# COMPARISON METHODS OF TERRESTRIAL LASER SCANNING, PHOTOGRAMMETRY AND TACHEOMETRY DATA FOR RECORDING OF CULTURAL HERITAGE BUILDINGS

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**ABSTRACT:**

Cultural heritage documentation projects very often combine different acquisition methods as tacheometry, photogrammetry and terrestrial laser scanning. In this paper we compare these three methods for recording of heritage buildings. Our test object is the medieval castle of Haut-Andlau (Alsace, France), documented in 2006-2008. This castle is of particular interest for our investigations since its architecture is the result of different construction styles completed over the centuries. Old buildings are rarely regularly shaped and most of their facades are made of very complex curved structures. The documentation of the castle 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 close to the castle. It became rapidly obvious that a unique technique would not overcome the vegetation and relief obstacles. The main part of the data capture was based on TLS. For completion of the laser scanner data at occluded building parts and for accuracy assessment, stereoscopic as well as multi-image models have been captured. Advantages and disadvantages of the different methods will be discussed in this paper. A quality assessment leads to the analysis of the models derived from each technique and to a crucial experience for further campaigns.

## 1 INTRODUCTION

For the documentation of large objects, architectural mapping, accurate topographic surveys and laser scanning are used along with photogrammetric techniques. In this paper we consider the medieval castle of Haut-Andlau (Alsace, France) to compare the most recent recording techniques. This castle with two towers (Figure 1) and several architectural features dates from the 14th century and was built on the top of a rocky hill in a dense forest. Two universities shared their experiences and instruments on this project: the MAP-PAGE Group (INSA de Strasbourg, France) and the Institute of Photogrammetry and Remote Sensing (Universität Karlsruhe (TH), Germany). Data gathered from the recent documentation have been processed in different ways and compared. First results about this project have already been presented in (Landes *et al.*, 2007).

## 2 RELATED WORK

In cultural heritage documentation, choosing the appropriate technology (sensor, hardware, software), the appropriate procedures, designing the workflow and assuring that the final output is in accordance with the set of technical specifications is always a challenging matter (Patias *et al.*, 2008). The leading parameters are the size and the complexity of the object and the level of accuracy required. These are the major factors which crucially influence the procedure to be followed. Advices about photogrammetry (Grussenmeyer *et al.*, 2002) and guidance to users on laser scanning in archaeology and architecture (English Heritage, 2007) promote the use of these techniques appropriately and successfully.

Generally, 3D data acquisition as well as 3D modelling of cultural heritage monuments 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). Indeed, whereas several authors advise the use of photogrammetry as an image based method (e.g. Hanke and Oberschneider, 2002; Mayer *et al.* 2004; Kersten, 2006, El-Hakim *et al.* 2007), others recommend laser scanning (e.g. Allen *et al.*, 2003). Advantages of imaging methods are their level of details, economic aspects, portability, handling in spatial limited environment and a short data collection time. Disadvantages remain in the post processing when the texture of the object is poor. Advantages by using an active sensor system like terrestrial laser scanners are 3D survey capacities and the 3D surface acquisition. Nevertheless, this technology is not optimal for capturing linear elements and produces a large amount of data which implies to be reduced for further processing. Consequently, in most cases a combination of the above mentioned methods regarding their benefits may be the best solution (e.g. Fuchs et al., 2004, Gonzo *et al.*, 2004).

Due to the complex structures of medieval castles, commonly used assumptions made on standard architecture, like parallelism, perpendicularity or symmetry are not applicable. Thus, the recording of such sites results in a huge amount of data and consequently the question of automation comes up. Whereas classical photogrammetry implies a heavy amount of manual and very time consuming interaction (e.g. Hanke and Oberschneider, 2002; Grussenmeyer and Yasmine, 2003), nor the automation around laser scanning acquisition and data processing is really developed.

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). More and more, modelling issues are related to the automation of

photogrammetric methods and to the fusion of 3D models acquired with different techniques, at different point densities and measurement accuracies (Voltolini *et al.*, 2007). The combination of different 3D modelling techniques is therefore essential for the virtual reconstruction of complex architectures, like those found in medieval castles.

Before combining different techniques, a comparison of them is necessary. Indeed, methods to compare both photogrammetric and laser scanning spatial data are interesting to understand the recording procedures and processing steps (Demir *et al.*, 2004; Kadobayashi *et al.*, 2004, Kersten, 2006).

### 3   LIMITATIONS OF EVERY RECORDING TECHNIQUE

#### 3.1    Limitations of the involved TLS

The biggest part of the castle as well as the surrounding gaps and the main parts of the fortifications have been captured by TLS via 19 stations. The scanner has been set up and oriented over known geodetic points belonging to a 3D network of about 45 points. Therefore, the point clouds were directly geo-referenced and can already be visualized in the field.

But rapidly it became obvious that some parts of the castle can not be captured by the TLS used in this study. For instance, due to the surrounding relief and ditches and the limited field of view of the Trimble GX scanner, no station was high enough to acquire the upper parts of donjons. In particular the south's tower of the castle causes difficulties and has been captured by deactivating the electronic level and tilting the instrument. Unfortunately, the TLS could not provide a reliable point cloud, because the not georeferenced cloud could not be fitted to the georeferenced one neither automatically nor manually. The reason for this is that the castle's donjons are homogeneous shapes and do not include characteristic discontinuities which could be considered as homologous areas. So the consolidation did not converge to a solution. Increasing the scan window and adding more textured surface was not a solution, since the dense vegetation occludes the main part of the south-west façade. Finally, the cloud obtained on southern part of the castle retains the lowest point density.



Figure 1. Point cloud currently recorded on the Haut-Andlau Castle

In the same way, regarding the low gap provided around the castle and the minimum range required by TLS acquisition (> 2m), the lower parts (basement) of the castle could only tediously or not at all be recorded. Figure 1 shows the currently recorded parts of the castle and surroundings. In this visualisation, each point is coloured with the RGB value provided by the built-in video camera. At this stage, 25 million points have been registered, as summarized in Table 1.

| Data | Instrument | Amount of data | Accuracy |
|---|---|---|---|
| Laser | Trimble GX | 25 million points all around the castle + inside | 7 mm at 100 m |
| Tacheo meter | Trimble 5500 | 400 points (1 day); Eastern façade (windows), inside and outside | +/- 3 mm + 3 ppm; Spot diameter: 3 mm at 50 m |
| Camera | Zeiss SMK (analogous) | 50 stereoscopic models; Lower parts of the castle (whole courtyard and adjacent parts of towers) | 200 GCPs with accuracy about +/- 5mm in (X,Y,Z) |
| | Canon EOS 5D (digital) with different lenses | 100 photographs; all around the castle (exterior facades + donjons) | Image pixel size: 8.24 µm; Object pixel size: approx. 1cm |

Table 1. Overview of the instruments used for acquisition and summary of the amount of data recorded.

#### 3.2    Limitations of the photogrammetric data

For completing occluded or not reachable building parts of the laser scanner data, approx. 50 stereoscopic models have been captured with a stereometric Zeiss SMK camera. Limitation of the camera is its laborious implementation and the fact that it is not very handy if the station is far from vehicle.

For this reason, also a digital camera has been used, i.e. Canon EOS 5-D, for taking photos all around the castle. Aim of this acquisition is to cover the complete exterior facades as well as the donjons and to provide the final texture mapping of the castle.

In a first step only significant contour lines were digitized in the oriented images in order to compare them with the same corresponding lines obtained by classical surveying technique or laser scanning technique.

#### 3.3    Limitations of the surveying data

Of course tacheometric measurements were indispensable not only for providing a geodetic network, but also for acquiring control points on the façade. Moreover, especially the windows have been captured by this technique, in order to provide a skeleton plan representing the outlines of significant objects or contours (windows, doors, ridges, etc.).

### 4   COMPARISON AND QUALITY ASSESSMENT

Aim of this section is to compare the models derived from the different techniques. For comparing laser and surveying data, a point to point comparison makes no sense, since laser scanning

technique does not allow choosing the point to be measured. That's why wireframes obtained independently via each technique constitute a first comparison basis.

### 4.1 Comparison of the three techniques based on wireframes

Each wireframe is composed of 21 windows which contour lines have been digitized on each data set. Thus, a wireframe produced by point cloud digitizing has been compared to tacheometric data. In the same way, the photogrammetric model has been compared to laser scanning model and to surveying model. Then, the 3D distances between each wireframe have been computed and analysed. Results showed that the detection quality or the similarity between models must be related to the type of window. Detailed analysis can be found in (Landes et al., 2007). More particularly, laser scanning and survey models show the lowest deviations for rectangular reveal windows. The main reason is the difficulty to measure the circular and chamfered parts of that kind of windows by tacheometry. On the other hand, the laser scanning enables to acquire each little detail, like for instance the sandstone linings of the windows. Globally, the absolute accuracy of every model is in agreement with the inherent accuracy of the geodetic network, i.e. +/- 5cm.

Additionally six object edges have been analysed to compare photogrammetric and laser scan recording (Figure 2). To derive the edges from the TLS point cloud, adjusted planes had to be estimated in a local area left and right of the edge (Figure 3). By intersection of these two planes the particular edge can be determined and compared to the corresponding edge in the photogrammetric restitution. To determine the deviations, the mean distance between the photogrammetric edge points and the laser derived edge has been calculated. Dependent on the regularity of the edge the mean distances vary between ± 2.0 cm and ± 3.7 cm. Due to the typical characteristic of the edges of a medieval building the photogrammetric edge points lie closer to the object than the laser derived edges which lie slightly outside the building.
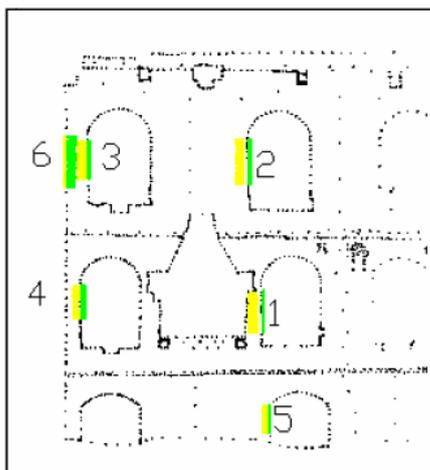
Figure 2. Selection of six edges for comparison of photogrammetric and laser scan recording

Globally the 3D distances calculated between the three models are similar with respect to the tolerances fixed by the specifications (± 5 cm in X,Y,Z). So, the results of this wireframes comparison confirm that the 3 techniques –

conventional surveying, laser scanning, photogrammetry- are in accordance to the accuracy required for the documentation of the castle.
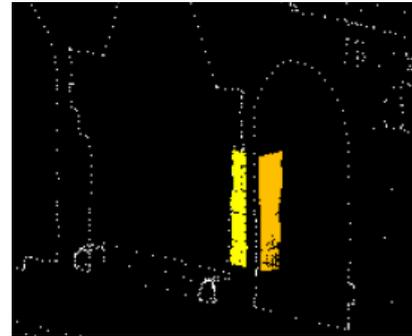
Figure 3. Local areas left and right of an edge for determination of adjusted planes

### 4.2 Photogrammetric model compared to laser scanning model based on triangulation

Another method to compare photogrammetric recordings and laser scanning is based on the triangulation of the object points captured by photogrammetry.

Laser scanning covers an object by a more or less regular grid of points without taking specific object structures into account like corners, edges, windows etc. On the other hand, photogrammetric measurements concentrate on object discontinuities and representative structures. Consequently the triangulation of these photogrammetric points leads to a representative surface of the object even if a point cloud with comparable density is not provided, especially at flat object parts. Therefore rather than comparing edges and the deviations between them, the presented method proposes to compare the laser points (Figure 4b) to the triangles derived from photogrammetry (Figure 4a).

Thus, to extract the differences to laser scanning (Figure 4b), the distance of each laser point to this triangulated surface is determined. For this purpose a search algorithm selects the corresponding triangle for each laser point and calculates the orthogonal distance to it. These values have been visualised and numerically analysed.
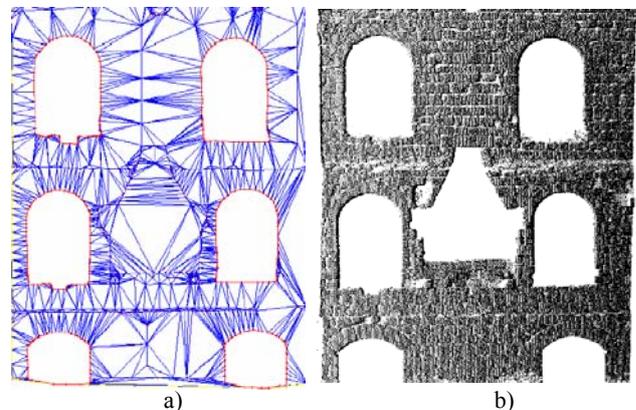
a)                              b)

Figure 4. a) Triangulated photogrammetric points of a wall (subset); b) Corresponding laser scanning point cloud.

Figure 5 is a colour-coded illustration of the resulting distances where the main differences in the characteristic of the two acquisition methods can be observed. The main feature is that laser scanning captures much more object details (seams, rifts, holes etc.). For instance the laser points fall partly into the seams between the bricks and therefore, cause systematically slight differences to photogrammetric recording. The numerical results are sampled in Table 2. However, also a lot of details the user is not interested in or which are even destructive are recorded. An example in our application is small vegetation growing at the walls and on the ledges.

| Distance D of laser points | Mean value [cm] | Number of laser points |
|---|---|---|
| 6cm < D < 10cm | 7.7 | 31 603 |
| 4cm < D < 6cm | 4.7 | 65 988 |
| 2cm < D < 4cm | 2.7 | 372 476 |
| 0cm < D < 2cm | 1.1 | 706 026 |
| -2cm < D < 0cm | -0.8 | 210 951 |
| -4cm < D < -2cm | -2.9 | 60 660 |
| -6cm < D < -4cm | -4.9 | 25 665 |
| -10cm < D < -6cm | -7.8 | 23 450 |

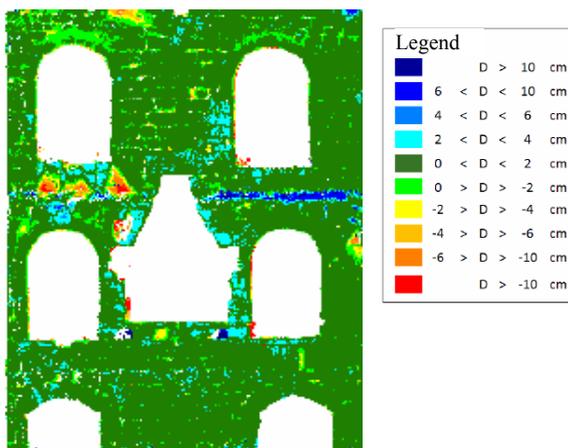Table 2. Mean distances values between photogrammetry and laser points



Figure 5. Colour-coded distances of laser points to the photogrammetric surface

The majority of laser point distances lie between -2 cm and +4 cm which confirms the results of the comparison of edges. The larger amount of distances below -6cm (points lie behind the photogrammetric surface) are caused by numerous gaps and holes which commonly occur at medieval walls while the values above +6cm (points lie in front of the photogrammetric surface) are mostly caused by    vegetation objects.

Therefore, best results can be obtained by combining the mentioned advantages of both methods. However, the decision for a combination or a single method depends on the aim of the data acquisition and the application behind.

### 4.3 Laser scanning model compared to automatically extracted planes

Because automation will be an important aspect of recording, modelling and analysing heritage buildings in the future, we additionally compare the laser point cloud with automatically extracted building planes. In a first step this method samples the point cloud in regularly structured voxels (volume elements), e.g. 0.2m x 0.2m x 0.2m. Due to data reduction, the gravity point of each voxel is calculated as geometric representative for the points lying inside (Figure 6, red points). Using a voxel and its 26 spatial neighbours a normal vector for the local object surface can be estimated (Figure 6, green vector). During a specific region growing process neighbouring voxel gravity points are grouped together to estimate adjusted planes. The homogeneity criterion is the maximal acceptable difference in the direction of the surface normal and the maximal acceptable distance of the origin of the normal vector to the extracted plane.
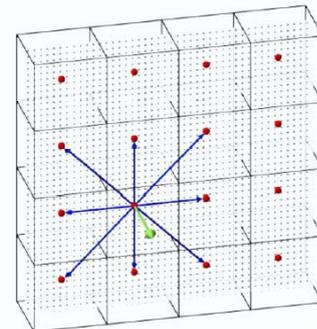


Figure 6. Principle of voxel gravity points (red) and determination of normal vectors (green) for automatic plane extraction.

This method was applied to the data of the courtyard of the castle (Figure 7). Figure 8 shows the original laser point cloud of the part of the courtyard framed in Figure 7, while in Figure 9 the extracted voxel gravity points are depicted. Figure 10 illustrates the results of the region growing process for the determination of planes and Figure 11 the CAD data of some extracted planes. For visualisation of the deviations between the original laser points and their corresponding plane isolines representing the same distances have been calculated. One of the results is depicted in Figure 12.
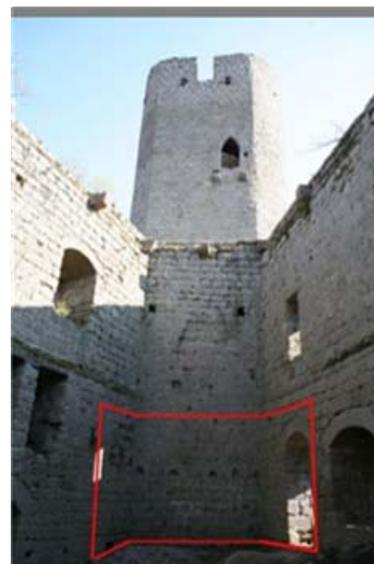


Figure 7. Photo of the part of the courtyard under study

As can be seen the predominant majority of these deviations lie inside the interval of ±2cm, similar to the results obtained by photogrammetry. Only at parts which contain holes in the wall (yellow and red isolines) the deviations exceed this interval up to 20cm or more (corresponding to the depth of the holes).
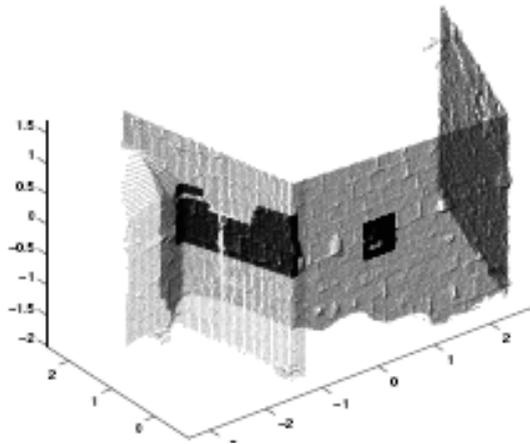


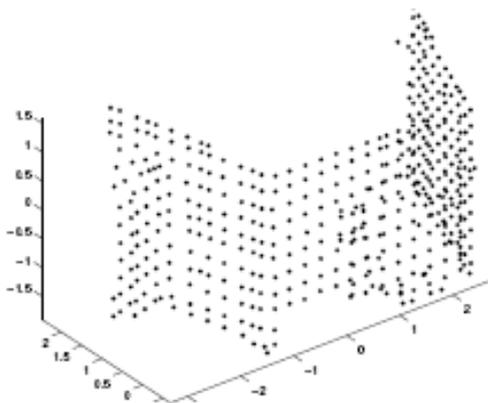Figure 8. Original point cloud of a part of the courtyard (red box in Fig.7)



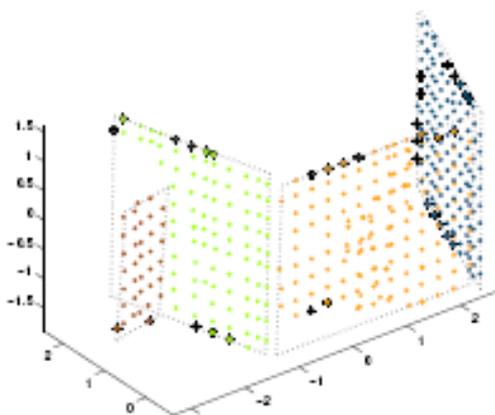Figure 9. Extracted centres of gravity points of the voxels



Figure 10. Result of region growing process for extraction of planes (uniform colour for points of the same plane)
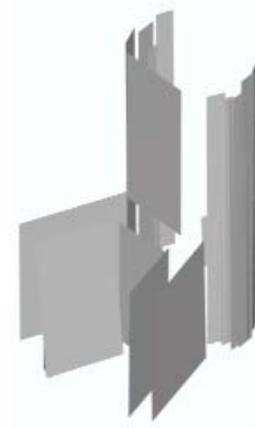


Figure 11. CAD data of some of the extracted and adjusted planes belonging to the south tower of figure 7
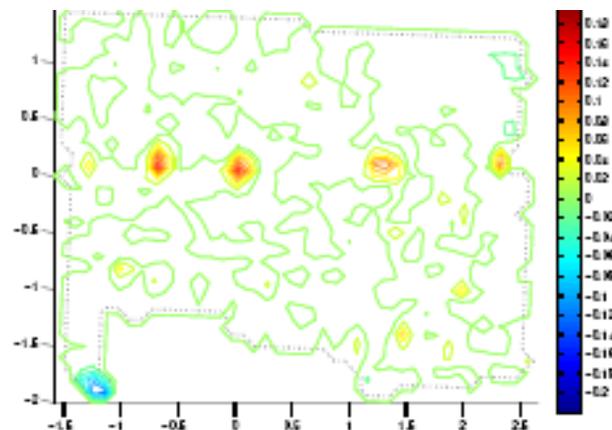


Figure 12. Isolines of the deviations of original laser points from the corresponding adjusted plane

As a conclusion the automatic extracted surfaces show slightly larger differences to the original laser point cloud compared to photogrammetric restitution and therefore can be applied equivalent, at least for flat, regular shaped object parts.

## 5 CONCLUSION

What is the most adapted surveying workflow allowing the recording of heritage buildings like a medieval castle? The answer to this question is not univocal. The experiments performed in this work do not lead to the conclusion that one unique technique is recommendable. Every acquisition technique, i.e. laserscanning, photogrammetry or conventional surveying techniques presents obviously some limitations, but also very complementary assets. Even a method to compare them is not trivial, since each one involves another modus operandi and other acquisition schemes. Hence, a first confrontation based on wireframes obtained through each dataset has been carried out. Even if the final accuracy obtained for each technique is quite similar, the differences lie more in the acquisition characteristics. In this context, a comparison based on surfaces instead of edges seemed to be a good completion because it allows to observe new additional characteristic differences. Thus, 3D faces like triangles calculated on the photogrammetric wireframe as well as automatic extracted planes were compared to laser scanner's

point cloud. The results showed small differences in the deviations between the models. Therefore, laser scanning or photogrammetric techniques can be applied equivalently at least for flat and regular shaped objects.

Currently, complementary data from recent spatial imaging total stations have been acquired and will be analysed. This kind of innovative instrument combines 3-D scanning, optical positioning and video technologies. It captures survey-precise ground-level data, which are fused with images to produce directly orthophotos. Consequently it is intended to supply complete 3D deliverables, in which interest is steadily increasing. Further work will be carried out in order to prove if it is an alternative to the combination of the three techniques evoked in this paper.

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