

Cultural heritage documentation by combining near-range photogrammetry and terrestrial laser scanning - St. Stephens Cathedral, Vienna

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Abstract. A powerful sensor system providing both high resolution textures and highly accurate 3D geometry information is created by combining near-range photogrammetry and terrestrial laser scanning. As both sensors are integrated closely into a single system, the textures can be applied to the 3D data automatically and with high precision. These sensors have proven as extremely valuable tools in applications of cultural heritage, architecture, and archaeology. We demonstrate the capabilities of the RIEGL LMS-Z420i system with an integrated high resolution camera by presenting the work flow of data acquisition and post-processing performed for modeling St. Stephens Cathedral in Vienna/Austria, with an emphasis on the construction of CAD models.

Objectives of the project

It turned out more and more necessary to record restoration-work accurately, not only to proof the quality of restoration but also to provide long-term detailed documentation. To obtain the indispensable exact plans for some monuments expensive photogrammetric maps (e.g. for St. Stephens in a scale of 1/50) were commissioned. As unscalable analogue drawings they can hardly be used by modern technologies and are not likely to be sustainable.

Therefore, a research-project was initiated, aiming at an economic way to produce an exact three-dimensional basis for damage recording and general mapping on monuments.

The restorer/stonemason should be able to handle the 3D-based damage recording system to do the regular documentation of restoration work.

The system should be compatible with commercial databases providing information on damages and restorations, but also on history and art (CIS cathedral information system).

In times of short public money the cost-factor becomes increasingly important, high accuracy is, however, necessary to watch development of damages and to analyze the nature of the building.

The mapping team too should be capable to control accuracy, as there happen mistakes in photogrammetric measurements.

Irregularities serve as indicators for construction steps astray from original plans, static problems or later changes as e.g. the reconstruction after the Second World War.

2D-Recording on paper or computer with enhanced CAD-Programs:

Paper-based mapping is limited to a fixed scale, allowing only raw description and accuracy of groups of phenomena, due to limitation of discernable hatches to signify the affected area. Computer Aided Mapping provides a differentiated glossary to describe the phenomena and a wide range of scale, where even small, but essential damages can be shown even in overview-scale. Damages and measures can be located and described easily.

Problems of 2D-Recording, however, are the invisibility of some areas on the map masked by other pieces, and the impossibility to show spatial connexes and curved surfaces such as vaults or the exact shape of pillars. The novelty therefore consists of an expansion of this method to 3D mapping.

Data acquisition

System description

The whole system is battery powered and portable, but yet robust and operable in a wide range of environmental conditions. Data acquisition, sensor configuration, data processing and -storage are effectuated by the companion software RiSCAN PRO.

Hybrid Sensor	RIEGL LMS-Z420i with Canon EOS 1Ds
Measuring range	up to 1.000 m at target with 80 % reflectivity
Ranging accuracy	10 mm (single shot) 5mm (averaged)
Beam divergence	0.25 mrad
Measuring rate	8000 points/sec
Scan range	0 to 80 deg vertically, 0 to 360 deg horizontally
Scan resolution	up to 0.004 deg
Camera resolution	approx. 12 Mega-Pixel
Camera lenses used	20 mm focal length
Specs of lighting	sunlight color / 3lamps, 2.5 kWatts each

Table 1. Key specifications of the system.

The characteristics of the most powerful instrument of the RIEGL LMS scanner series, the LMS-Z420i, are: its narrow beam divergence, its wide operating range, and its excellent single-shot accuracy. As a consequence, the raw scan data provide a precious basis for various post processing techniques. The scanning system is perfectly complemented by the photogrammetric method (high pixel density, hence definition and vectorisation of edges and high accuracy of details). The hybrid sensor provides geometry data from the laser scan and image data from the camera. These data can be automatically processed to generate products such as textured triangulated surfaces or orthophotos with depth information. Additionally, all tools developed for image analysis, such as edge detection, can be used for direct extraction of 3D content from the combined image data and scan data. The collected data therefore provides a solid and large data base for any measurements related to construction, destruction and decay of the scanned object.

Strategy

For scanning a complex building a strict workflow strategy should be respected. In general it is helpful to create a logical, hierarchic dissection structure of the building. At St. Stephens the established dissection-structure defining pillars and bays was adapted to the needs of IT and helps to structure even the archives. For the interior of the cathedral 37 vaults, 18 freestanding pillars, 36 wall-pillars and 42 wall-parts are defined. N09 e.g. assigns the 9th bay counted from west in the north nave. It is necessary for postprocessing to name each scan position according to the dissection structure of the building.

In a single scan one construction part should be recorded as complete as possible under constant illumination - „object-oriented scanning“. To follow this guideline we scanned twice in every bay, in diagonal direction (to record the pillars), and once parallel to the axis to record the walls.

To stitch all scans immediately after the recording, the approx. 300 retro reflecting markers were measured previously with a total station in the national coordinate system, thus permitting a permanent check on accuracy.



Fig. 1. Preparation of the scanning mission: map of the dissection-structure

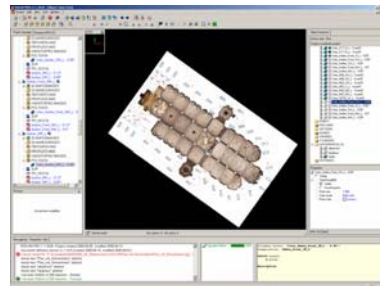


Fig. 2. Check while the data acquisition: Point Cloud and dissection-structure

Data acquisition

Due to special circumstances of a cathedral all data acquisition had to be done at night in order not to bother services and for tourists not to disturb the measurement proceedings. Besides, professional artificial light at nighttime guarantees regular lightness with daylight temperature. Compared to the advantages of night-work the fact of not recording the remaining mediaeval stain-glassed windows is a minor disadvantage.



Fig. 3. Photograph of the system at daylight in front of the cathedral



Fig. 4. Photograph of the whole system at operation at night within the cathedral

The specific challenge however was to supply constant illumination of the photographed area. The distance between recording system and object varied from 5 m to 25 m. We used three floodlights to achieve homogeneous brightness. It took 7 nights from 8:00 p.m. to 6:30 a.m. to acquire all necessary data of the interior of the cathedral.

Postprocessing

Point-Cloud / Merging / Data Reduction

We took 130 positions to record the entire cathedral. At every position, 2 Mio. points and 10 photos were taken. So the final data collection consisted of 1300 photos and a total amount of raw data of approx. 15 Gbyte.

To enable the representation and processing of the whole model, data were resampled with a resolution of 5 cm. The resulting point cloud of the cathedral (20 Mio. pixel) can be split into single elements, layers or sections. Of course for detailed processing of every step of the workflow the original data can be retrieved. However, with regards to the present capacity of computers it can not be considered as useful to load more than 5-10 scans simultaneously.

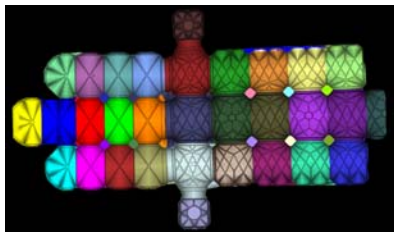


Fig. 5. Segmentation in about 120 basic elements of the interior:

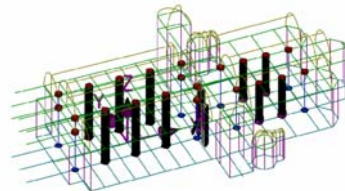


Fig. 6. Framework of the cathedrals irregular coordinate system

Triangulation:

The result of scanning, the so called point cloud, does not form a surface, but only isolated points. To gain a surface useful for further processing the points have to be triangulated or „meshed“. There are two ways to achieve a triangulated surface:

- All points are connected to a more or less complete mesh. For vaults or walls this is a good method, in other cases – as in the pillars - the relevant structure is covered by sculptures or altars. Compound pillars have many areas hard to be reached by the laser beam, because they are intrinsically shadowed. Triangulation of our model was effectuated by the software „RiSCAN PRO“ (www.riegl.com).
- Another method is the so called „Monoplotting“. A corpus is modelled by CAD based on scan- and photo-data (to a so called "low poly model"). Surfaces can easily be identified in the point cloud, edges in the congruent photos and thus a CAD drawing is generated. A compound pillar, for example, can be extruded along its elongation out of a section. For vaults, the caps are approximated by automatically generated segments of cylinders or cones. This simplification showing cylinders and their axes gives important information about irregularities of the building and of damages and static problems. (The high steeple caused displacements in the foundation, but also in the vaults, subsidences caused by underground work can be shown, etc.). Of course, this method approximates the shapes, but missing details can easily be inserted in the overall complete model when required. Monoplotting is implemented in the software Phidias (see 11. www.phocad.de)



Fig. 7. Triangulated polygonal model of the ceiling

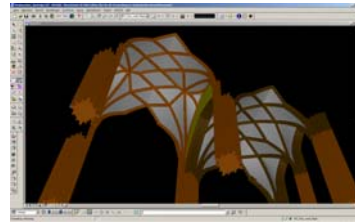


Fig. 8. Low polygonal CAD model within Phidias for MicroStation

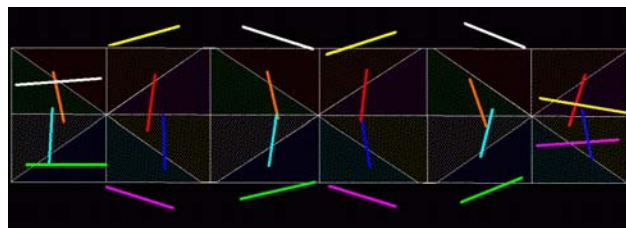


Fig. 9. Distorted axes of vault-caps in the choir-bay next to the steeples

Textured triangulated surfaces

To use a 3D-surface-model for damage recording, calibrated photos are mapped on the mesh. Both monoplotted and triangulated models were texturised in Riscan PRO. Previously, the CAD-model had to be converted into the STL-format.

For using the textured 3D surface model in the mapping-software "aSPECT 3D" (see 12 www.arcetron.de) it was exported into WRL-format.

3D Mapping / Damage-Recording

Applied 3D-Recording

For 2D recording of St. Stephens', a catalogue of approx. 6.000 phenomena - describing the status of the building and the activities of preservation- has been established.

The catalogue consists of 12 basic groups - materials (stone, plaster, metal etc.), damages, and measures.

This is a quite complex system of description, but it proved as very useful for our purpose and has been applied in a 2D-System by craftsmen and restorers of the lodge for several years and, besides, it is not a tool that can be used by specialists only.

Due to the size of the monument and the manifold attributes it is necessary to establish a powerful database in the system to execute queries for combinations of specific phenomena of the whole cathedral (e.g.: sandstone, that was treated with a method that had turned out problematic).

The handling of 3D-Objects turned out to be easier than expected. For architectural objects it is not necessary to turn the object and to draw on it at the same time.

Recording in CAD for low poly models

Presently, no CAD-application providing a comfortable function for mapping and drawing on a 3D-surface is available on the market. However, it would be possible to combine a number of different functions mapping drawn objects to a 3D-surface. This is only a first step, but due to existing database-engines of CAD-software it could be possible to develop a functional mapping-tool based on 3D CAD.

Recording in aSPECT 3D for triangulated models

For triangulated surfaces the software aSPECT 3D with the necessary options was developed.

The advantage of this solution is the ability of exact drawing on the surface – the lineation of the mapping expert is independent of triangles. For the definition of the parts of the surface (e.g. a particular piece or damage), the triangles will be cut on the drawing line. The surface is textured and can be drawn like a vaulted paper. A database-connection is already established, further developments are foreseen.

Our recommendations for the future functionalities are:

Possibility to handle several overlapping Mapping-Objects on a 3D-surface (e.g. stone/damage/measure).

Possibility to define a more complex database, which can handle several files of 3D-Mappings a complex building has to be divided into for better handling.

Query to find any combination of phenomena.



Fig. 10. Detail of 3D Mapping / Damage-Recording of wall element "N09"

Outlook

There are systems to:

- Organize a “virtual Cathedral”,
- Describe the phenomena and the condition of a monument in 2D,
- Easily produce 3D-data in both mesh and low poly CAD models,
- Do Mapping in 3D for specific topics.

What we would need and are working on is:

To combine all these topics to allow craftsmen, restorers and not-computer-skilled users to carry out accurate documentation, using standard laptops for a 3D-model that can be easily generated and that provides sufficient accuracy.

The system should be able to combine models of different sources and in different accuracy according to the nature of the object (e.g. architecture/sculpture = laser scanner/stripe light scanner etc.).

The system should be regarded as a tool to be handled as easily as a “pencil on a curved surface”.

Apart from the “classic” 3D-model-application like showing the cathedral or visualize projected adaptations (pictures, new altars, acoustic adaptations, new

stain-glassed windows etc.), the exact documentation provides a precious tool for preservation itself and for its sustainability.

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