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3D DIGITIZATION AS A TOOL IN THE CONSERVATION AND RECREATION OF CULTURAL HERITAGE - A CASE STUDY OF THE ICONOSTASIS OF A DESTROYED SERBIAN ORTHODOX CHURCH IN BUDA

Abstract. The 19th century iconostasis of the destroyed Serbian Orthodox church in Buda represents one of the finest masterpieces by the Serbian painter ArsenijeTeodorovic. After the church was demolished in 1949, assorted icons and carved wood fragments were rescued and taken to the Serbian Church Museum in Szentendre, Hungary. In 2013, the conservation project which covered documentation, reassembling of the original pieces, conservation and restoration of icons and models of presentation inside the museum was set up. Due to its size, it would be impossible to display the iconostasis in its original form. This presented an opportunity to apply new technologies to preserve these unique heritage artifacts by digital reproduction such as virtual 3D visualization (which comprises 3D digitization, geometrical reconstruction and artistic presentation of the real object).

The challenges include creating 3D models of curved icons, reconstructing the missing pieces of woodcarving and, following the completion of the conservation work, considering suitable display options for the purposes of a permanent museum exhibition.

The paper presents strategies for resolving the identified problems and a detailed explanation of the applied 3D digitization method based on close range photogrammetry and demonstrated on the example of curved icons. As part of the 3D digitization task, the emphasis will be on data acquisition approaches and image processing methods. Geometric reconstruction will focus on refining the obtained polygonal models to achieve the final model of desired accuracy. This will also include an analysis of issues associated with parts assembling, primarily related to the missing details and damaged edges. Subsequently, possible approaches for virtual model accuracy verification will also be explored. Finally, issues surrounding the preservation of cultural heritage will be discussed, as well as the presentation solutions for the iconostasis' final museum destination.

Keywords. conservation, iconostasis, 3D visualization, photogrammetry

1. Introduction

The idea of using 3D models in the conservation and visualization of cultural heritage, otherwise non visible in its completeness, is far from being new. In the case of the iconostasis of the destroyed Serbian Orthodox Church in Buda (Hungary), due to its state of preservation, 3D visualization becomes a useful tool in the reconstruction of the carved wooden support, too. The specific shape of curved icons represents the challenge for the creation of 3D models with desired accuracy and for finding suitable display options for final museum presentation. Hence, it offers a research problem for digitization experts as well as an opportunity for conservators and curators to implement new technologies in the process of heritage preservation.

The iconostas is in the Orthodox churches are painted structures, most frequently consisting of paintings on wooden support, that separates the nave from the altar apse. The type of structure, the style of woodcarving, dimensions of single icons and of the complete iconostasis has been changing through centuries, developing from low medieval structure with a small number of icons to high and elaborated baroque and classicist iconostasis that fill the entire aperture of the altar apse. The iconostasis of the Serbian Orthodox church in Buda, painted in 1820 by Arsenije Teodorovic, is one of the biggest in Serbian churches, covering not only the aperture of the altar apse but extending on sides and continuing along north and south wall of the church, with curved icons posted in corners.

Figure 1: The view of the iconostasis in its original appearance before demolition of the church

The church, erected in Buda (Hungary) between 1742 and 1751, was demolished in 1949 [1]. The icons survived and are kept in deposits of the Serbian Orthodox church museum in Szentendre (Hungary) [2]. The woodcarved frames of icons, as an important construction, stylistic and aesthetic part of the whole, are missing in a large extent. Fortunately, wooden frames or parts of them survived in an extent that offers the possibility of reconstruction of the whole. The ongoing conservation project includes documentation, archival and technical research, conservation, restoration and partial reconstruction, as well as developing the museum concept for display of icons in the available spaces of the Serbian Orthodox church museum. The complexity of a structure and its parts challenges the engineers to improve existing and create new strategies in 3D digitization. The tight collaboration between art historians, conservators and engineers is fundamental in obtaining good results.

Choice of the optimal method for cultural heritage surveying depends of many factors, such as geometry, size, and shape of object, mobility, and surrounding, properties of the surface material and other. Most of all it is important to define requirements for the final 3D model in the terms of accuracy, level of details, importance of texturing and other data. Photogrammetry is often used for cultural heritage surveying [3-13] often combined with other methods such as laser scanning [14-16] or single-image based reconstruction [7, 17-22]. Properties of iconostasis of a destroyed Serbian Orthodox church in Buda indicate that close range photogrammetry (SfM algorithm) is optimal method for surveying.

2. 3D Digitization

3D digitization is a basic step in a process of the reversible engineering. Many different methods od 3D digitization have been developed untill now, with inherent advantages and disadvantages. Nevertheless, the common characteristics remains the need of collecting spatial 3D coordinates from the physical sufrace of the object. The most widely used method in the 3D digitization of the cultural heritage filed is close-range photogrammetry.

According to [23] "*Photogrammetric method for surface measurement uses at least two images and image matching approaches for the determination of 3D coordinates of object points. As a prerequisite, the surface must provide a sufficient texture that enables the detection and matching of corresponding points"*, this principle is named Structure from Motion (SfM) principle. The method was described by [24] "*Structure from Motion operates under the same basic tenets as stereoscopic photogrammetry. It differs fundamentally from conventional photogrammetry, in that the geometry of the scene, camera positions and orientation is solved automatically without the need to specify a priori, a network of targets which have known 3D positions"*. Due to its accessibility, simplicity, speed, ease of obtaining the textured 3D model and growing precision, this method competes other optical 3D digitization methods.

2.1. Data acquisition. In order to carry through the successful acquisition of photographs it is necessary to plan the surveying, have adequate equipment, and create optimal light environment or adjust to the lighting conditions. The object should be suitable for close-range photogrammetric surveying in the means of size, geometry, surrounding space, characteristics of the surface (especially considering the transparency and reflection of the material). In order to minimize the error of the resulting model, proper calibration of the camera and setting of internal camera parameters is advisable.

Camera properties, such as size of the sensor, the pixel size, maximum aperture of the lens, and ISO sensitivity directly influence the quality of the photographs. Large sensors are better suitable for photogrammetric survey because of the large pixels size. This benefits to the good signal-to-noise ratio in large sensors and increases the image quality. Size and distance of the pixels also protects the image from the blooming artefacts (smearing colors or flared highlights) which can appear in small sensors.

Image exposure is important in order to provide quality input for the software to find the internal and external camera parametras. Three camera parametrars, aperture, shutter speed, and ISO influence the exposure. If the lightnig conditions allow, aperture should be set to f5 or f8. At other values difraction will be apparant in the photograph and that increases the error in the final model. Distribution of the difraction intensity in the image can be checked by specialised software for each specific lens. Shutter speed should be set to minimal possible value that are limmited by current lightning conditions. High values of shutter speed cause motion blure which is very undesirable in photogrammetric reconstruction. ISO sensitivity affects the image quality in the sense of lightness, meaning that with the same set-up for aperture and shutter speed and higher ISO sensitivity, the resulting effect is brighter image. The disadvantage of the increased ISO sensitivity is higher content of the noise, affecting the quality of the photograph.

When setting the aperture value it is very important to consider the depth of field required for the surveying. Online depth of field calculators should be used in advance in order to avoid blur to appear on parts of the image that represents the surveyed object. Blur increases the error of the final model. Depth of field depends of the camera parameters, aperture, distance to the object and focal length. Therefore, before depth of field is calculated, survey should be carefully planned.

The lens construction is relevant too, in the sense that the zoom lenses should be set to maximum or minimum value, in order to avoid the focal length variation during image acquisition [25]. In the photogrammetry, single focal length lenses are more suitable than zoom lenses. In the photogrammetric orientation, the principle distance plays the crucial role. It depends of the focal length but also of the focus distance. This means that variation of the focus target during the survey can cause increment of error in the final model. Hence, focus distance should be calculated in advance considering the object size, distance from the object and depth of field and should stay fixed during the survey.

In this case study, the digital photo camera Nikon D3000 with AF-S DX VR Zoom-Nikkor 18-55mm f/3.5-5.6G lens was used. For the purposes of surveying focal length and focus is fixed to 18 mm (27mm considering the crop factor). This camera has CCD sensor, dimensions 24x16 mm, which enables maximum image size of 3872x2592 pixels.

Next factor important for obtaining quality images is lighting that influence the exposure value of the photograph. The best source is sunlight as it has the widest color spectrum, but the object should not be exposed to direct sunlight. On one hand, it is not advisable because of the harsh shadows, very high dynamic range (that can not be captured by camera) and possibility of high reflection on flat and glossy surfaces. On the other hand, cultural heritage objects are sensitive to the temperature and humidity variations, and exposure to the direct sunlight should be avoided for conservation reasons. The object chosen for the beginning of the 3D digitization of the iconostasis was the woodcarved and traditionally gilded frame of a concave shaped icon, before cleaning and conservation treatment. It was photographed in daylight, but in the diffuse lighting condition, protected from the direct sunlight, posed on a table as shown in Figure 2.

Figure 2: Wooden frame of curved icon

The first phase of the work was acquisition. Optimal distance from the object is calculated considering the expected level of details, object size and camera parameters (pixel size, focal lengths, depth of field). Photos are taken in a full circle around the frame, from the distance of 1,65 m to 1,85 m in order to cover the basic geometry and maintain the object in the calculated depth of field range. The optical axe of the camera was parallel to the ground and passing through the center of the wooden frame.

The baseline is calculated considering the overlap needed for the software to calculate the external camera parameters. Hence, the photographs taken in a basic circle were 21, uniformly distributed. In order to increase the image overlapping, in the next step the camera was brought closer to the object, taking additional 34 photos, with higher concentration to the front, decorative surface of the wooden frame. At the end of the process, total number of photos was 55 ready for software processing. These two series of photographs are treated as separate sets in the software since they differ in focal length and principal distance. All the photos were taken without a tripod since the lightnihg conditions was good enough for very short shutter speed.

2.2. Images processing. Photos were processed using Agisoft Photoscan software. According to [25]*"Agisoft PhotoScan is an advanced image-based 3D modeling solution aimed at creating professional quality 3D content from still images. Based on the latest multi-view 3D reconstruction technology, it operates with arbitrary images and is efficient in both controlled and uncontrolled conditions. Photos can be taken from any position, providing that the object to be reconstructed is visible on at least two photos. Both image alignment and 3D model reconstruction are fully automated"*.

Few basic steps in the image processing can be pointed out. The first one is the mask creation. They are very useful if the object doesn't occupy big portion of an image. The masks in this case are binary images, manually created using available tools for the selection (b/w image, Figure 3a). The parts of the main image overlapped with the black area of the mask do not participate in the orientation of photographs (Figure 3b). With the use of masks the specify image areas is reduced, resulting in the reduced processing time and the reduced possibility of the software error during the matching of common points.

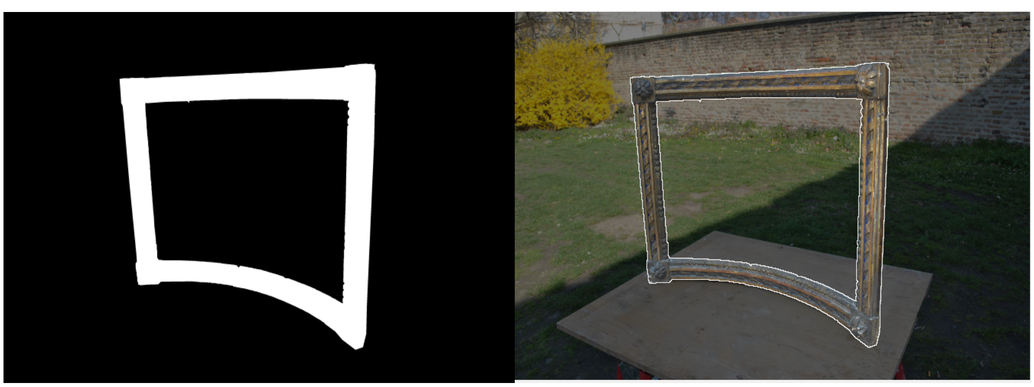

Figure 3: Mask – a) created binary image, b) overlapped on main image

The process of search and overlapping of the photographs is the orientation. *"At this stage PhotoScan finds the camera position and orientation for each photo and builds a sparse point cloud model"* [25] Figure 4 shows the strategy used for image acquisition: a circle for obtaining the main geometry and the detailed photographing of the front side of the object: the wood-carved gilded concave frame of an icon.

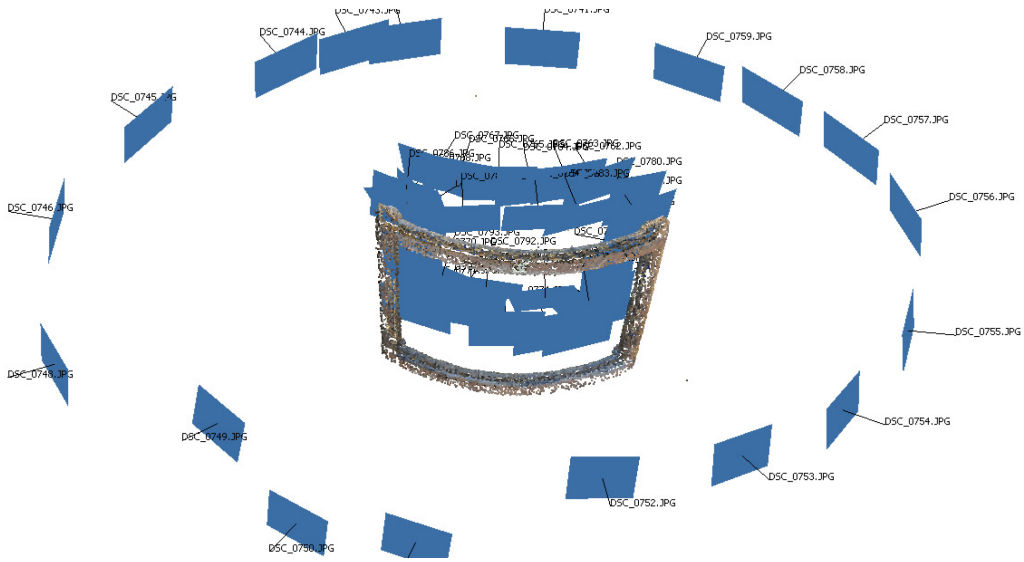

Figure 4: Sparse point cloud with camera estimate position

3. Results and discussion

Figure 5a shows distribution of points in the sparse point cloud. Upper and lower bar of the frame have very good distribution and density, contrary to the left and right vertical bar of the frame. The absence of points on vertical bars is the consequence of the characteristic concave carvings combined with the position of the camera axes. *"As a software derived from the SfM philosophy, Agisoft works better with many images taken with a short baseline rather than few images with a relatively long baseline as in standard photogrammetry"* [26].

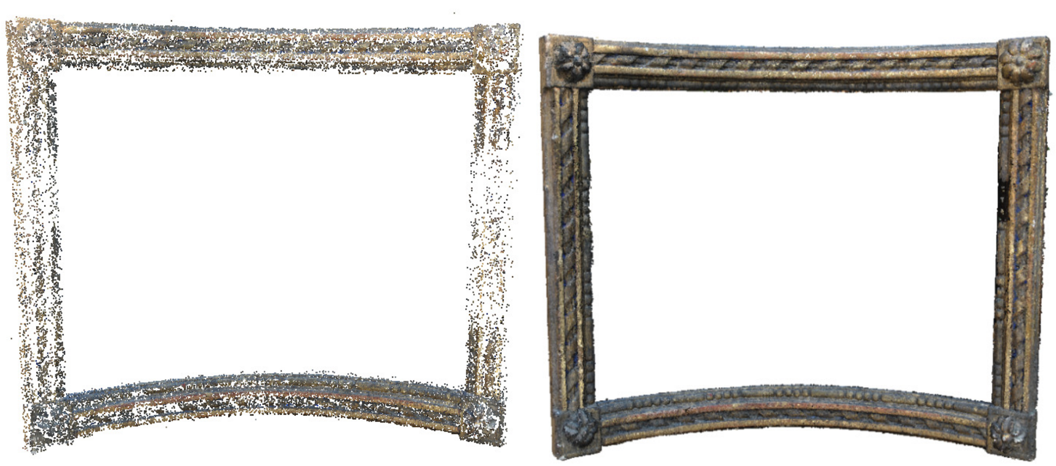

Figure 5: Distribution of points a) Sparse point cloud; b) Dense point cloud

Dense point cloud is shown in Figure 5b is the result of software approximation. The quality of the approximation can be selected from very low to ultra-high, depending on the quality and distribution of pixels in the sparse point cloud. According to the published research results, "*The medium quality seems the best option in terms of quality and time in the processing"* [27]. Therefore, the medium quality of approximation was used in this case.

After the dense point cloud has been obtained, the next step is the generation of the polygonal 3D model, which can be done choosing one of three possible geometries: with the interpolation, without the interpolation and with extrapolation. Each option generate polygonal model. After testing all three possibilities, the best option in this case proved to be the option with interpolation, which characteristic is to add missing geometry by interpolation [25]. Figure 6a shows the polygonal 3D model of the wooden frame for the icon, while Figure 6b shows the details of the upper left and lower right angle of the frame.

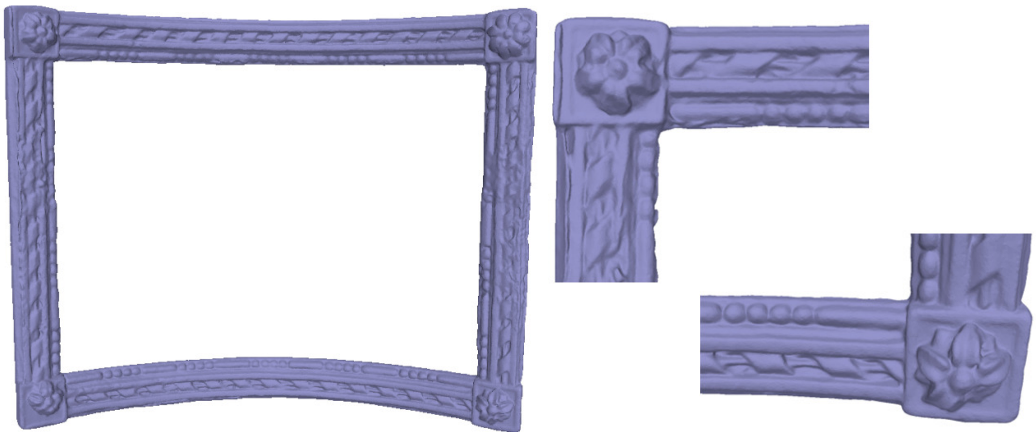

Figure 6: Polygonal 3D model a) Full frame b) Upper left and lower right corner

The absolute scale of the model is determined on the base of known dimensions of the table on which the wooden frame was standing. This model represents the real object in the virtual world, therefore the texture is very important for 3D virtual presentation. The texture is obtained by applying the colors from the images onto the polygonal 3D model. The texture can cover smaller imperfections, errors and the parts of the geometry generated by the interpolation. Nevertheless, if the larger parts of geometry are added by interpolation, the texture will not appear and those parts of the model will be presented in black. This property of the applying texture can be used for visual estimation of the accuracy of the created polygonal model (Figure 7).

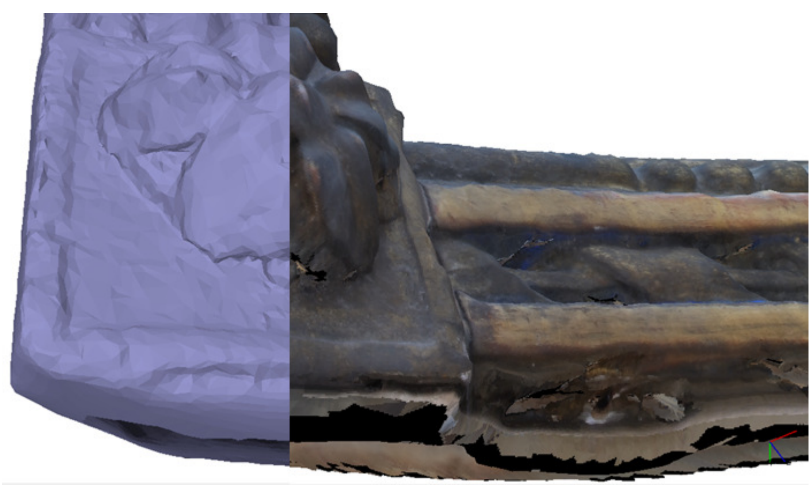

Figure 7: Texture on polygonal 3D model

4. Conclusion

The methodology of data acquisition and photogrammetric processing applied in the case of the curved icon frame gave satisfactory results and offered multiple possibilities for the documentation of conservation treatments of the artworks, as well as for the development of museum products using advanced technologies. In the case of the iconostasis of the former Serbian Orthodox church in Buda, there are several facts that make 3D digitization an important tool that adds value to the traditional conservation and museum solutions.

First of all, the reconstruction of missing woodcarving parts in a traditional way, with manual woodcarving and gilding is hardly probable in this case, due to the their dimensions and number. Such approach would require many hours of specialized work with resulting high costs for the reconstruction. Moreover, due to the dimensions of icons (the biggest is 2.8 m high), and the overall height of the iconostasis (cca 15 m) there is no possibility to recreate the entire structure in the museum rooms. The reconstruction of the original container (the church) is even less possible.

Therefore, in the final exhibition concept, 3D visualization of the whole iconostasis will offer a unique possibility to recreate this important heritage virtually, offering the museum public and the local Serbian society in Hungary an insight it the important historical and artistic heritage.

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