3D-visualization and Reconstruction with Computed Tomography:

Scanning and Reconstruction of a Late 15th-century Polychrome Stucco Relief

HAWK HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFT UND KUNST Hildesheim/Holzminden/Göttingen

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Project supervisor: Prof. Dr. Ursula Schädler-Saub (HAWK Hildesheim)

Salome Larina Hunziker (freelancer, lecturer)
salome.hunziker@gmail.com

Image 1: Polychrome stucco relief *Adoration of the Magi*, Freiburg, status quo; picture: Axel Killian 2018.

Picture 2: Stucco relief *Adoration of the Magi*, Berlin, lost in 1945, Photo Archive National Museums in Berlin - Prussian Cultural Heritage (scan photo glass plate).

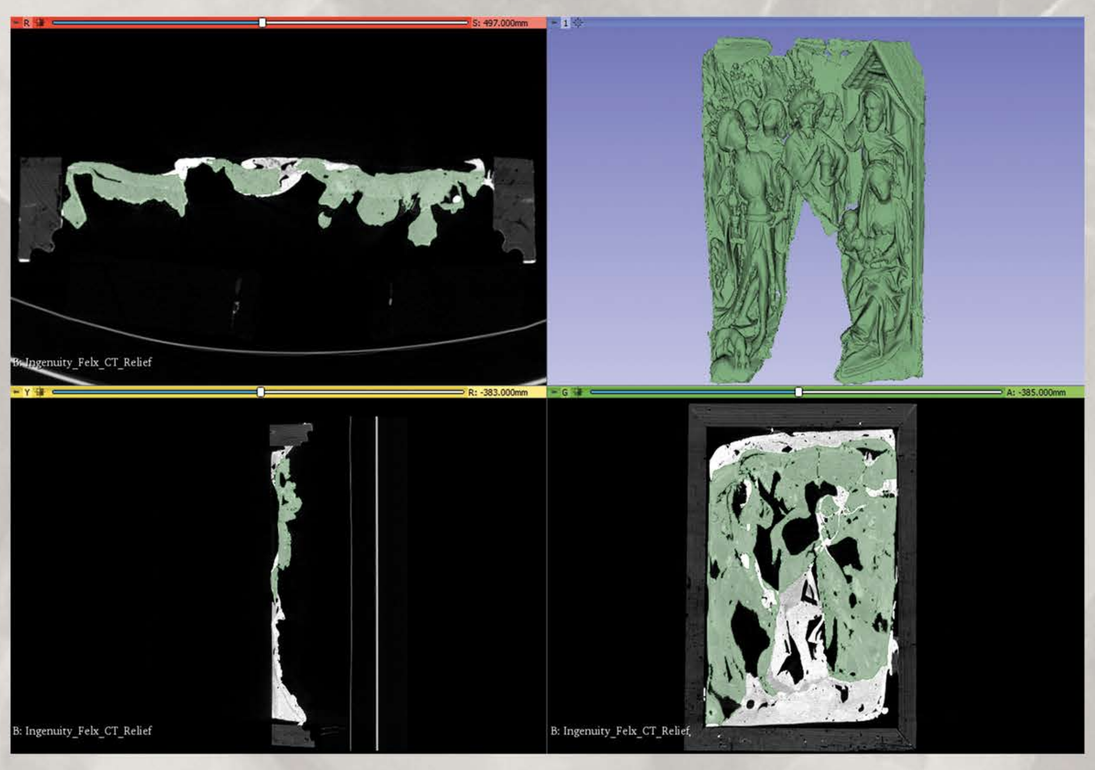

Image 3: Screenshot of 3D Slicer in the Segmentation Editor with segmented cross-section images and 3-D visualization, Top: Left: Top view, Right: Preview of the segmented 3-D model; Bottom: Left: Side view, Right: Rear view.

Image 4: Comparison of manually modelled model (left) and digitized, post-processed model (right).

Image 5: Final result of the digital reconstruction. Left: The exported 3D model of the relief after the segmentation without any newer additions. Right: Segmented 3-D model with the reconstructed kneeling king after the historical image of the comparative relief from Berlin. To divide the reconstructed parts from the original parts the models are colored differently.

References and Notes

1 Miles, James et al.: The use of computed tomography for the study of archaeological coins; in: Journal of Archaeological Science: Reports Volume 6, April 2016, P. 35-41. DOI: https://doi.org/10.1016/j.jasrep.2016.01.019

2 Maxzin, Joerg: Der Bozzetto oder die Suche nach der verlorenen Form, in: Technische Hochschule Deggendorf (Hrsg.): Lukas aus der Asche, Auferstandenes Kulturerbe aus dem 3D-Labor, 1st. Edition, Lindenberg im Allgäu 2016, P.115-139.

Hunziker, Salome Larina: Aus Zwei mach wieder Drei: technologische Untersuchung und digitale Rekonstruktion des gefassten Stuckreliefs „Die Anbetung der Könige" im Augustinermuseum Freiburg; Master-Thesis University of applied sciences and art - HAWK, Hildesheim 2020. DOI: 10.5165/hawk-hhg/465

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Introduction

Over time, works of art experience changes, including significant losses in the case of sculptures. The original appearance can be discovered in historical photographs and archives, if they are available and in good condition. In the case of plaster reliefs, historic photographs can show the object only two-dimensionally, whereas the depth effect is lost. When losses have been filled and parts have been added, it is not always possible to reconstruct exactly how the additions are located within the object, and what has been preserved from the original substance.
3-D model visualization and more specifically computer tomography (CT) can provide clarity.
A program in which both the CT cross-section images can be evaluated, displayed and processed as a 3-D model is required.

Case Study

The Augustinermuseum Freiburg, Germany, presents a polychrome stucco relief (late 15th century), which shows the adoration of the magi.Over the centuries, the kneeling king in the center, in the foreground, was lost. When the missing section was restored in the past, the lost king was not reconstructed. Instead, the addition was adapted to overall form of the relief.

The archives of the National Museums in Berlin contain a historical photograph of a comparable lost stucco relief, which shows the same arrangement of the figures but with an additional king in the foreground. With the combination of CT scans and 3-D digitization procedures, newer additions could be identified, digitally removed and exported as a 3-D model.
The missing king was re-modeled according to the historical image and will be fitted into a 3-D model with the reconstructed missing section.

Procedure

1. Software selection

In order to view and evaluate the CT images, there are various free applications, developed for image analysis in the medical field. The selection criteria for the software was that cross-section images should be displayed as a point cloud 3D model and that the model could be edited and analyzed directly in the program. It should also be easy to use, accessible for free and available for any operating system. In this case, 3D Slicer, a program developed by scientists from multidisciplinary backgrounds, was the best choice. More info at: https://www.slicer.org/

2. Computed tomography scan

At the Technische Universität (TU) Munich, the relief was first scanned in three parts using a high-resolution micro-CT scanner, for technological research. For the generation of the 3-D model, the relief was scanned in one pass using a Helix CT for human medicine. In both scans, grayscale 2-D cross-section images from all three axes were generated.

3. Segmentation and 3-D-model export

Segmentation is the marking of areas in the cross-section image which belong to the original substance, according to the gray value range. For segmentation, all cross-sections of the relief were viewed individually and the areas were marked manually. Similar to image editing programs, painting tools were used for manual segmentation, where the program directly uses the 3-D arrangement of voxels instead of two-dimensional pixels. A simultaneously generated real-time 3-D visualization provides direct visual feedback to guide the user through the segmentation process. The marked areas in the cross-sections were exported later as a 3-D polygon mesh. Manual segmentation can also be prone to errors if certain greyscale ranges are misinterpreted or the marking is not carried out properly. This technique has been used in archaeology for some time, as shown by the X-ray scanning and segmentation of a Roman coin find in Yorkshire[1] . However, in the field of conservation, no comparable publication could be found where the segmentation was carried out with a freeware program such as *3D Slicer*.

4. Reconstruction of the lost king

The digital reconstruction of the lost king began with manual remodeling. One of the biggest challenges was to get the right feeling for the plasticity, height and angle of wrinkles and hands, but also of facial features. A similar problem arose at the reconstruction of the life-size, fully plastic figure of the Evangelist Luke in the Theatine Church St Kajetan in Munich, which was destroyed during the Second World War. Major parts of the figure had to be re-modeled, on the basis of a single frontal shot and the artist's style had to be imitated. One of the preserved figures served as a style template for this.[2] This type of digital reconstruction is still very rare and so far still rather novel.

The modeled king was then digitized by photogrammetry (structure from motion), post-processed in the 3-D graphics program Blender, and fitted into the loss in the middle of the segmented 3-D model. With the Boolean modifier, the edges of the loss were subtracted from the reconstructed part, so the fragment could fit in perfectly. Aspects of conservation ethics must also be taken into account: even though a reliable photographic template was available, the lack of depth perspective can lead to misinterpretations during modeling. The hypothetical aspects of the reconstruction should be as minimal as possible. In order to clearly differentiate between free reconstruction and original substance, both models were coloured differently.

Conclusion and reflection

With the segmentation of the original carrier areas and the digital reconstruction, two 3-D models were created, which visualize the material history of the relief. In combination with the 3-D model, it can be shown for the first time how much of the material of the original relief has been preserved and which areas are modified. The visualization and the processing of the CT images as a 3-D model offer great potential for conservation. The setup and training in the two programs 3-D Slicer and Blender required a lot of time, since knowledge of the programs was acquired autodidactically.

Additionally, due to the large amounts of data in the models, both programs required a lot of computing power. Despite close inspection and marking of the individual layers and cuts, areas with a similar grey value can be subject to misinterpretation. Since none of the automatic segmentation algorithms could provide an error-free result, the process had to be carried out completely by hand which was time-consuming.
When reconstructing the missing figure, it was difficult to find the right style to the overstretched posture, the facial features as well as the shaping of the hands. It is important for the visualization of the reconstruction that the 3-D model alone shows comprehensibly which areas have been reconstructed and which areas show the original substance.