Compiling a Digital Toolbox: The Use of 3D Technology for the Restoration of Intricate Artworks

AUTHORS

Lien Acke*
Conservation-Restoration
Antwerp University, Belgium
lien.acke@uantwerpen.be

Kristel De Vis
Conservation-Restoration
Antwerp University, Belgium
kristel.devis@uantwerpen.be

Stijn Verwulgen
Product Development
Antwerp University, Belgium
stijn.verwulgen@uantwerpen.be

Jouke Verlinden
Product Development
Antwerp University, Belgium
jouke.verlinden@uantwerpen.be

**Corresponding Author*

KEYWORDS

Restoration · Porcelain · Drape lace · 3D scanning · Computed tomography · 3D modelling · 3D printing

Figure 1. *Porcelain figure group. Schwarzburger Werkstätten für Porzellankunst, ca. 1940-1990 CE. Academic collection, H 22.8 cm × W 29.0 cm × D 20.2 cm · Courtesy of University of Antwerp*

PILOT STUDY

Starting with the complex nature of drape lace mounted on porcelain figurines, methods of 3D technology for use in restoration were examined in a pilot study. A porcelain figure group, including a lady wearing a porcelain lace dress with many lacunae was chosen for testing (Figure 1). The dress exists of an extremely fine lace imitation, made with real lace dipped in porcelain slip, mounted in place before firing. Because of the intricate details, small scale, and fragile nature, the dress cannot be easily restored manually without risking further damage.

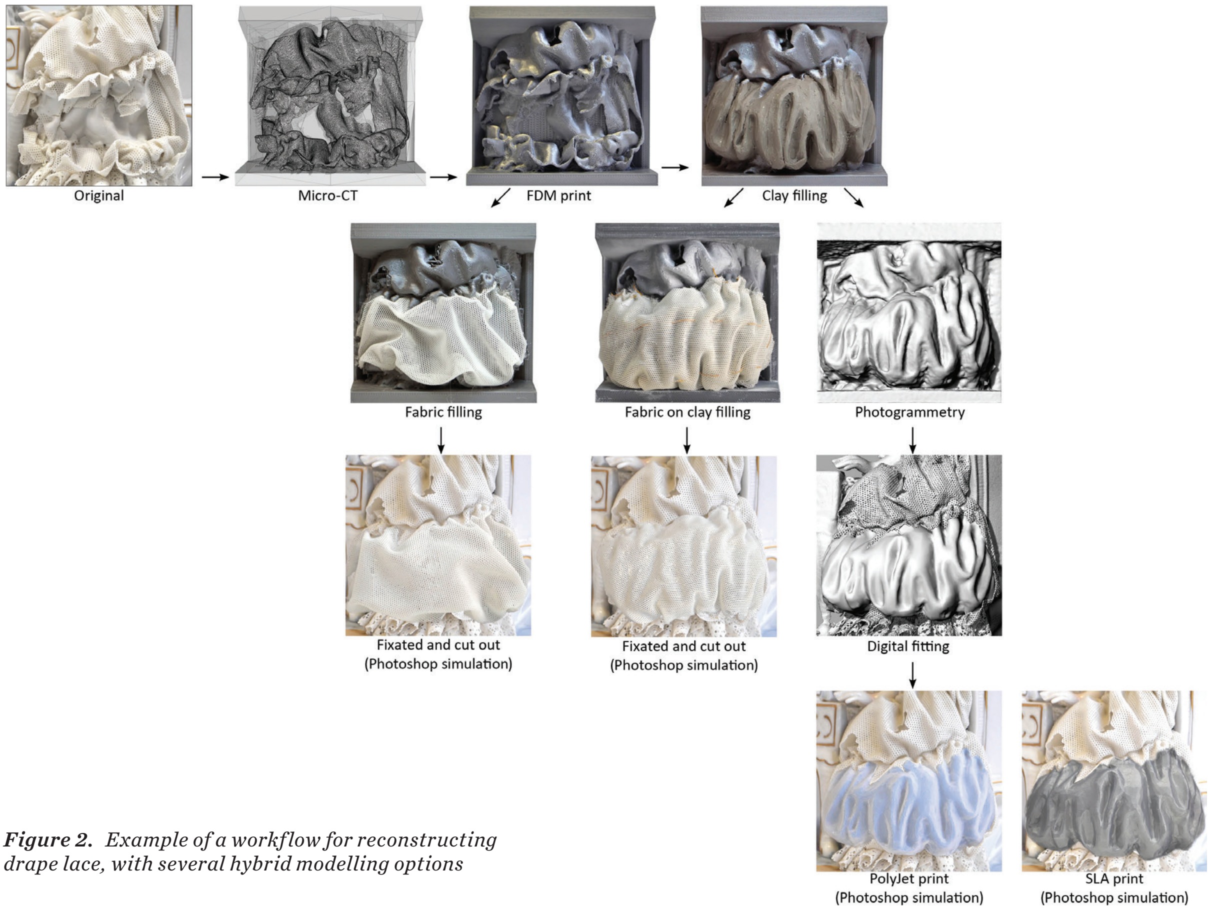

Figure 2. *Example of a workflow for reconstructing drape lace, with several hybrid modelling options*

Due to the highly reflective nature of glazed porcelain, taking a structured light scan to capture digital data was not practical. Therefore, the figurine was instead scanned with computed tomography (CT). A medical CT and a micro-CT, with a much higher spatial resolution, were executed and compared.

Computer-aided design (CAD) or digital modelling with Rhinoceros 5.0 was used for a small lacuna. Mixed methods of both manual and digital modelling were necessary for shaping the biggest lacuna: a fused deposition modelling (FDM) print of the medical CT was used as a starting point for draping fabric and fixating it. Another method consisted of sculpting a fill with modelling clay on the FDM-print and scanning that using photogrammetry. The micro-CT and this scan were combined as input for 3D modelling in Rhinoceros 5.0 (Figure 2).

Requirements for printing were based on the thinnest possible wall and layer thickness and in a lesser extent on the material properties of the print material. The finest result (16 μm) could be obtained with a PolyJet printer, but the print material, an unstable acrylic photopolymer, was found to be unsuitable for adequate longevity. However, this technique was used for systematic testing. The final prototypes (50 μm) were printed with a stereolithography (SLA) printer operated by Materialise, Belgium.

Although post-processing of the employed scanning techniques is time consuming and accurate 3D modelling is difficult and requires significant practice, the employed methods, with some optimisation, can be effectively used in the restoration of intricate and complex structures. It can be concluded, however, that manual techniques remain indispensable within the use of a digital workflow. Furthermore, scanning, modelling, and printing are extensive domains with many possibilities, and in ever-constant evolution. Only a few techniques have been tested and discussed within the framework of physically shaping the fill. The next steps include attaching and retouching the 3D print.

FURTHER RESEARCH

The above-described experimental pilot study provided a subject for further research. The restoration of the figurine has not yet been finished due to limitations in each phase of the aforementioned process. The goal is to complete the restoration of the figurine, as well as other fragile, intricate, complex cases.

The main limitations encountered during the pilot study were (Acke et al. 2018):

- Optical 3D scanning: reflective surfaces, glaze translucency and hard-to-reach areas complicate the requirements for desired resolution and accuracy.
- Executing (micro)computed tomography: presence of chemical elements in the glaze with a high atomic number can influence the noise and complicate the tomographic reconstruction.
- Digital storage: intensive post-processing is necessary and large file sizes are generated from the datasets.
- Digital modelling: difficulty depends on the presence of extant structures for recreating missing pieces. When no reference piece exists, a 'copy-paste' technique is not possible. CAD-modelling is not generally known by restorers, and remodelling a complete shape can thus be a difficult or an impossible option.
- 3D printing: not all printing techniques are capable of printing very fine results and not all print materials are suitable for use in restoration. Decision-making can be complicated by a lack of applied research in this field.

DIGITAL TOOLBOX

To avoid or overcome these limitations, our ongoing research project aims to provide a comprehensive 'digital toolbox', an overview of emerging and existing scanning and printing techniques. It will map out useful information and provide links between listed techniques and expected results, and suggest which technique may be best for different types of objects.

In a digitally-restored object's lifecycle, certain steps should be followed to achieve adequate restoration (Figure 3). Secondarily, the digital toolbox will aid restorers by sharing case studies performed by other restorers or researchers. The toolbox can be seen as a restoration report of integrated documentation (Stylianidis et al. 2016) where all the different steps are documented and the visual (2D and 3D) information can be stored for possible reuse.

As opposed to scanning and printing, physical (re)modelling missing pieces is not only a technical challenge, it requires an understanding of the missing shape. Generally, restorers are well trained to tackle this, both by education and experience. It is mainly a manual process and the result depends on the restorer's hand skills. This research will investigate and experiment with different types of conventional manual methods, but also with digital and combined hybrid methods. A digital intermediate process can be necessary for objects that are considered impossible to restore without causing further damage to the object. It is crucial to test different methods and to (publicly) evaluate the results, both visually and practically.

DIGITAL SHAPE INPAINTING

Within this workflow for remodelling, a complete digital approach will be considered: digital shape inpainting. This means the digital reconstruction of missing parts in three-dimensional objects using CAD-software or different automatic algorithms. Both digital options will be explored; however, the automatic generation of a shape is the option that raises the most questions, methodologically and ethically.

It is important to make a distinction based on the nature of the missing part:

- When dealing with incomplete scan models, the holes in the point cloud or mesh need to be fixed in order to obtain a watertight model. As previously stated, faults in scan data could occur because of occlusions, reflectance, missing views, unreachable parts, or perhaps carelessness. Many authors have already addressed this issue, from early 2000 to today. (Davis et al. 2002; Attene, Campen, and Kobbelt 2013)

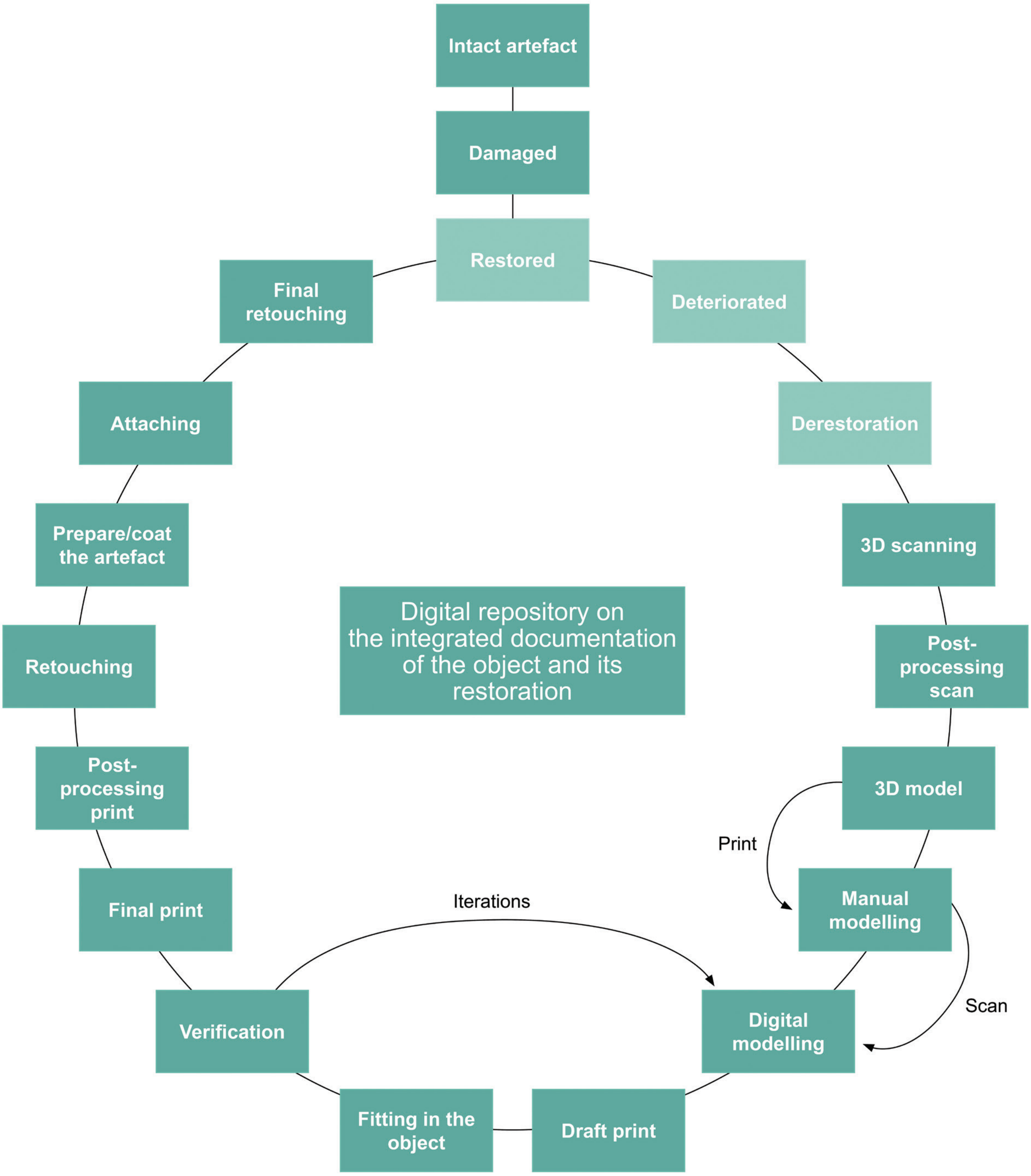

Figure 3. *Lifecycle of a digitally restored cultural heritage object*

- Regarding art restoration, we have objects with missing pieces specific to the state of the object. A completion of the shape is (often) desirable. Fewer publications are made about this type of missing part; as far as the author knows, only the results of Sahay and Rajagopalan (2015); Setty, Ganihar, and Mudenagudi (2015); and Setty and Mudenagudi (2018) are available.

Setty and Mudenagudi (2018) give a thorough review on related work, making a distinction between hole filling in meshes or point clouds working with patches from neighbouring regions (context-based methods), next to using other existing external examples for hole filling (exemplar-based methods).

The article concludes by stating that not all of the related work is suitable for complex, large, irregular regions, with possibly high curvature. This is often true with any loss compensation treatment of cultural heritage objects. They apply on the UNESCO world heritage site of the Hampi temples, India, a region-of-interest based inpainting method, using different extant examples and by selecting the most relevant basic shapes from these examples, corresponding to the missing the regions.

With this method, a new shape is created based on other, similar, extant examples, but without having documentation of the original shape. When this technique is to be used as a method for loss compensation of broken statues or other cultural objects, thorough research should be done into what this means for the authenticity of the object and its restoration.

CONCLUSION

The pilot study proved there are many limitations to consider during a digital workflow. Determining which techniques are available and applicable to certain types of objects and materials is a tricky and time-consuming task. Therefore, a comprehensive and practical overview, a digital toolbox, will be constituted. Next to a practical overview of the different options for 3D scanning and printing, the toolbox will provide a workflow for different types of modelling (manual, digital, hybrid) and guide restorers in this process. This will mainly focus on uses for objects that are fragile, intricate, miniature in scale, and/or with complex features, such as the figurine with drape lace porcelain. Such objects can be considered as some of the most difficult to restore and with the most limitations. The presented techniques can also be used for larger, less complex-shaped objects, provided there is need and capability for 3D technology to be used within the process of restoration. Ultimately, the digital toolbox aims to bridge the restorer and the 3D technology specialist by making these techniques more available for the field of cultural heritage.

ACKNOWLEDGEMENTS

This project is funded by Research Foundation-Flanders (FWO).

REFERENCES

Acke, L., K. De Vis, T. De Kock, E. Indekeu, J. Van Goethem, S. Van Akeleyen, M. Cornelis, J. Verlinden, and S. Vermulgen. 2018. Treatise of digital reconstruction and restauration of lace porcelain. In *Digital heritage. Progress in cultural heritage: Documentation, preservation and protection. (Lecture notes in computer science, volume 11196)*, eds. M. Ionnides, E. Fink, R. Brumana, P. Patias, A. Doulamis, J. Martins, and M. Wallace, 15-26. Cham: Springer.

Attene, M., M. Campen, and L. Kobbelt. 2013. Polygon mesh repairing: An application perspective. *ACM Computing Surveys* 45(2): 1–33.

Davis, J., S.R. Marschner, M. Garr, and M. Levoy. 2002. Filling holes in complex surfaces using volumetric diffusion. In *Proceedings: First international symposium on 3D data processing, visualization, and transmission, Padova, 19-21 June 2002*, ed. B. Werner, 428-441. Los Alamitos: The Institute of Electrical and Electronics Engineering Computer Society.

Sahay, P. and A.N. Rajagopalan. 2015. Geometric inpainting of 3D structures. In *2015 IEEE conference on computer vision and pattern recognition workshops (CVPRW), Boston, 7-12 June 2015*, 1–7. Los Alamitos: The Institute of Electrical and Electronics Engineering Computer Society.

Setty, S., S.A. Ganihar, and U. Mudenagudi. 2015. Framework for 3D object hole filling. In *2015 fifth national conference on computer vision, pattern recognition, image processing and graphics (NCVPRIPG), Patna, 16-19 December 2015,* 1–4. Los Alamitos: The Institute of Electrical and Electronics Engineering Computer Society.

Setty, S. and U. Mudenagudi. 2018. Example-based 3D inpainting of point clouds using metric tensor and Christoffel symbols. *Machine Vision and Applications* 29(2): 329–343.

Stylianidis, E., A. Georgopoulos, and F. Remondino. 2016. Basics of image-based modelling techniques in cultural heritage 3D recording. In *3D recording, documentation and management of cultural heritage,* ed. E. Stylianidis and F. Remondinio, 253-304. Caithness: Whittles Publishing.