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Surveying 3D Data as Basis of a HBIM for the Management of Cultural Heritage Objects

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Abstract. Like all areas of life, science is currently in a phase of upheaval in which we are learning to make use of the advantages of digitalisation. The most important aspects of this digital turn are the acquisition of information and the development of problem-related data collections that help us to document and analyse problems and developments, but also to predict them. In analogy to other research disciplines (e. g. geography), the creation of a database-supported information system is obvious. Based on these considerations, the present case will use Hanfelden Castle as an example to show how the integrative use of selected methods from the field of geospatial technologies can be used to generate integrated 3D geodata intended as a fundamental work for the future development of a multi-disciplinary Building Information System for the management of historical buildings (HBIM).

Keywords: Terrestrial Laser Scanning, Structure from Motion, UAV Mapping, HBIM, Archaeology, Hanfelden Castle (Austria)

1. Introduction and background

Georeferenced 3D data are commonly understood as one of the most important data sources for generating HBIM, whereby - regardless of the dominant functional orientation (rather documentation or monitoring) - a maximum level of details should be aimed for. This applies to the geometry as well as to the thematic attributes or temporal resolution of the data. If one follows this often-suggested approach (Riemenschneider, 2018; Mascort-Albea et al., 2020; Murillo-Fragero et al., 2020) then decisive parameters of data acquisition can be derived from certain structural and functional properties of the object under investigation.

In the case of Hanfelden Castle, we are dealing with a compact four-sided stone building with 3 storeys, which is also enclosed by an approximately 3.3m-high circular wall with towers. This ensemble is located at an altitude of approximately 900m a.s.l. on the edge of the Styrian village of Unterzeiring in a side valley of the Mur on the southern slope of the Niedere Tauern (Fig. 1).

Based on the available archaeological and dendrological research, it can be assumed that the oldest parts of the object, which measures about 25m by 27m, were built at the turn of the 15th and 16th centuries and were only gradually extended over time (Aigner, 2002; Fürhacker and Theune, 2016; Theune and Winkelbauer, 2019). At present - and this is highly relevant for the objective of this work in the sense mentioned above - the building fulfils the function of a kind of architectural-historical data repository, which is particularly expressed in the fact that preservation work but no renovations in the strict sense are being carried out. In this context, it should be particularly noted that the work presented here derives its significance primarily from the fact that until now, no comprehensive digital data acquisition has existed for this object. Furthermore, the working bases available so far are almost exclusively analogue plans with the associated quality characteristics regarding accuracy, precision and integration of the object into a higher-level reference system. Therefore, the present creation of a complete 3D database represents the first step towards a kind of digital twin.

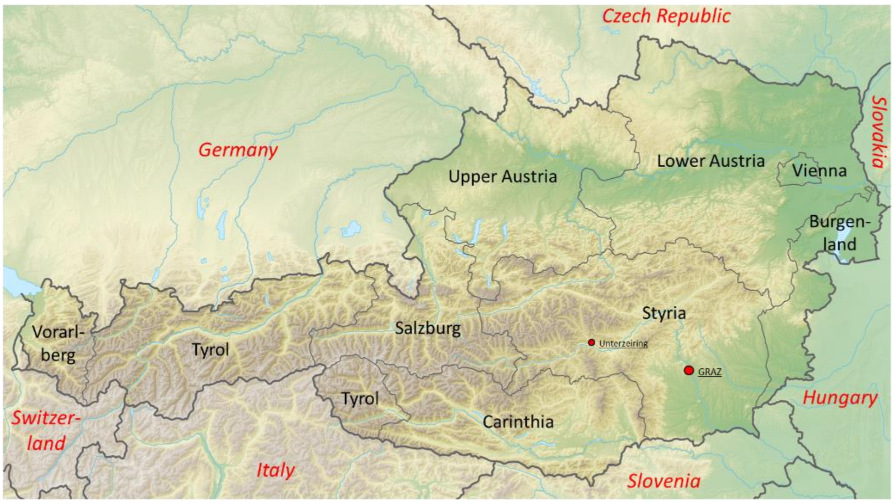

Figure 1. Location of the study area (Unterzeiring) in relation to the relief and the borders of the province of Styria and Austria (source: Wikipedia base map, content extended by the authors).

Generally, in the initial phase of work on a GIS, there are usually two work packages to be mastered: on the one hand, the definition of a purpose-optimised data model and, on the other hand - beforehand or in parallel - the parameterisation of the geometry part. In view of the currently unsatisfactory data situation (until now, project documentation has only been carried out with the help of paper plans), the main focus in the present case was initially on recording the geometry. In principle, laser-based methods such as terrestrial/airborne laser scanning (TLS/ALS) or photogrammetric image combination methods (terrestrial photography/TPH or UAV-based Structure from Motion/SfM methods) are used for this purpose. However, a number of specific problems resulted from peculiarities of the situation on site including the following ones: the parameters of the TLS system used, the complex ground plan and the height of the building made a pure TLS solution extremely difficult or impossible (see Fig. 2), so that certain parts of the outer wall, the lower parts of the main building and the roofs as well as the inner side of the ring wall had to be recorded with SfM methods. Finally, data on the inaccessible roof areas could only be collected using UAV-based camera systems.

Figure 2: The figure clearly shows the selected scanner positions (ScanPos###) and the locations of the drum reflectors (CR#) which were chosen in such a way that an optimal merging of the individual point clouds could be ensured. Note the group of trees on the right (eastern) edge of the image, which complicates the measurement and noticeably reduces the quality of the overall model.

The georeferencing of the object and its integration into the national reference grid was carried out using a series of local auxiliary points precisely measured using Differential corrected GPS, which also were used as reflector positions for the laser scanning procedure. In this way, a network of additional reflectors could be integrated with the help of which the combination of the partial point clouds into a total point cloud was made possible. With this configuration, a calculated resolution of approximately 1.4cm (on the object) can be achieved. Even considering the relatively rough masonry of the ring wall, it can be assumed that this point density is sufficiently accurate for most of the intended applications. More concretely, the data framework generated in this way is to be used to create a local 3D reference system with which as many types of object- and theme-relevant information as possible can be linked in the future. This includes, for example, photographs of details as well as true orthophotos, the condition of a wall surface or further processing into VR elements; countless potential areas of application can be found in the relevant literature (amongst others see Stylianidis and Remondino, 2016; Yitmen, 2020).

2. Materials and methods –design, methodology and approach

The selected scan positions were chosen because the ring formation around the outer wall of the Hanfelden Castle turned out that the overlapping areas complement each other optimally, as well as the shadow areas are minimized (Kushwaha et al., 2020). In addition, the texture of the walls from different scan positions becomes more distinguishable. Furthermore, the view angle of the Riegl VZ-6000 is limited in its vertical extension (60°). For this reason, the gables, base areas of the castle as well as the roof areas are hardly to not visible for the TLS. In addition to the Riegl VZ-6000, a total of five cylindrical reflectors and 17 flat circular reflectors (diameter: 13cm) were used in this study. The cylindrical reflectors (32cm height * 16cm diameter) were placed relative to the scanner positions so that they could always be seen at least from three scan positions simultaneously (Fig. 2).

The supporting flat reflectors were mounted directly on the outer wall of the castle. Five reflectors were installed on each side of the wall. An even distribution of the reflectors was considered. Two reflectors left and right along a section of the wall were installed near the ground and about 2m above. The fifth reflector was installed approximately in the middle of a section of the wall and at a medium height. This alignment allows to see the reflectors on the wall from the three scan positions. This layout was adjusted to make it possible to see all reflectors placed on the wall from three scan positions.

Despite the problems described above (natural conditions and technical parameters, architectural specifics and geometric structure of the object), a general resolution of 2 cm should be achieved for the resulting overall model. Therefore, a constant maximum distance of 40m – 50m from the wall was chosen. In combination with a frame resolution of 0.02° the desired quality of the final model was ensured. The vertical angular step has been adjusted according to the horizontal resolution. In principle, the Riegl VZ-6000 scanner offers the possibility of pulse repetition rates between 30 and 300 kHZ for better resolving ambiguities of the reflected signal. Due to the relatively short distance from the signal source to the target object to be scanned, the entire measurement process could be carried out in MTA zone 1 (MTA1 = no ambiguity/only 1 pulse in the air).

For the data processing "RiScan Pro", the accompanying software for Riegl terrestrial 3D laser scanner systems, was used. In particular, the tool "Multi Station Adjustment", which makes it easier to match the eight different scanner positions and reflectors placed around the castle. On the east side, the quality of the result is reduced because of the vegetation already described, which impedes the scanning process. Besides, because a part of the enclosing wall has collapsed here, it was impossible to attach the flat reflectors in the layout described above. In general, it has been shown that areas with good to very good distribution of reflectors bring significantly more accurate results, so that these deficits naturally affect the adaptation quality of the point cloud of the east side. However, the processing, apart from the difficult eastern part, can be regarded as very successful (Fig. 3).

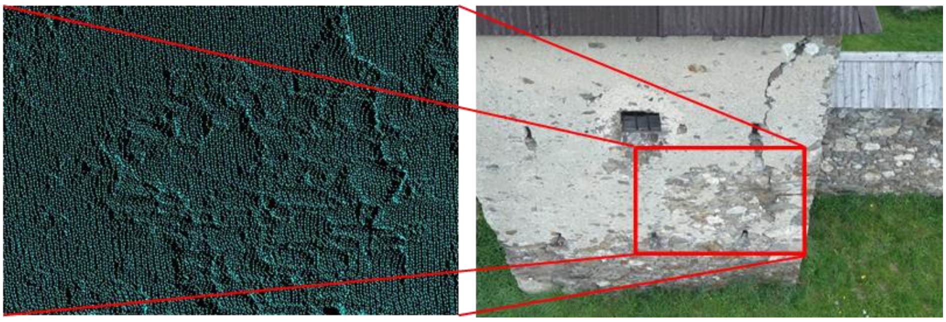

Figure 3: Comparison of a selected area from the outer wall between the TLS point cloud (left) and a photo from an UAV (right). The selected area in the photo is about 1.7 x 1.3 m. The structure of the damage to the surface of the building can be clearly seen.

No single sensor, respectively data from TLS, ALS, UAV or terrestrial photography (TPH) can acquire complete 3D information about a cultural object. Some studies have been done by integrating TLS an UAV platforms for 3D reconstruction of large and complex scenes (Xu et al., 2016). In addition, the rapid development of advanced image-based reconstruction techniques enables to obtain 3D reconstructions from threefold image sources (TLS, UAV and TPH).

The first step in processing initially includes a selecting and sorting of the obtained images, as well as radiometric adjustments to the raw images. This is followed by generating point clouds from the images and the merging of these with the point clouds generated by the TLS measurements - with models without TLS data also being created for comparison purposes. In order to obtain robust results, these point clouds must also be adjusted to the relevant areas and linked to the images (draping by overlay). All photogrammetric or result-related steps were carried out for this work using software “Agisoft Metashape”. For modelling the ring wall, 538 images (221 cameras, 317 UAVs) were taken for the western part alone. To facilitate generation of a 3D model from the numerous images, it is also necessary to carry out some radiometric corrections so that links between the images (recorded with different cameras at different times) are possible and the result has a uniform appearance. For this purpose, the exposure of all images to be used was automatically corrected in “Adobe Photoshop”; in addition, few problematic images had to be corrected manually.

3. Results and discussion

After the unification of the TLS-based data, it was found, that merged point clouds of the western scan positions showed an average standard deviation of about 2cm. As already mentioned, the eastern area was more difficult to access, so within the whole TLS point cloud the overall standard deviation increases to 5.4cm. But nevertheless, these values illustrate the good robustness for the western part of our research area (Zang et al., 2019).

Subsequently, the point clouds generated by TLS and by UAV were merged and compared by the software “CloudCompare”. This cloud-to-cloud difference had an RMSE of 0.017m which indicates a very high grade of fitting (Son et al., 2020). One of the most important reasons why this value is comparatively low is probably the optimal selection of setting parameters used for processing. Firstly, only certain pairs of points, for example the top of the towers, were selected. These areas are best separated and show a "clean cut" from the surrounding areas and a selection of points was thus guaranteed in the best possible way. Secondly, the combination of just a small overlap area from the TLS and UAV point clouds, like parts of the outer wall, towers, and upper part of the castle. If we would try to reconcile both point clouds with each other, a higher RMSE would be the result.

Due to the very high resolution from the wall areas of a few centimetres, the resulting point cloud, which reflects the current state of the building, can serve as a basis for possible renovation work. Rather, the point cloud can be used to detect weak spots and areas in the walls if repeated measurements are made. Early intervention is only made possible by the high resolution. Fig. 4 demonstrates the 3D reconstruction of western part of the ring wall with complete and textural information. The results demonstrated that integration of the threefold image data points from the TLS, UAV and TPH sources met the demand of digitisation and texturing for image reconstruction. Nevertheless, a better result between the two point clouds could be achieved, for example, if the reflectors had a better distribution or if the point clouds had a similar size for the final comparison with CloudCompare. The TLS point cloud is with 14 million points significantly bigger than the first version of the UAV data with about three hundred thousand points. Unfortunately, not every reflector was so called fine scanned by the TLS. With a more accurate selection of the centre from the reflector it is possible to increase the precision of the results.

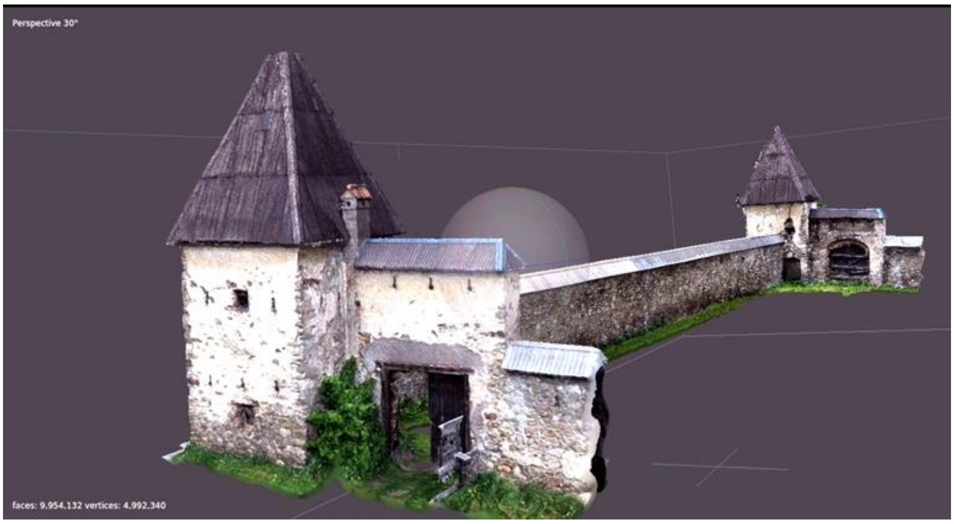

Figure 4. This 3D visualisation of the western section of the ring wall shows the potential of the already collected data material (a combination of TLS, UAV and TPH images), which can be used and further developed in many directions (e.g., the creation of virtual walk-throughs).

4. Conclusion

This paper gives a short overview for the design of 3D reconstruction of cultural heritage object (Hanfelden Castle). The attention was primarily focused on implementing a 3D geo-database which will meet the needs of upcoming research works on behalf of the multi-sensor image fusion (TLS, UAV and terrestrial images).

The complete 3D model was obtained from the integrated point clouds obtained using SfM methodology (UAV and TPH image-reconstruction) and TLS measurements. With reference to the original situation, the variables (combined point cloud, mesh, true orthophoto and volume or surface model) can be regarded as of sufficient accuracy and universal database for further relevant work. Nevertheless, there is a great potential for further improvement, for example, by densifying the UAV-based point cloud, by re-scanning previously poorly/not scanned parts of the object or by improving the point cloud merging process.

According to the progress of the presented work, the attributive part of these GIS data is still exhausted at this stage in the provision of metadata for quality assurance. The development of a fully-fledged database part (also including topological information) will be reserved for future development. However, it will in any case depend to a large extent on the needs of the users. Due to the hardware/methods used in this first phase, the adequate recording of the interior spaces has had to be dispensed with so far. The integration of this data represents the extension of the current data model to be completed in the next phase. It will be possible to use entire objects or their parts in a sense of the complete BIM or as a basis for the VR/AR environments and to extend this study using the presented background.

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