# *Reconstruction and Change Management for Cultural Heritage*

*Anton Fuhrmann**, *Gerd Hesina**, *Stefan Linsinger*†
* VRVis Research Center; Donau-City-Strasse 11, 1220 Vienna, Austria
† Linsinger ZT GmbH, Hauptstraße 31, 5600 St. Johann im Pongau

Corresponding author: hesina@vrvis.at

## 1. ABSTRACT

Restorations and building projects in the building are playing an increasingly important role in the field of building management. Building inventory documentation therefore forms the basis for all types of planning. In the meantime, data acquisition using 3D laser scanners and subsequent evaluation has established itself in the field of internal service. This provides an effective planning tool for the architect, restorer and craftsman. We use unmanned aerial vehicles equipped with high-resolution cameras which can produce hundreds of photos of the building from many angles within a short time. From these "photo clouds" a three-dimensional model of the building can be calculated by means of photogrammetric methods on highly parallel computer clusters.

These models can be viewed in real-time from all sides and serve both to document the actual state as well as to create conventional representation, such as a line drawing in orthoprojection, which represents an arbitrarily large part of the facade undisturbed.

By using the methods described above, the condition of buildings can be described very well, but some aspects of aging are difficult to detect: efflorescence and mossing is difficult to identify visually or from photogrammetric reconstructions. Therefore, we employ additional methods:

**Photometric methods** allow the reconstruction of minimal differences in height, even brush strokes and scratches are clearly visible. Thus, the course and spread of minor changes in the surface can be tracked and documented.

**Far Infrared Vision - FIR**, also referred to as thermal photography - allows to detect and display the slightest differences in the temperature profile, for example, due to spalling or vegetation (Abb. 4). A combination of visible light and FIR allows us to fuse the detailed reconstruction of buildings with the measurement of finest temperature differences ($<0.04$K).

The combination of multispectral data with the high resolution of photometric reconstruction allows the long-term observation of the subtlest changes to the building. Thus, potential damage points can be detected in a timely manner to avoid greater damage or even danger to persons.

## 2. INTRODUCTION

In Europe, and especially in Austria, many buildings fall in the category "cultural heritage". Per definition, these buildings are old and must be closely monitored for structural damage: on one hand, irreparable damage could occur if this was neglected, on the other hand a very real danger exists for accidents to occur when parts of buildings hit pedestrians.

This articles covers a work in progress, in which we describe the methods we use to make 4D building monitoring – monitoring three-dimensional objects over time – of large cultural structures economically and technically feasible.

## 3. UAV WITH SENSOR ASSEMBLY

We use a Phase One IQ 180 with an image resolution of 80Mpx and alternatively a Sony Alpha 7R with 24Mpx. The RAW Images deliver the necessary dynamic range to detect features even in shadowed areas of outdoor scenes. It is mounted together with a FLIR Tau2 micro-bolometric thermal camera on an Octocopter 6S12 by Mikrokopter (Octocopter MK 6S12).

*Figure 1: Octocopter 6S12 with mounted camera Sony alpha 7R for photogrammetric measurements*

### 3.1. Difference Detection

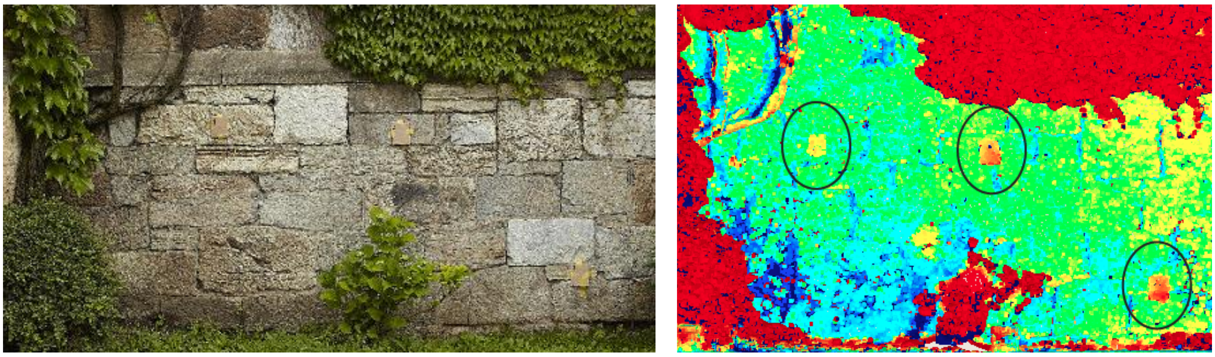


*Figure 2: (left) church wall with applied test strips; (right) test strips visible in depth difference image*

Since one of the goals of the project is to determine if spalling has occurred on the monitored surfaces, we tested the quality of the photogrammetric reconstruction by reconstructing a wall before and after we mounted test strips of different gauge on it (Figure 2, left). A false color visualization (Figure 2, right) of the distance between the two reconstructions (before and after) clearly shows the test strips (gauges from left to right: 2mm, 5 mm, 7mm). The other red areas in Figure 2 are vegetation, which naturally changes slightly between different scans.

## 4. THERMAL CAMERA CALIBRATION

Westfeld et.al. (Patrick Westfeld, 2015) investigate the possibility to efficiently reconstruct 3D scene geometry purely from thermal image data by using structure from motion techniques. They acquire their images using a low-cost, lightweight thermal camera mounted on an octocopter platform, resulting in a 3D point cloud containing geometric information plus thermal attributes (Figure 3). Their paper gives an overview of the automatic data processing chain and detailed aspects of the geometric calibration process for the thermal camera.

*Figure 3: (left) CAD model of an octocopter UAV sensor platform equipped with a thermal imaging camera (right) false-color thermal image of 640 pixels x 512 pixels. Source: (Patrick Westfeld, 2015)*

They designed a 3D calibration plate based on two material components: Silver heat protection foil with strong specular reflection for circular measuring marks is combined with black velour foil with high absorption for target edging. In combination, both components provide a strong contrast in visible as well as the far infrared spectrum (Figure 4).

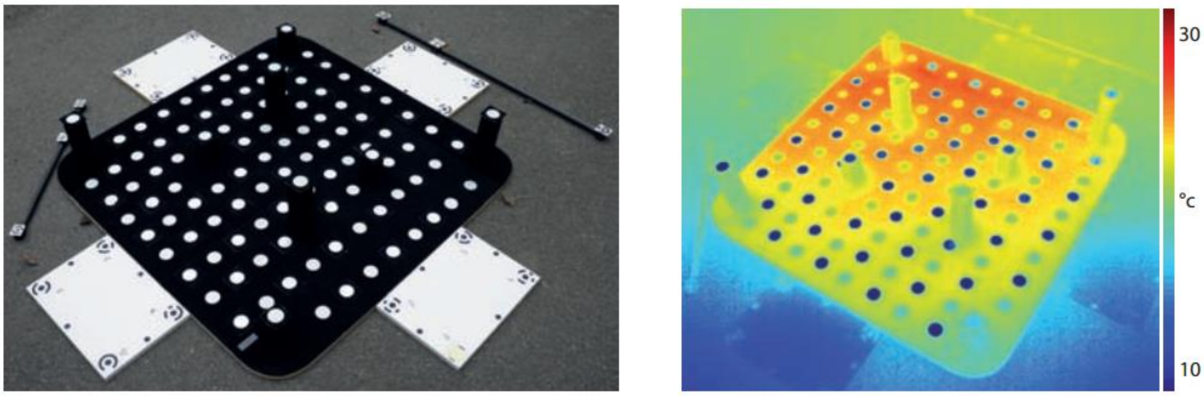


*Figure 4: (left) True color image and (right) false-color thermal image of a 3D calibration target.*

Using similar targets, we can calibrate the intrinsic and extrinsic parameters of the infrared as well as the visible light camera. We use the well-known camera model described by Hartley and Zisserman (Hartley & Zisserman, 2003), which is like the model used in our structure-from-motion software. Since the cameras are mounted in fixed positions to each other, the extrinsic calibrations give us the relative transformation between the cameras, a feature we use later when aligning thermal imagery with the 3D model generated from visible imagery.

## 5. PHOTOGRAMMETRIC RECONSTRUCTION (STRUCTURE-FROM-MOTION)

We generate highly detailed 3D geometry from aerial images taken by octocopter using a commercial structure-from-motion software package (Agisoft PhotoScan). This software is ideally suited for our purposes, namely the reconstruction of static 3D geometry from large image clouds. It generates detailed, textured geometry automatically and uses GPU acceleration and distributed processing to speed up the reconstruction process. Like most photogrammetric methods, it only works reliable for surfaces which do not change their appearance over time or viewing angle: changing illumination (e.g. wandering shadows, clouds, or different positions of the sun over time) or reflecting/shiny surfaces (glass, metal) generates artefacts or holes in the reconstruction (Figure 5, left).

These problems occur for most imaging techniques – even laser scanners – and cannot easily be overcome. But since our main area of application is in cultural heritage, most facades consist mostly of weathered brick or stone, which is an excellent input for the feature analysis necessary for structure-from-motion algorithms (Stockman & Shapiro, 2001).

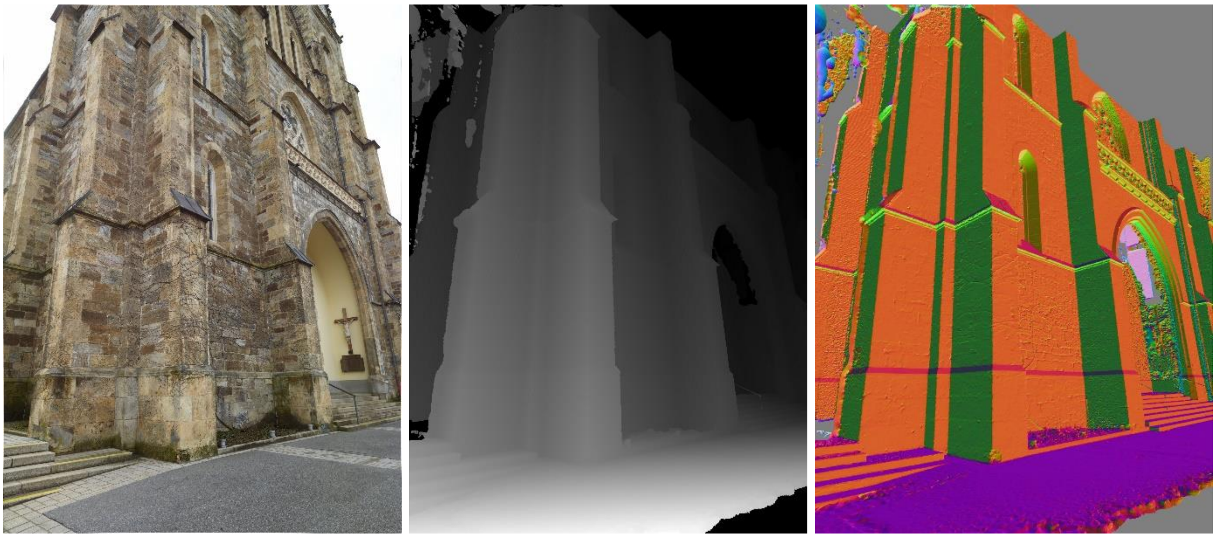


*Figure 5: Terrestrial laser reconstruction of a church; from left: original image, depth image, normal image*

While terrestrial laser scans from the ground or from cranes deliver in most cases high-quality results (Figure 5), the nature of many cultural heritage buildings – especially gothic ones, with many turrets and crenellations – results in many occluded areas. These occlusions can only be filled by additional scans from different angles, which is often not easily possible.

Since most lasers cannot generate useful results when mounted on an UAV, photogrammetry is the

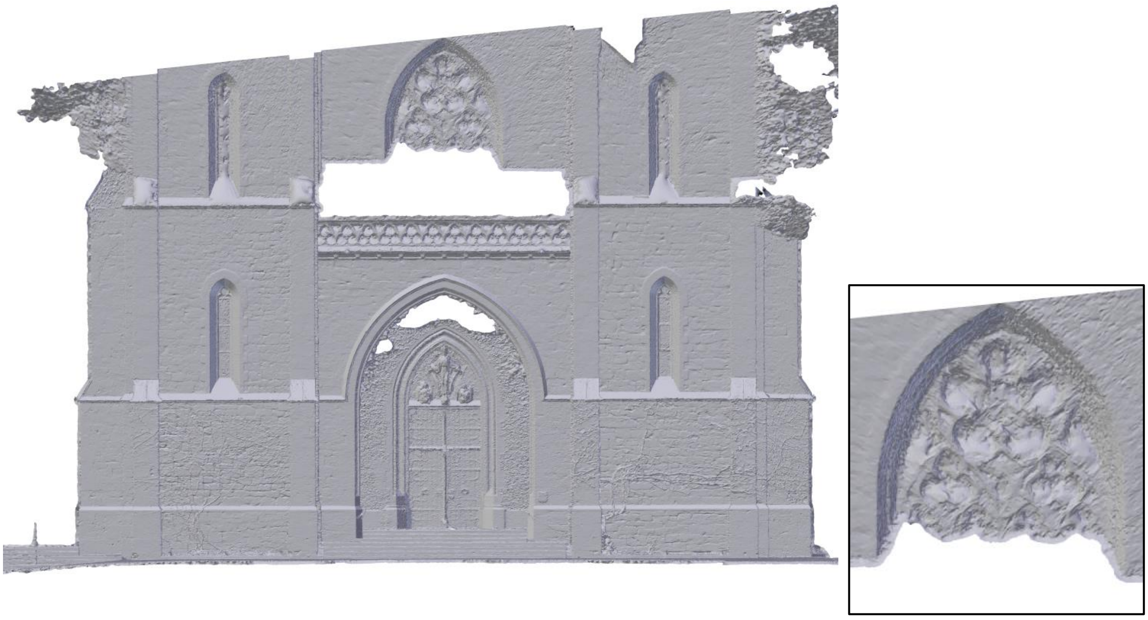
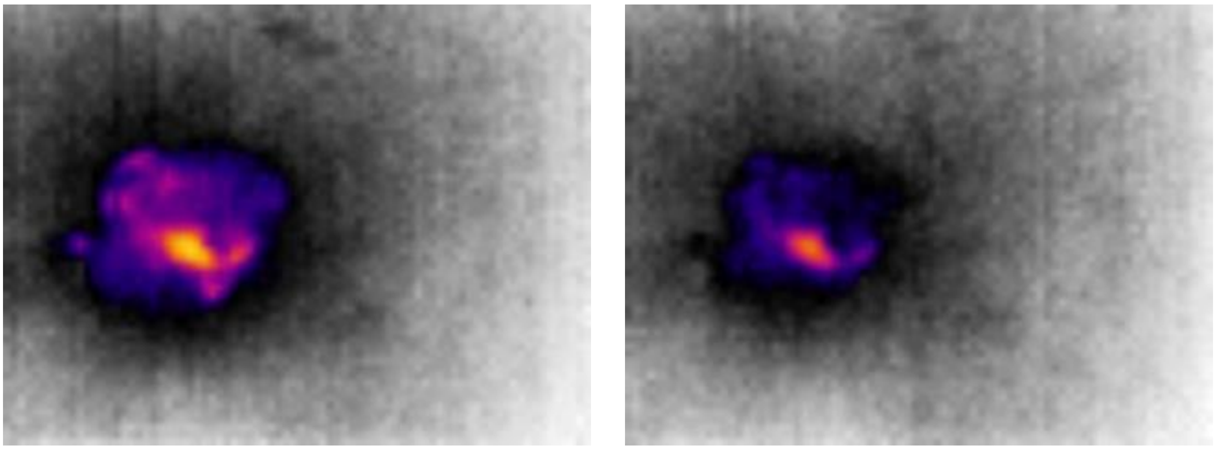


*Figure 6: Visible occlusions (holes) in terrestrial laser scan data; (left) artefacts on glass windows*

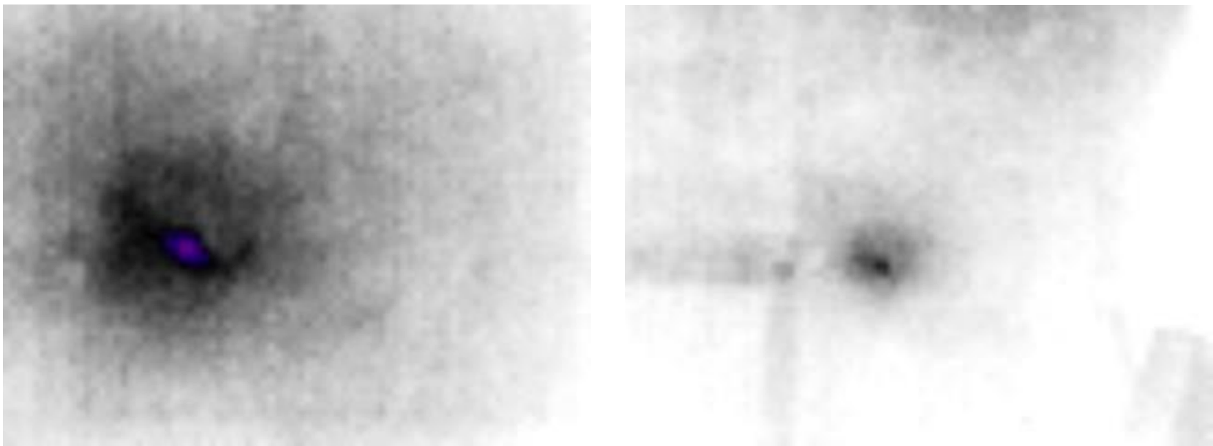
## 6. THERMAL IMAGES

Like Westfield (Patrick Westfeld, 2015), we employ thermal cameras on our drone (Octocopter MK 6S12), to gather additional information about the monitored buildings. Internally heated buildings can be analysed regarding possible thermal bridges caused by moisture or unusual material combinations.

Thermal gradients can also be caused naturally by the sun's heat stored during the day, which is released after sunset. We simulated such a scenario on a recently repaired part of a wall by heating it with a 1000Watt lamp for several minutes and then recording a time series of thermal images (Figure 7). The different cooling rates caused by the different building materials are clearly visible.



(a) (b)



(c) (d)

*Figure 7: Time series of cooling material discontinuity in wall surface. From (a)-(d) the time was 0s, 10s, 30s, and 5minutes.*

## 7. ALIGNING THERMAL AND VISIBLE DATA

It has already been demonstrated that photogrammetric reconstructions from thermal images are possible in many cases when the thermal images show enough visible features (Patrick Westfeld, 2015) (Stockman & Shapiro, 2001) (Hoegner & Stilla, 2015).

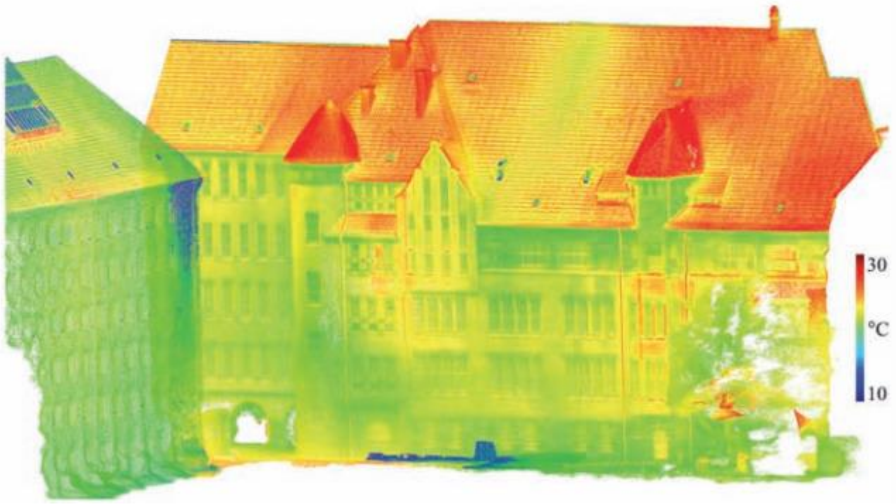


*Figure 8: SfM reconstruction from thermal images. Source: (Patrick Westfeld, 2015)*

But since we can explicitly calibrate the extrinsics of the thermal camera and the visible light camera in the same coordinate system, we can use this information to reproject the low-resolution (640×480) thermal images onto the detailed model generated from the high-resolution visible light images.

## 8. PHOTOMETRIC RECONSTRUCTION OF SURFACE DETAIL

The SfM reconstruction discussed above produces models with detail down to the sub-centimetre range, provided there are enough visible details, which on the surfaces of old buildings normally is the case. But spalling in the millimetre range and below, e.g. of paint layers, and small cracks are not reconstructed, even if they are visible in the source images.

Even tiny structural detail on building surfaces is visible in the high-resolution images we gather. To generate detailed micro-surface models, we use photometric stereo (Woodham, 1980) (Holroyd, Lawrence, Humphreys, & Zickler, 2008), a method which reconstructs geometry from images taken under multiple, different lighting conditions (Figure 9). By capturing images with artificial lighting – photographic flashes – we can reconstruct models with surface detail well below the resolution of the photogrammetric or even the terrestrial laser reconstruction.

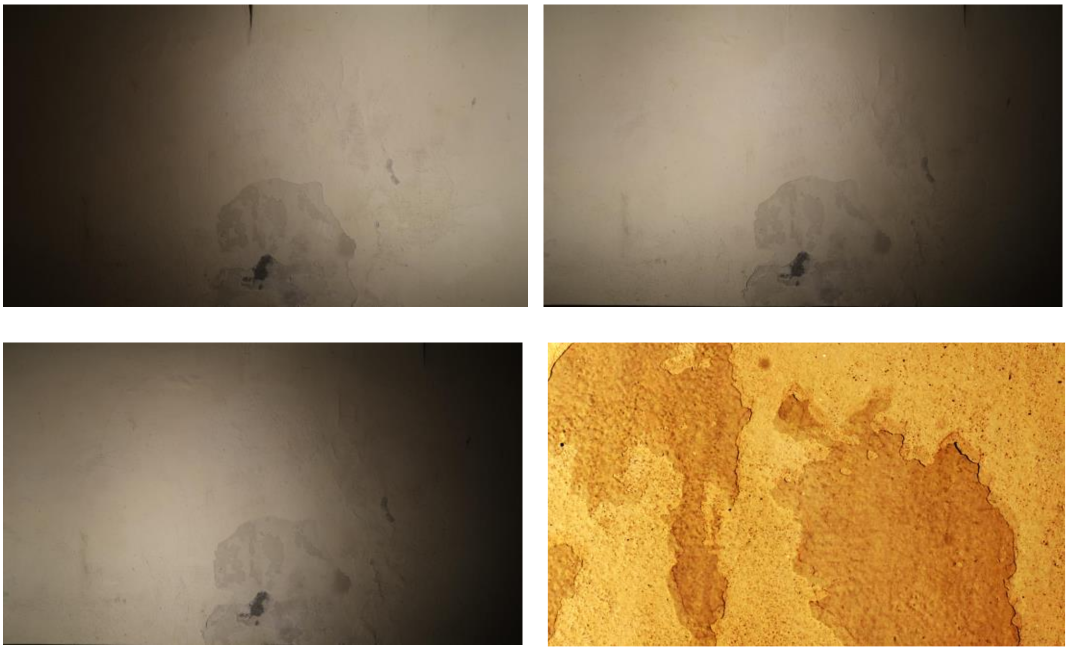


*Figure 9: Input images for photometrics stereo taken under different light angles; right bottom: detail of merged images*

When taking images in the field, ideal conditions like in a studio never exist. Especially when using a UAV, we must take slight position and orientation variations between exposures into account (Figure 9, left bottom). We compensate these offsets and the brightness variations using computer vision techniques. While this method does only deliver approximate depth values, the reconstruction resulting from applying photometric stereo to the compensated images enables us to detect cracks and measure surface roughness.

The resulting models show depth differences in the order of tenths of millimeters. Even the differences between layers of paint are visible (Figure 10). The algorithm can reconstruct a normal map, which can be used for rendering under different (synthetic) light directions for visual inspection and for measuring surface roughness. This normal map can be integrated to produce a depth model (Figure 11), which can be used to evaluate the nature of surface defects.

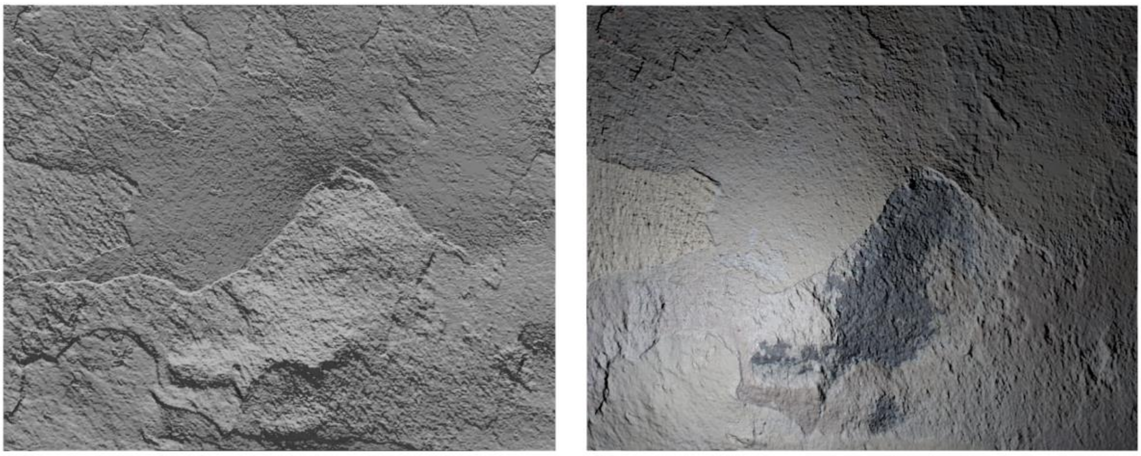


*Figure 10: photometric reconstruction: (left) neutral material; (right) with original albedo*

*Figure 11: photometric reconstruction in isometric projection*

## 9. CONCLUSION AND FUTURE WORK

The combination of (relatively) inexpensive visible light and thermal cameras with unmanned aerial vehicles allows us to cover large cultural heritage sites efficiently enough to cover them at least once per year. Inexpensive high-performance computing solutions based on graphics processors deliver the processing power necessary to reconstruct highly detailed, textured 3D models from these image clouds.

In combinations with automatic comparison and analysis algorithm which we are currently developing, documentation and monitoring of the huge mass of Europe's cultural heritage will finally be made economically and technically feasible.

### Acknowledgements

*VRVis is funded by BMVIT, BMWFW, Styria, SFG and Vienna Business Agency in the scope of COMET - Competence Centers for Excellent Technologies (854174) which is managed by FFG.*

## 10. REFERENCES

Agisoft PhotoScan. (n.d.). Retrieved August 2017, from http://www.agisoft.com/

Hartley, R., & Zisserman, A. (2003). *Multiple view geometry in computer vision.* Cambridge university press.

Hoegner, L., & Stilla, U. (2015, #mar#). Building Facade Object Detection from Terrestrial Thermal Infrared Image Sequences Combining Different Views. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 55-62. doi:10.5194/isprsannals-II-3-W4-55-2015

Holroyd, M., Lawrence, J., Humphreys, G., & Zickler, T. (2008). A Photometric Approach for Estimating Normals and Tangents. *ACM SIGGRAPH Asia 2008 Papers* (pp. 133:1--133:9). New York, NY, USA: ACM. doi:10.1145/1457515.1409086

Octocopter MK 6S12. (n.d.). Retrieved August 2017, from http://www.mikrokopter.de/en/products/mk6s12e/flightsystems

Patrick Westfeld, D. M.-G. (2015, November). Generation of TIR-attributed 3D Point Clouds from UAV-based Thermal Imagery. *Photogrammetrie - Fernerkundung - Geoinformation, 2015*(5), 381-393(13).

Stockman, G., & Shapiro, L. G. (2001). *Computer Vision* (1st ed.). Upper Saddle River, NJ, USA: Prentice Hall PTR.

Woodham, R. J. (1980). Photometric Method For Determining Surface Orientation From Multiple Images. *Optical Engineering, 19*, 19 - 19 - 6. doi:10.1117/12.7972479