Photorealistic 3D-Roof and Façade Mapping of St. Stephen's Cathedral

Pushing technological boarders in completeness, resolution, and accuracy

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Introduction

The top of the southern tower of St. Stephen's Cathedral in the inner city of Vienna, Austria, is 136.44 m above ground level. From 1433 on, when the tower was finished, it was the highest building of Europe for more than 58 years. Since 2001, it is part of the UNESCO World Heritage Site "Historic City of Vienna".

Being built of limestone makes a continuous restoration of the building structure inevitable. The Masons' Lodge of St. Stephen's Cathedral is responsible for this task. More than 30 highly qualified people from various professions including stone masons, climbers, and engineers realize a complete restoration cycle within 35 to 40 years. To fulfil safety requirements for both, the building and its visitors, additional inspections, so far realized by specialized building climbers, are necessary to inspect the structure of exposed objects with a high risk.

Within this contribution, we describe an experiment which was carried out in December 2020 to support this time consuming and risky task by means of UAV-based inspection using a high-resolution camera. In the following, we describe the entire workflow from data capturing to 3D-mapping of a finial at the roof of St. Stephen's.

Related Work

The Masons' Lodge of St. Stephen's initiated more than 15 years ago a first 3D-documentation of the cathedral (Zehetner and Studnicka, 2007). Using a terrestrial laser scanner (TLS) *Riegl LMS-Z420i*, scans from 130 scanning positions have been merged to a 3D point-cloud enabling 3D-analysis of the geometrical shape of the building for the first time. From 2018 to 2019, the entire building was scanned using a *RIEGL VZ-400i* which measures with millimetre resolution and precision (Studnicka and Zehetner, 2020). Using integrated GNSS and IMU sensors and a powerful processor, on-site registration of the individual scans is enabled. By means of this, up to 400 scanning positions can be realized by a single operator per day. Multi Station Adjustment, a fine-registration post-processing step, copes with reference points to increase the absolute accuracy of a project. The resulting point-cloud captured at St. Stephen's Cathedral comprises the data of approx. 1,000 scanning positions with a total number of 20 billion points at the object. By means of a geodetic network of control points, an absolute accuracy of ±6 mm was achieved.

Although scans have been taken from various positions including roof-tops of adjoining buildings, shadowed areas, i.e. areas that could not be measured from a stable platform, occurred at high elevated areas. Figure 1 shows the resulting 3D-point cloud of the laser scanning campaign.

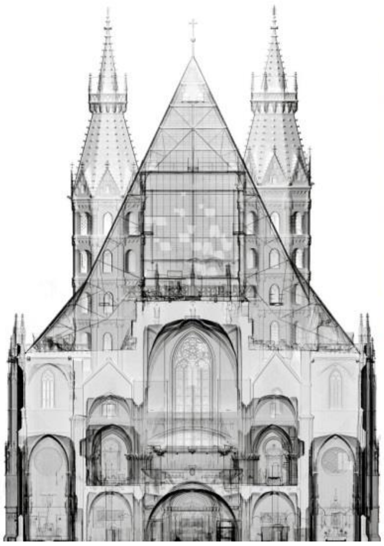

Fig. 1. Different renderings of TLS-point-cloud. Left: X-ray view along main axis of the cathedral making structures orthogonal to the viewing direction visible (black) while structures parallel to the projection plane become transparent. Right: Coloured TLS-point-cloud of high up regions showing shadowed (i.e. invisible) areas.

To fill the remaining gaps with correct and precise 3D-geometry and texture without the necessity of using scaffolds or hoisting platforms, we propose a hybrid approach using UAVs and high-resolution cameras. Image based solutions for 3D-reconstruction have become very popular and hence the application of respective software tools is a wide spread technology. Especially for UAV-based applications, so called videogrammetry approaches are emerging. To simplify the data-acquisition process (i.e. selecting the view-points), entire video streams are captured and subsequently, the individual frames are processed to generate 3D-point clouds. Terrosani & Remondino (2019) analyse the differences between videogrammetry and “conventional” photogrammetric approaches. They conclude their work with “3D documentation of heritage scenarios with high-end high-resolution cameras will be never surpass”; especially if high-resolution, high-quality, and high-accuracy are of major demand.

Data Acquisition and Processing

The acquisition of the TLS-point-cloud was realized as described by Dorninger & Studnicka (2021). The resulting point-cloud with an absolute accuracy of ±6 mm was used as reference for the photogrammetric data.

Figure 2 shows the UAV carrying a *Phase One iXM 100* medium format camera. The sensor of this camera is 43.9 x 32.0 mm and has a very high radiometric sensitivity. Equipped with an *RSM 80 mm AF* lens, it is necessary to adjust the focal distance. For this, the *4DU-RangeFinder* (Figure 2, right, mounted on top of the camera) was used, measuring the distance to the object 100 times per second and providing the current distance to the camera on the one hand while providing feedback to the pilot on the other hand. At a distance to object of 10 m, we achieved a pixel size of <0.5 mm.

In addition to the radiometric brilliance of the sensor, the lens has a very high geometrical quality. By means of the very stable intrinsic calibration of the camera system, the resulting point-cloud has an inner accuracy of ±2 cm. Data acquisition of the roof area of the northern façade took approximately 10 minutes. The image data was processed using Agisoft Metashape and globally referenced to the TLS data. The mesh model was generated using an advanced implementation of the Poisson triangulation described by Nothegger (2011).

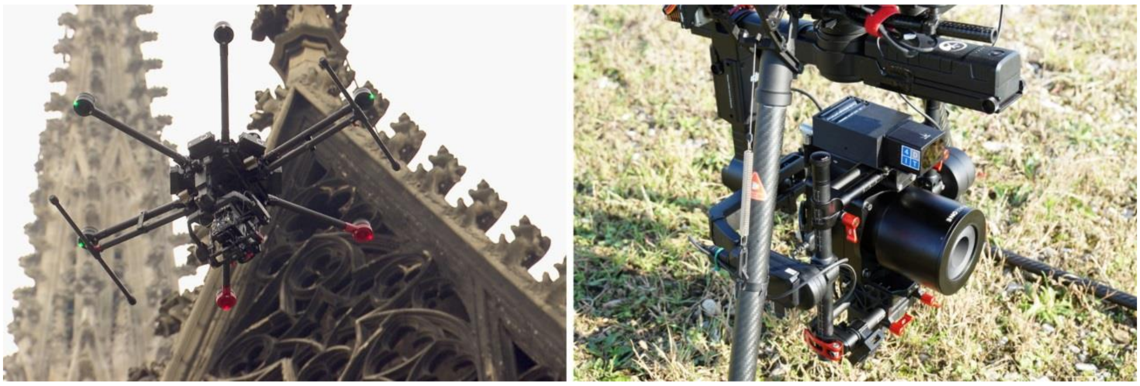

Fig. 2. UAV flight at St. Stephan's was realized with a DJI Matrice 600 pro and Phase One iXM 100 camera with RSM 80 mm AF lens and 4DU-RangeFinder. The system during data acquisition is shown left and the sensor system right.

Results

Figure 3 shows high-resolution, photorealistic renderings of the resulting 3D-model of the high-up areas of St. Stephen's Cathedral. The top-view shows the completeness of the data even in hardly accessible areas. Thanks to the radiometric quality of the images, the dark and shadowed areas are modelled properly as well (Figure 3, centre). The quality and resolution of the 3D-renderings make it hard to distinguish them from original photos.

Fig. 3. High-resolution, photorealistic renderings of the textured 3D-model. Areas without TLS points (see Fig. 1) could be modelled completely.

Figure 4 shows different mapping approaches derived from the 3D-model. Various orthogonal projections can be generated and texture, either derived from the geometrical model or RGB-images, can be mapped, supporting the work of the modeller.

Discussion and Conclusions

We demonstrated a hybrid approach for 3D-documentation, modelling and mapping huge heritage objects or entire heritage sites. Efficient and highly accurate TLS data acquisition served as foundation for a complementary UAV-based data acquisition with a high-resolution, high-quality camera. The resulting 3D-mesh model was automatically derived from the point-cloud and textured with high-resolution images. The mapping accuracy is locally at millimetre scale (resolution of image texture) while the absolute accuracy is approximately 2 cm. By means of the proposed workflow, the finial and the surrounding roof landscape could be captured completely and in 3D within 10 minutes and without the necessity of establishing a scaffold or climbing the building. Data processing is based on a highly automated workflow, making the application of the proposed approach economically feasible.

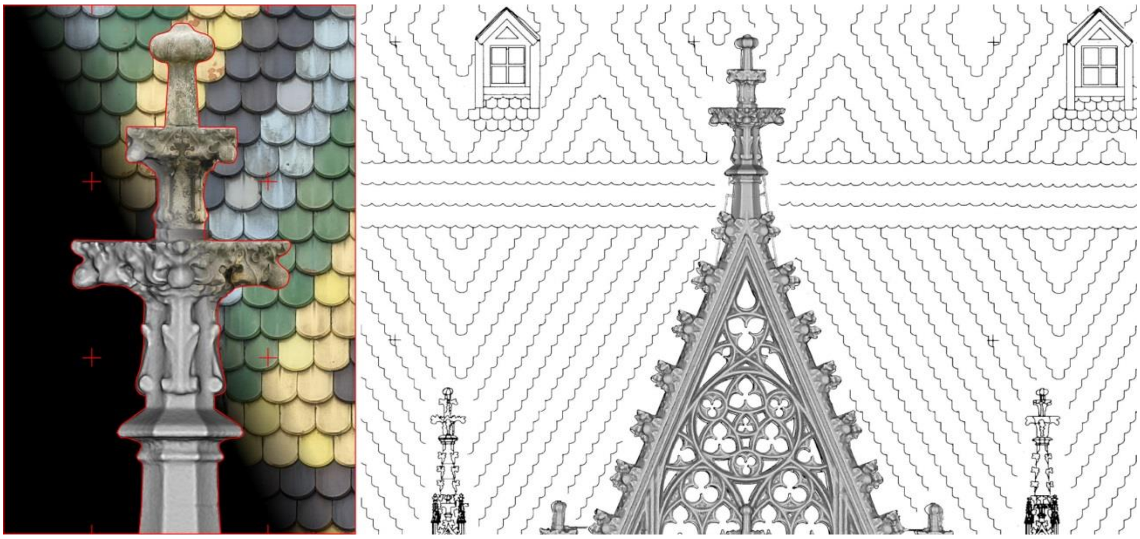

Fig. 4. 2D-Mapping of finial based on an ortho-projection of the 3D-model (left). Ortho-projection of a shading of the 3D-model into existing line drawing from 1991 (Bildmessung GmbH, Germany) (right)

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Author Contributions

Conceptualization, Funding Acquisition: Peter Dorninger, Nikolaus Studnicka
Investigation, Methodology, Visualization, Writing: Peter Dorninger

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