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The use of digital 3D techniques to copy works of sculptural art

Summary

Thus far, in conservation, the commonly used method for making copies of sculptural objects was the use of stucco techniques. These consist in preparing a form of the model, which is its negative, usually with the use of silicone rubbers. The form obtained gives rise to an impression, which reflects the shape of the original. It may already constitute a target copy or it may be a transitional form – serve as a model in the process of copying with a punch, sometimes supported by pre-treatment with a CNC milling machine.

The copy obtained using the stucco technique impeccably reproduces the structure of the material, the network of cracks in the mortar and holes left by wood-eaters, which makes it more authentic. Obtaining a form in this technique, however, involves covering the surface of the copied work with silicone rubber which may damage the polychrome on its surface, the gilding or lead to a color change of the object through its excessive saturation. In addition, as silicone affects highly perforated structures, it can be difficult to be removed completely. While removing it, the more delicate fragments of the sculpture may also be mechanically damaged. It is not always possible to use protective layers before applying silicone (e.g. in the case of highly porous materials) and their application may also lead to a change in the saturation of the original color.

Acquiring a negative form is therefore a physical interference with an object, which carries a certain risk of changes in its substance and structure. Moreover, the stucco technique does not enable one to make a technological copy of wooden or stone objects. Additionally, in the case of objects in a religious cult, making copies in plastic can be an obstacle.

Taking the above into consideration, the use of this copying technique in the case of extremely valuable works of art is not always possible or acceptable, among others, by the monument protection services.

Whereas impression copies, allowing for the reproduction of a sculpture in wood or stone, are based on the craftsmanship and intuition of the sculptor who made them. It is similar in the case of copies reproducing the model with the use of a punch, the esthetic value of which largely depends on the sculptor's ability. Neither, however, is usually able to reproduce the object in the smallest details.

Therefore, the non-invasive methods of making copies of spatial objects with the use of digital 3D techniques, which have been developed for several years, prompted the author

to look into the possibilities of using them for the purpose of copying works of sculptural art. Their undeniable advantage is the possibility to avoid direct contact with the historic structure of the work during the copying process.

3D measurement methods and computer-aided manufacturing techniques were initially developed for industrial needs and became more commonly used at the end of the 1980s. Their use for the purposes of art began with the first 3D scanning of the Michelangelo's *David* sculpture, in 1998/1999. On the other hand, the first instance of copying the sculptural form of a piece with the use of 3D techniques, known to the author, comes from 2005. At that time, three small-size copies of the figure representing Michelangelo's *David* and a copy of another sculpture by this author, *Moses*, were made.

It was traditionally assumed that in order to faithfully reproduce a normal-sized human bust, a sculptor, using the traditional technique of working with a point marker, should mark about 250 points on the copied object. Meanwhile, modern structured-light scanners can map 10,000 measurement points on the surface of... 1 mm2! In the course of the author's preparation of a copy of a small sculpture of St. Catherine, 50 cm in height, the final 3D model consisted of a triangle mesh, containing 4.02 million points and 8.04 million triangles.

It could seem that due to their potential, expressed in the greatest advantage, i.e. non-invasiveness and previously unattainable accuracy of mapping, the 3D methods will be able to completely replace other techniques of copying works of art that have been used up to now.

However, this has not happened so far. Admittedly, in recent years, commercial projects have already been developed in which copies made with incremental techniques appeared in the space of original monuments, but these are still only single realizations. The reasons for this are very complex. The issues discussed in this paper and a comprehensive look at the process of copying with digital 3D techniques were, among other things, aimed at answering the question of why this solution has still been so rarely used up to date.

The second objective of the work was an attempt to present the whole proces of making copies with the use of 3D techniques, which is very complicated and involves a team of people representing many specializations; from the moment of its planning, through individual stages, to the final implementation. So far, the literature on this process has been very scattered. It often focused solely on selected methods or even one measurement method, sometimes it considered only a few manufacturing techniques. Some of the publications were mere mentions. In addition, the specialized language used in publications concerning modern technologies is a certain barrier for a wider group of non-related recipients.

Certain elements of digital 3D techniques in the field of copying works of sculpture art are already in use and others are being implemented. This requires people responsible for

historic works of art to be aware of their basic aspects. To fully harness the potential of modern technology and obtain the intended objective with its help, one should possess appropriate knowledge concerning the available possibilities that allow achieving a three-dimensional model and the methods of its later production. Although the conservator will not perform all the associated tasks personally, he or she must be aware of the possibilities and limitations of individual methods at each stage of implementation in order to make the optimal choice as regards the intended goal. Even more so as the specific manufacturing method determines the choice of material with peculiar properties, the accuracy of the model mapping, its durability and a number of parameters that should be taken into account as early as at the design stage of works.

The author, seeing the importance of developing 3D techniques, made an attempt to collect and systematize the currently available knowledge on the possibility of copying works of art with the use of digital 3D techniques. It was written from the perspective of a conservator of monuments who is facing the necessity of makinga copy of a sculptural work of art. This viewpoint may be fundamentally different from the perception of the process and the end result by computer scientists, computer graphic designers or other people from technical fields, most often involved in copying works of art using modern digital methods. Most of the publications available until now were written with only the technical dimension of this type of undertaking in mind. The problematic aspects of copy authenticity, mapping of the pattern of cracking, holes left by wood-eaters, the weft of the canvas, i.e. everything that has a huge impact on the final esthetic reception and credibility of a copy of a historic object was often omitted in publications analyzing the proces of reproducing a work of art using digital methods.

For this reason, the aspects discussed in this work are not developed symmetrically. More attention was given to the issues more important from the point of view of conservators-practitioners who, among other things, make copies of works of art. The principles of operation of particular techniques of additive manufacturing are described in detail because they make it clear what the structure of the objects that were already finished is. It is vital as their construction has a direct impact on their durability, which is of great importance in the case of historic objects and their often very expensive copies.

The present doctoral dissertation has been divided into two parts. The first one, theoretical, consists of six chapters and it is a kind of introduction, without which the issues discussed later would be difficult to understand.

The techniques of mapping a sculptural form into a digital 3D model are subsequently discussed in more detail, with particular emphasis on the most commonly used 3D scanning techniques. In addition, photogrammetric techniques, methods of obtaining a shape from a contour and building a 3D model from non-oriented 2D photos as well as tomographic techniques were discussed. The possibility of using holography and interferometry to obtain three-dimensional images was also suggested. The review of

measurement techniques was summarized through the comparison of their possibilities and limitations.

The following chapter outlines the process of creating a 3D model on the basis of data obtained in the course of measurements carried out with the use of the methods mentioned above. The process of creating a virtual model is discussed, in sequence: from the point cloud obtained during 3D scanning; from photogrammetric data; from a set of tomograms obtained with tomographic techniques and from a series of non-oriented images.

The possibilities of modeling the copied object in its entirety in a virtual environment were also demonstrated, which could be useful if it was impossible to carry out measurements in the case of, for example, objects not preserved to our times, recorded only in photographs.

Next, the methods of producing 3D physical models are discussed, divided into cutting techniques (using CNC machines) and incremental techniques (SLA, FDM, SLS, LOM, 3DP and PolyJet systems). Their benefits and limitations have been listed.

The materials used in individual 3D printing techniques were also reviewed, discussing the ones that are most widely used, among others, PLA, ABS. Attention has been drawn to the issue of their durability, which may turn out to be a serious problem. The materials used for additive manufacturing are mainly plastics, which are expected to last for 15–20 years by industry standards. Some of tchem are biodegradable under less demanding conditions. Additionally, these plastics are often composites or blends of many chemical substances, each of which may affect the nature of the aging processes. Moreover, the method of connecting the materials in a particular technique may also be significant for the durability of the printed object. As regards copies created in layers, which is the case with incremental techniques, the possibility of, among others, anisotropy should be taken into account.

In the next chapter, attention is drawn to virtual copies, because many historic objects function in this space and fulfil an important function. Possible areas of their application were indicated in terms of research, protection and popularization of cultural heritage or indexation of the available knowledge about the object and its transformations, e.g. in the course of conservation works.

The second part of the doctoral dissertation contains a description of the proces of making copies of specific historic objects with the use of various methods. The author has made these copies on her own or with a team, as the supervisor.

An example of 3D scanning techniques in conjunction with CNC milling in wood is the copy of a wooden, polychrome and gilded sculpture of Christ from the *Tribunal's Crucifix* (1578) from the Archcathedral in Lublin, which was prepared in a smaller scale. The possibilities and limitations of the incremental technique are demonstrated on the example of the executed copies of: a wooden bas-relief entitled *Christ's Prayer in the Garden of*

Gethsemane (approx. 1493–1495) by Wit Stwosz from the All Saints' Church in Ptaszkowa using the Woodfill material and the wooden, polychrome, silver-plated sculpture of *St. Catherine* from the *Silesian Triptych of the Maria's Family* (approx. 1500) from the collection of the Collegium Maius Museum of the Jagiellonian University in Krakow. Under the framework of the research work, wood-like materials, Laywoo-D3 and Woodfill, were compared when making copies of *St. Catherine*. The sculpture was also reproduced in the traditional stucco technique with the use of silicone rubber while comparing the quality of the reproduction of the copy made traditionally and the one obtained using digital 3D techniques.

A copy of a wooden polychrome sculpture entitled *Christ on a Donkey* (16th century) from the Monastery of the Poor Clares in Stary Sącz, executed in the traditional stucco technique and carefully analyzed in the text, served as a background to compare the possibilities, but also limitations, of the contemporary techniques for copying works of sculptural art, apart from the already mentioned copy of the sculpture depicting *St. Catherine.*

The implementations described in detail were aimed at tracing the entire proces of making copies in practice using each of the methods in order to determine the advantages and limitations of the given techniques and outline the optimal contexts for their application. It was particularly important to compare the quality of mapping the surface of the copied object with the selected methods and the possibility of developing the surface of the copy made of synthetic materials employed in 3D printing techniques. As part of the description of individual projects, various motives for making a copy of a work of art were also indicated. A given, varying, aim of its production determined the selection of a distinct technique, which should also be taken into consideration at the stage of this type of implementation.

The dissertation ends with a summary presenting the advantages and limitations of the copying methods described in the paper. The final conclusions were based both on the analysis of the literature and personal experiences from the projects implemented or projects which the author supervised.

The dissertation also contains a very extensive reference list concerning copying works of sculptural art with the use of digital 3D techniques. It comprises printed and unpublished works as well as online publications.

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