRAPHIC CONSTRAINTS.
EXAMPLE OF THE CASTLE OF HAUT-ANDLAU, ALSACE, FRANCE

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ABSTRACT:

Perched on a granite rock, the Castle of Haut-Andlau is surrounded by forests and ditches which make its access difficult. Only after the first crumbling, the Lord of Andlau worried about its durability and conservation. Since only poor documentation about the castle exists, a complete surveying of the castle was demanded. The problematic became a true challenge, regarding the constraints implied on the one hand by the steep and abrupt terrain surrounding the castle and on the other hand by the dense and broadening vegetation in the immediate vicinity of the castle. In this context, two universities shared their experiences and instruments: the Institute of Photogrammetry and Remote Sensing (Universität Karlsruhe (TH), Germany) and the MAP-PAGE team (INSA de Strasbourg, France). It became rapidly obvious that a unique technique would not overcome the vegetation and relief obstacles. That's why several recording techniques have been investigated. A quality assessment lead to the analysis of the models derived from each technique and to a crucial experience for further campaigns. Therefore, recommendations for an efficient acquisition planning and data processing are gathered. These solutions will help the castle owner to establish the framework of restoration tasks, by showing the destroyed historical structures. Moreover, they will help us to convince the department council to extend these first conclusions to the documentation of numerous other castles of the same type and therefore to insure the future of the Alsatian medieval patrimony.

1. INTRODUCTION

As the main centre for the Grands Crus of Alsace, the town Andlau is - among others - famous for its remarkable architectural heritage. Especially, the castle of Haut-Andlau from the XIIIth century is of particular interest since its architecture, at first sight simple, proves to be the result of different construction styles completed over the centuries.

The Castle of Haut-Andlau, characterized by its two towers, dominates the valley of the Kirneck River and Barr to the north, and the valley of the Andlau River to the south. The early Castle, which had no courtyard, was built by the lords of Andlau between 1337 and 1344. The main facade of the long seigniorial dwelling shows large pointed arch windows. Although it has been classified as a historic monument in 1926, the castle is relatively unknown. Indeed, only hikers cross the castle by chance, on their way, although it is widely visible from the Rhine valley. Therefore, events of artistic nature like illuminations or expositions are regularly organized in order to make the castle more popular. Like other castles of that century, the Haut-Andlau castle was built on the top of a rocky hill for defensive purposes and had to make the most of readily available natural protective settings like hilltops and ridges. It is stretched at least 30 meters along this granite rock surrounded by dense forest (Fig. 1).

As the crumbling of a part of enclosing walls occurred, the Lord of the castle decided to start a restoration of the courtyard and the towers of the castle with support of the department council. In that context, it has been noticed that no maps or plans of the castle and its surrounding exist; only documents like drawings or engravings between the XIIIth and the XVIIth century give an insight into the former building structures.
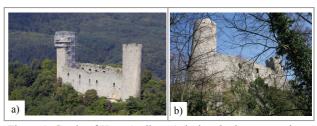

Figure 1. Castle of Haut-Andlau; a) during donjon restoration; b) topographic and vegetation constraints

The aim of the presented work is multiple. Firstly, the produced data must enable the record and documentation of the site for different applications, like documentation of cultural heritage, support of conservation and restoration activities of the medieval fortress. Additionally, the task is to produce 2D and 3D data sets as a base for forthcoming landscape planning. Indeed, the clearing of some trees at strategic points of view in the surrounded forest will consequently optimize the visibility of the castle for hikers. Moreover, such data sets are welcome for the planning of future exhibitions. As a consequence, these elements also contribute to the popularity of the site and thus will automatically increase the tourist attraction.

Nowadays, the greatest difficulty consists in setting up an appropriate methodology for the whole recording and 3D modelling of such a medieval castle. One main problem is to find a sufficient number of suitable positions in the mountainous topography to capture photogrammetric images or

laser scans. On the other hand the possible field of view is restricted by obstacles like vegetation and trees. Additionally data acquisition is restricted by limited space and a considerable complexity and elevation of the architectural elements. Therefore, in this context not only one method for data acquisition is required for 3D reconstruction but a combination of multiple recording techniques.

2. RELATED WORK

3D data acquisition as well as 3D modelling of architectural objects can be performed by different approaches, like analyses of existing plans or maps, surveying, laser scanning, photogrammetry or computer vision methods (Gonzo *et al*., 2004). Especially at a medieval fortress it is a particularly challenging task, since commonly used assumptions made on standard architecture are not applicable, like parallelism, perpendicularity or symmetry. In this context a lot of authors use image based methods (e.g. Hanke and Oberschneider, 2002; Mayer *et al.* 2003; Daskalopoulos *et al*., 2003; Mayer *et al.* 2004; Kersten *et al.* 2004), partly added by other methods like surveying or use of existing plans (e.g. Georgopoulos and Modatsos, 2002; Gonzo *et al*. 2004; El-Hakim *et al*., 2005). The reasons for using mainly image data are the high degree of details, economic aspects, portability, handling in spatial limited environment and a short data collection time. The disadvantage of image analyses is that the captured objects must have a significant texture which may be a problem especially at indoor scenes. This can be avoided by applying an active sensor system like terrestrial laser scanners.

Several authors presented projects where laser scanners are used for recording of cultural heritage sites (e.g. Allen *et al*., 2003). Laser scanners are advantageous regarding areal data acquisition but not optimal for capturing edges and corner points. Furthermore laser scanning produces a large amount of data which cannot be handled without simplifications. Therefore, laser scanning will be often combined with photogrammetry which delivers contour lines completed by the details from scan data (e.g. Fuchs et al., 2004, Georgopoulos and Modatsos, 2002; Borg and Cannataci, 2002). Due to the exposed location on hilltops or ridges it is often necessary to record medieval castles (partially) from airborne platforms (e.g. Mayer *et al*., 2003; Gonzo *et al*., 2004). Therefore, in most cases a combination of the above mentioned methods regarding the particular advantages may be the best solution (e.g. El-Hakim *et al*., 2005).

Due to the complex structures of medieval castles the recording of such sites results in a huge amount of data. Therefore, automation is an important aspect not only from the economic point of view. Classical photogrammetry with a huge amount of manual interaction has proved to be very time consuming (e.g. Hanke and Oberschneider, 2002; Kersten *et al.* 2004, Grussenmeyer and Yasmine, 2003). A similar situation can be observed concerning laser scanning, where the degree of automation seems to be not too high at the moment. Due to the complexity of such historical sites some authors have developed semi-automatic approaches where limited interaction is needed to define basic relations and the main data processing works automatically (e.g. El-Hakim *et al*., 2005). Mayer *et al.* (2004) proposed a fully automatic approach for model generation based on computer vision techniques, but intended for completion of some smaller details and not applicable for the whole castle.

3. RECORDING TECHNIQUES

Due to the necessity to combine different data acquisition methods for medieval buildings (cf. section 2), three techniques have been used for the recording of the castle: geodetic surveying, photogrammetric and laser scanning techniques.

3.1. Conventional surveying technique

A network of almost 40 geodetic 3D-points has already been measured through conventional surveying methods in the close surroundings of the castle. This network constitutes a support of major importance for the geo-referencing of the surveys presented below. The instrument used for creating the network was a servo-driven total station 5500 (Trimble). It is able to work reflectorless thanks to the long-range direct reflex system option (DR 200+ EDM). Performance specifications are summarized in Table 1.

Technical specifications (total station 5500 Trimble)	
Angle measurement	3" (1.0 mgon)
Distance measurement	+/- 2mm+2ppm (prism)
	+/- 3mm + 3 ppm (reflectorless)

Table 1: Technical specifications of the total station 5500 used

Furthermore, measurement of control points, main ridges and windows of the castle facades have been carried out. The control points are useful for further photogrammetric processing and the ridges and window contours for undertake modelling and accuracy assessment. Measurements with telemeter were only performed between scan stations and laser targets.

3.2. Laser scanning technique

Laser scanning is increasingly being used for large site recording and allows providing directly a realistic representation of any shape.

The terrestrial laser scanner used in this study is the Trimble GX, which technical specifications are reported in Table 2. The scanner uses an auto-focus method for the laser, guarantying a constant small laser spot even at different distances within a scan. In addition, the built-in video camera is useful for framing the area of interest as well as for colouring the point cloud. The workflow proposed with the GX scanner is close to the traditional total station survey workflow (Lemmon and Biddiscombe, 2006; Hanke *et al.*, 2006).

Technical specifications (Trimble GX scanner)	
Wavelength	532 nm (class II)
Field of view	360° around the vertical; +38° to -22° around the horizon
Distance accuracy	7 mm at 100 m (overscan mode : up to 350m)
Position accuracy	12 mm at 100 m
Angular accuracy	60 µrad (horizontal plane) 70 µrad (vertical plane)
Grid Resolution over 360°	3 mm at 100 m with no restriction on number of points in a scan
Spot size (with auto-focus)	3 mm at 50 m (0.3 mm at 5 m up to 1.5 mm at 25 m)
Speed	up to 5000 points per second

Table 2. Technical specifications of Trimble GX laser scanner.

Major limitation of that scanner is its field of view. Indeed, when the scanner is levelled and used in the surveying mode, objects with high elevation are difficult to record (asymmetrical vertical part of 38° above and 22° below the horizon).

3.3. Photogrammetric technique

Several image acquisition devices were used. Their technical specifications are reported in Table 3. The Zeiss SMK is an analogous stereo camera where both images can be captured simultaneously. With its large aperture angle the SMK is predestined for recording of architectural objects. The digital Canon EOS 5D camera has previously been calibrated.

	Zeiss SMK 120	Canon EOS 5D
Number of pixels	analogue	4368 x 2912 pixels
Sensor format	90 mm x 120 mm	24 mm x 36 mm
Focal length	60 mm	28mm - 85mm
Image data	analogue	About 8 MB compressed data (jpg)

Table 3: Specifications of the camera used for the project

The authors tried to apply the recommendations of the CIPA 3x3 rules for the planning of the photogrammetric survey.

4. DATA ACQUISITION AND 3D RECONSTRUCTION

4.1. Surveying data and model

Data acquired by tacheometry are a sample of single points. Points have been measured on the facade, especially around the windows. Only one station was used for the surveying of the eastern side, since the already growing vegetation around the castle did not allow acquiring from another point of view.

In this context, only a light and skeleton plan representing the outlines of characteristic objects or contours (windows, doors, ridges, etc.) has been delivered at this stage.

4.2. Laser scanner data and model

Regarding the castle size, the surrounding relief, and vegetal occlusions, it was necessary to combine multiple scans. They have been taken from different points of view in order to cover the whole object surface.

In our experiment, the scanner has been set up over known points belonging to the 3D network. Simultaneously, the point clouds are automatically geo-referenced. Hence, the result can already be visualized in the field without additional post-processing. Also the quality and coverage of the survey data could be verified in the field, reducing survey time or further re-measurements. It was necessary to activate the auto-focus mode, because it guarantees a constant small laser spot even at different distances within a scan.

10 stations were occupied for acquiring the interior (main dwelling) and exterior of the castle. Among them, 6 were used for scanning the exterior facades of the castle (see Fig. 2-a). However, only 5 were exploitable. Firstly, the terrain slopes steeply away in particular in the south side of the castle. In this case, considering the limited field of view, the station chosen for scanning the southern donjon did not provide enough range to catch the upper part of the donjon. A solution for

circumventing this defect consists in deactivating the electronic level and to tilt the instrument. The point cloud must then be integrated to the rest of the acquisition by a consolidation technique, since it is not possible to calculate the exact location of the station in non levelling mode. Despite this idea, the dense vegetation surrounding the south sector prevents correct passage of the laser wave. Added to the homogeneous aspect of the donjon surface, the automatic consolidation of the clouds was not successful and no significant cloud could be reached on the southern part of the castle.
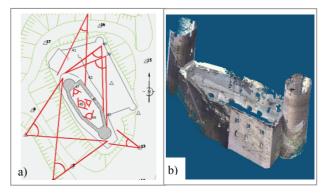

Figure 2. a) Field of view from the stations used for scanning the castle (in red); b) Result of multiple scan fusion

At last, the complete interior courtyard was successfully recorded from 4 stations on the ground. Again, the minimal range for acquiring the upper part of the donjon was not available. So an inclination of the laser was necessary and since no occluding object was present, the consolidation of that cloud with the geo-referenced ones was successful.

Concerning the spatial resolution, generally a grid of 1 point every 2 cm has been chosen along each scanned surface. This choice fulfils the requirements to keep the details of the facade without overcharging the data volume and computing time.

At this stage, the major part (about 80%) of the castle is covered by laser scanner data. After merging the 9 point clouds, an already realistic-looking representation is available. Fig 2-b presents the result of this fusion, where each point is coloured with the RGB value provided by the built-in video camera. A total amount of 12 million points has been registered.

For modelling the castle, a first segmentation erasing the surrounding elements (ground, vegetation, noise) is carried out. Since the aim of the study was to compare several techniques, the rate of automation was not a priority in the exploitation of the data. Thus, a manual digitizing has been performed on the segmented point cloud using Realworks software (Trimble) and provided a 3D wireframe model (see Fig. 4 and 5).

Another way to produce a more realistic 3D model is to interpolate the grid structure into a mesh structure. This can be done semi-automatically using commercial software like for instance 3D Reshaper (Technodigit). This computing tool analyses the point's layout and the shape they represent to keep only those that are strictly relevant according to an imposed tolerance. Then, the points kept are meshed to obtain a polyhedron with triangular facets. The accuracy of the result can be improved by eliminating incoherent points through filtering and smoothing. The mesh of the castle was built with a regular meshing, by introducing a space between points of 2 cm for coherency with the spatial resolution used. The best result

was reached by building a mesh in two steps. The first mesh is created based on a set of points and on a deviation error value. Then, the original point cloud is compared to the polyhedron. If necessary, in a second step, the meshing precision is improved by re-meshing with other points. At last, the holes appearing in some areas like the west facade can be filled more efficiently by selecting manually two borders which need to be connected. Then, a meshed bridge is built between them.

Fig. 3 shows the effect of vegetation masks on the final result. However this gives a useful indication about the trees which should be pruned or cut if the visibility of the castle has to be improved. Moreover, the critical lack of points on the upper part of the donjons as well as on the lower part on some facades (due to a surrounding wall and topographic constraints) affects the final model accuracy. This problem can easily be circumvented by integrating points provided by further photogrammetric restitution.
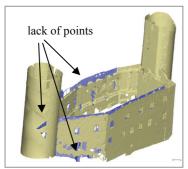

Figure 3. Meshed model affected by occlusions (lack of points)

Nevertheless, the rendering quality is not sufficient and must be improved by photogrammetric texturing.

4.3. Photogrammetric data and model

For completion of the laser scanner data at occluded building parts and for accuracy assessment, approx. 50 stereoscopic models have been captured. Out of these about 35 models were necessary for completion. With the remaining images the whole courtyard and the adjacent parts of the towers were recorded. Approx. 200 control points have been measured with an accuracy of about ± 5 mm by tacheometry for orientation of these photogrammetric models. As mentioned above, especially the lower parts of the facades which are occluded in the laser scanning data had been acquired by photogrammetric technique.

Additionally about 100 photographs have been taken with the digital camera Canon EOS. They were taken all around the castle, in order to cover the complete exterior facades and more particularly the donjons (stereo-pairs and multi-image mode as recommended by the 3x3 rules). These photographs will also be used for the final texture mapping of the castle.

For the 3D restitution, two techniques were used: traditional stereo-photogrammetry based on an analytical plotter, and multi-image photogrammetry with the PhotoModeler software. The best accuracy of approx. ± 5 to 6 mm was achieved by traditional technique, after relative and absolute orientation of the models by means of the control points. In a first step only significant contour lines were measured for comparison with the other techniques, as explained in the next section.

5. QUALITY ASSESSMENT

5.1. Geometric accuracy

The comparison of each model is based on the contour lines of 21 windows, digitized on each data set. Thus, an extensive calculation of 3D distances between each wireframe has been performed. The mean and standard deviation based on theses approx. 90 comparison points have been calculated and showed that the investigations must be related to the type of window. The results of these calculations are presented in Table 4.

5.1.1. Laser scanning model compared to surveying data: Globally, the results are satisfactory whatever the window type and both wireframe models coincide adequately in the facade plane (see Fig. 4). Nevertheless it can be observed, that the 3D distances separating the models are larger for windows with semi-circular or ogival arch (especially for the few geminate windows) than for rectangular reveal windows. The main reason is the difficulty to measure the circular and chamfered parts of that kind of windows by tacheometry. Moreover, the laser scanning enables to acquire each little detail, like for instance the sandstone linings of the windows.
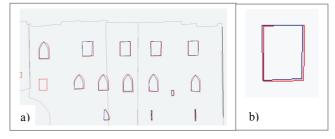

Figure 4. Surveying measurements (connected in blue) and point cloud digitizing (red); a) Eastern facade; b) Zoom on a rectangular reveal window.

5.1.2. Photogrammetric model compared to laser scanning model: Again, both wireframe models coincide adequately in the facade plane (see Fig. 5). Here the semi-circular and ogival arch windows show a slightly better correspondence than rectangular windows. Nevertheless, the obtained accuracy is in agreement with the inherent accuracy of the geodetic network.
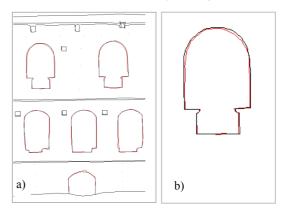

Figure 5. Photogrammetric restitution (dark) and point cloud digitizing (red); a) Interior courtyard; b) Zoom on a semi-circular arch window

5.1.3. Photogrammetric model compared to surveying data: As already mentioned, the interior courtyard has completely been restituted by photogrammetric stereovision. As shown in

Table 4, good matching occurs for these models. This can be explained by the fact that for orienting a couple of photographs, a few control points among those provided by tacheometry have been used.

	Windows type	rectangular reveal	ogival arch	semi-circular arch
Laser / survey	Mean (cm)	4.5	5.6	6.2
	Std Dev.(cm)	1.8	1.9	2.1
Photog Laser /	Mean (cm)	4.9	3.9	4.5
	Std Dev.(cm)	2.0	2.8	2.5
Photog / survey	Mean (cm)	2.1	4.7	3.1
	Std Dev.(cm)	2.5	2.4	1.4

Table 4: Accuracy assessment related to window type

It can be concluded that typically the 3D distances calculated between the three models are similar and confirm that the 3 techniques are in adequacy with the accuracy required for the documentation of the castle.

5.2. Radiometric accuracy

Acquisition of radiometric information is mainly perturbed by two factors. Firstly, the vegetation masks, even in winter time, prevent a complete point cloud acquisition, as in the case of the western facade or the south donjon (Fig. 3). Secondly, the brutal descending slope around the castle prevents the normal acquisition of photographs and generates strong distortions near the upper part of the castle. On the other hand, after inclination of the available laser scanner system, collecting a point cloud in the superior parts of the south donjon was difficult as explained in section 4.2.

Therefore, the completeness of the castle is covered by none of the techniques suggested.

The level of details recorded is directly correlated with the spatial resolution of the cameras and of the point cloud. Since no small and architectural details decorate the facades, the chosen cameras and scan resolutions (2cm on the object) were largely sufficient.

Concerning RGB data capturing, images recorded by photographs remain more realistic and homogeneous than the RGB coloured points provided by the laser built-in video camera.

6. DISCUSSION ABOUT THE THREE ACQUISITION TECHNIQUES

In summary, the experiences gained through this project allow to draw up the limitations implied by the use of each technique. Consequently, recommendations regarding each recording technique and their combination are derived from it.

6.1. Limitations of models derived from surveying methods: the major advantage is the possibility for the operator to choose a particular point. However, only a few discrete points are measurable, so detailed architectural elements are not well reproduced. If possible, reflectorless measurements must be avoided. Therefore, tacheometry is only advised for establishing the ground control points network.

6.2. Limitations of models derived from photogrammetric techniques: Considering the considerable constraints generated by the topography and the surrounding forest, only a limited distance to the facade is available for capturing images of the exterior parts. Thus, an inappropriate base/depth ratio produces low angle shots and not adequate ray intersection geometry for the photogrammetric point determination. Additional oblique images have been taken to achieve a reliable geometry in a tool like PhotoModeler.

(El-Hakim *et al.*, 2005) emphasized that the methods based on photogrammetry and surveying are still time consuming. Indeed, the manual interaction for 3D restitution remains major limitation of the method.

6.3. Limitations of models derived from laser scanning techniques: In contrast to the latter techniques, the choice of characteristic points is not possible. Thus, some details masked by other facade elements require commonly to be scanned from different points of view.

However, laser scanning is recognized as a high efficient acquisition method. And the final representation in a true colour 3D point cloud is automatic and looks realistic.

Unfortunately, due to voluminous data, it is preferable and recommended to simplify the point cloud, by keeping only the profiles or sections needed by the client. For this purpose, a CAD plan can be drawn, but implies the subjective interpretation of the operator. Indeed, the choice of the points describing a plane as well as the contour lines is of crucial importance for the derived results. To reduce this subjectivity, the RANSAC algorithm has been used for detecting and extracting automatically the window planes. Thus, an improvement of 1 cm in mean and standard deviation could be obtained.

It can be noticed also that combination and fusion of different scans affect the final accuracy of the 3D model. At last, the limited field of view available for scanning the upper parts of the castle leads to the idea of installing scaffoldings during the next mission.

6.4. Combination of models: If none of the previous techniques is able to provide a complete and independent model, the combination of multiple data is the unique effective and reliable solution. Indeed, if the main parts of the castle can be acquired by laser technique, acquisition and modelling of the bottom and the top of the castle is easier with photogrammetry than with terrestrial laser scanning. This has to be related to the topographic constraints and vegetation masks surrounding the castle.

Considering the final product, image information acquired by cameras is relevant for improving the level of documentation quality. Therefore a texture can be mapped on the composite model in order to simulate a realistic rendering using multiple photographs (photo model).

Therefore the recommended solution benefits from the rapid, accurate and detailed first results provided by laser scanning technique, and simultaneously allows model refinement provided by photogrammetric processing.

7. CONCLUSION

The combination of several data sources raises the geometric as well as the radiometric coherence and accuracy of the model. Before combining techniques and obtaining a final 3D photo-model, a laborious workflow must be considered. It begins with the planning of the acquisition mission, the establishment of a geo-referenced network, the processing of each type of data and at last but not at least the processing of the data, up to derivation of the final product. Except for the fusion of all models, the whole production chain has been considered in this paper.

A quality assessment regarding geometric accuracy aspects as well as parameters like completeness or level of details was carried out. The possibilities, advantages and limitations of every recording technique for short range acquisition of objects with high elevation were investigated. Definitely, the combination of the three promises to provide a complete and reliable model.

Once the 3D photo-model is achieved, illumination studies as well as simulations recalling the aspect of the castle in the XIIIth century are envisaged. At last, its integration in an information system is also of crucial importance for handling all the available data (Grussenmeyer *et al.*, 2006). Indeed, by browsing in the 3D model, the link with a database describing the patrimony's referential allow finding existing maps and updating the archives by new measurements.

The results presented in this paper are preliminary. The reconstruction and modelling of Haut-Andlau castle is still in progress. Therefore, the objectives scheduled in the introduction are not yet fulfilled. Nevertheless, the way to handle complex and difficult-to-access sites has been analysed and has led to useful recommendations.

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