3D DIGITIZATION OF AN ANTIQUE DECORATIVE TEXTILE ARTIFACT USING PHOTOGRAMMETRY

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Abstract. This paper describes a project aimed to demonstrate the great potential of photogrammetry in realizing a detailed 3D digital model of an old Romanian traditional decorative textile piece, from a valuable collection, for 3D printing purposes. The challenge was to record with high precision the planar textile surface and then process the digital replica to the level of a printable 3D object. For the purpose of this experiment close range photogrammetry was employed. Within this paper we are going into every detail of the processing, online publishing and 3D printing stages and discuss each aspect that can influence the final results.

Key words: photogrammetry, 3D printing, textile digitization, mesh decimation, 3D digital replica, cultural heritage

1. INTRODUCTION

Photogrammetry was officially first put in practice in April 1885, when Albrecht Meydenbauer convinced the Prussian Parliament to fund the Royal Prussian Institute of Photogrammetry with the sole purpose of documenting the cultural heritage monuments. Meydenbauer observed that photographs can give precise metric information about the recorded scene or objects. In The Manual of Photogrammetry we find that photogrammetry is defined as “the art, science and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena” [1].

Ever since, photogrammetry has been considered an engineering discipline and is currently heavily influenced by recent developments in computer science and technology. With the increased use of computers and digital photography, photogrammetry has shifted from analog to analytical and digital methods and is mainly performed with mathematical modelling benefitting the high processing power of computers [2].

In the preservation and conservation of Cultural Heritage assets 3D digitization has a very important role. Complementary chemical analyzes, like FTIR [3] for CH artworks and objects or ground penetrating radar visualization of archaeological excavation sites [4] for historical ruins or monuments can deliver a complete digital model of the subject having the 3D replica at its core and all the other data as layers.

Textile digitization is an important and difficult issue that is currently addressed in the international scientific community, usually in corroboration with complementary investigation techniques [5]. Due to their fragility and difficulty of manipulation, textiles represent a tough material to tackle. In general, the digitization protocol includes spatial data acquisition, geometry modeling, digital archiving and online (web) publishing for viewing and studying purposes [6]. A true fact for any kind of cultural heritage asset, but especially for textiles, is that digitization improves the preservation of the artwork. A complete 3D digital model of an artwork will allow any researcher (or general public) to view and study in detail any part of the object without directly interacting with it. Periodic recordings generates direct comparison of the surface morphology evolution in time [7]. Another important feat of the digitization is the universal access it offers [8].

This paper describes the process of recording a 3D digital model of a Romanian traditional decorative textile artifact, coming from Astra Museum of Sibiu – Textile Clothing collection, for both digitization and exhibition purposes in a 1:1 scaled 3D printed format. This object was chosen not only for its cultural and aesthetical value but also for its high level of embroidery detail.

Since the owner of the decorative piece wanted a monochrome printed model it meant that the details of the digital model had to have a lot of 3D details. The texture of a printed model enhances the detail perception of a surface. So, in this case when the model had to be exhibited without a texture, all the textile details had to be visible in the 3D printed replica. The ornamental cloth actually is an embroidery representing Romanian traditional detailed motifs from significant regions of Romania, like an atlas of symbols, thus having a high cultural heritage value.

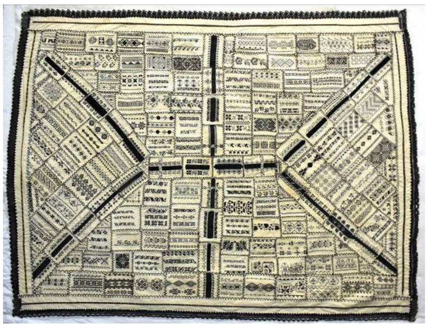

Fig. 1 - Textile decorative cloth photograph.

The challenge of this task was to realize a 3D digital replica of a surface recording the accurate details of cloth material, embroidery threads and seams in a very short time. Another challenge was given by the 3D printer software constraints regarding the amount of polygons processed per printable piece while keeping as much detail visible as possible.

2. MATERIALS AND METHODS

The 3D recording method employed was photogrammetry, mainly for the reason of testing its limits and to demonstrate its efficiency with high detailed surfaces. In order to obtain the best results in object photogrammetry, like in photography, the scene must be set up properly and the equipment set with the optimal settings.

2.1. Data acquisition

The investigated object surface was 1,2 m x 0,9 m and was mounted on a fixed vertical surface. The light source used was fluorescent white at constant intensity and evenly covering the object's surface. Camera used was a DSLR Canon 600D with a CMOS APS-C 22,3 x 14,9 mm sensor, with 18 mega pixels. Constant parameters were used for photography: a fixed focal length of 44mm, f/5.6 aperture with ISO 1600 sensitivity and custom white balance for color accuracy. Exposure time used was 1/100 s at a constant white fluorescent light.

The photography process was designed to capture a high level of detail in each image. Therefore using a tripod and a telemeter the camera was constantly kept at 23 cm distance from the object. At this distance the camera was slided horizontally along the object surface in 27 partially overlapping rows with an average of 21 photos taken per row. The average overlapping surface in each photo was around 40%-70% on horizontal and 50% on vertical.

In the end, after digital processing of the images there were chosen 561 good photos to be used in the following processing steps, each with a resolution of 5184 x 3456 pixels (72 dpi x72 dpi).

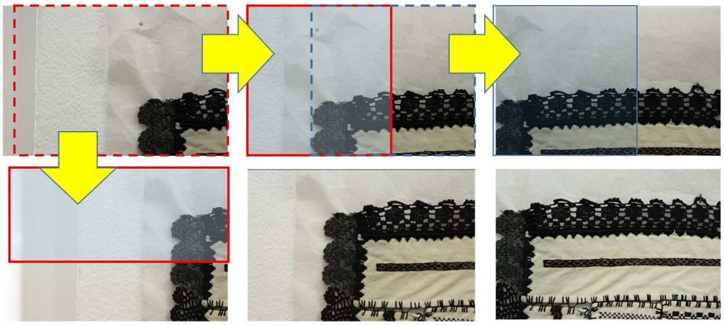

Fig. 2 - Overlapping areas in adjacent photos (vertical and horizontal).

2.2. Data processing

For a better understanding of the processing efforts required, we thought best to share the working conditions. The workstation used for data processing has 8 core processor running at 2,43 GHz, 128 GB RAM memory and a 12 GB GeForce GTX Titan X video card. This is not a top of the line workstation for photogrammetry purposes, but above the average. Each step of the data processing requires a different type of computing resource as we will see in the following. Photogrammetry processing is constituted by several steps and the software used to obtain the 3D model was Agisoft Photoscan.

Meshlab software was used for further mesh editing and quality checks. For 3D printing we used ZEdit Pro (3D models preparations) and ZPrint, softwares dedicated to ZPrint 450, the 3D printer used in this project.

2.2.1. Image alignment

The first step after the image collection recording and their adjustment is photo alignment. At this step the software processes all the photos used and finds the camera position and orientation for each photo and builds a sparse point cloud model. The sparse point cloud in this case was set to unlimited number of points because we wanted to obtain every detail possible.

The main resource used in this stage was the CPU which ran constantly at 89% of its capacity. The RAM memory used was 16,7GB. The project file at this stage was 375 MB.

2.2.2. Dense point cloud

The sparse point cloud can be used as a preview of the 3D model that is going to be built. But this data cannot be used as is for presentation or study purposes. A dense point cloud is generated in a second step of the processing based on the camera positions determined in the previous stage. The software calculates depth information for each camera that is going to be combined into a single dense point cloud. In this stage the dense point cloud shows a much detailed form of the 3D model and now it is the best moment to adjust the scene.

For this particular case the quality setting of the *dense point cloud* was set to downscale the images to 50% (high setting). For our purpose the geometry accuracy obtained this way was enough considering that for higher settings the processing would have taken a much longer time and would also have reached the maximum capabilities of the processing workstation. This step took 7 hours and generated almost 422 million points.

The main resource used in this stage was the RAM memory which variated around the 127GB value (out of 128). The CPU was used only up to 7% of its capacity.

Now we can cut undesired point clouds from the scene, leaving only the object/surface we are interested in. In this case the only undesired points were on the margin of the object.

2.2.3. Building the mesh

Once the dense point cloud has been cleaned up we tried to build up the mesh. A mesh defines the structure of a 3D model and is usually constituted by vertices, edges, faces, polygons and surfaces. Many applications creates meshes with data about only vertices, edges and faces (or polygons). A *vertex* is a position along with information about color, normal vector and texture coordinates. An *edge* is a connection of two vertices. A *face,* or a polyhon, is a triangle connecting three edges.

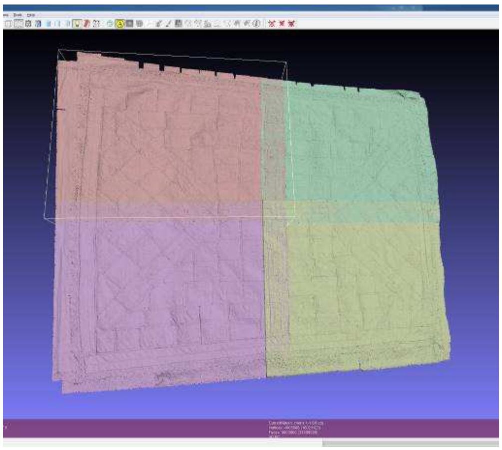

Fig. 3 - 3D mesh cut in 4 chunks with some overlapping in the middle.

Due to the great number of resulted points in the dense point cloud and after repeated failed tries to build a whole mesh at different parameters, the dense point cloud was split in 4 chunks and each of them was then processed with ‘unlimited’ number of faces. The chunks were separated with a small area of overlap for future merging. This overlapping however complicated things in the 3D printing stage as we will see later.

Each built chunk has an average 250 million faces which renders the whole object to 1 billion faces. Unfortunately the workstation was not able to support working with a mesh of 250 million polygons. Therefore we had to simplify the mesh. Mesh simplification (decimation) is a common practice in computer graphics related fields especially for highly detailed meshes [9]. First we decimated each chunk to 25 million (10 %), then to 8 million, 2.7 million and finally the best decimation that was also compatible with the 3D printing system capabilities, was 1,8 million polygons per chunk (approximatively 0,72%).

Before getting to the printing preparation stage, the mesh had to be scaled 1:1. Using measurements of certain details on the original artwork it was not difficult to measure the same details in the digital model and then to apply a scaling factor in order to obtain the desired scale.

2.3. 3D Printing

The 3D printer used for this project is a powder based printer and has a 300x450 dpi printing resolution. It can print color models with a speed of 2-4 layers per minute, with a thickness of 0.089 – 0.102 mm.

The main goal of the project was to realize a full scale 3D printing of the cloth. The size of the printer's building chamber limited our options so we had to further split the 3D model in 35 smaller pieces, with an average size of 17 cm x 19 cm. Unfortunately, the decision of leaving an overlapping area between the 4 big chunks created more problems. The 3D printing software was able to determine that in the model cuts containing the overlaps were indeed more than on mesh even if we merged the overlapping pieces in specialized 3D modelling software. Therefore we had to split those pieces in smaller cuts to avoid 3D printing errors. So the total number of pieces to be printed was 49.

Mesh splitting was realized with a dedicated 3D modelling software while the pieces were prepared with ZEdit Pro. The 3D file format used was STL (StereoLithography) which is imported in the editing software and converted after the proper preparations to ZBD file format, compatible with the 3D printing software. The 3D mesh of each piece was in average around 100.000 polygons.

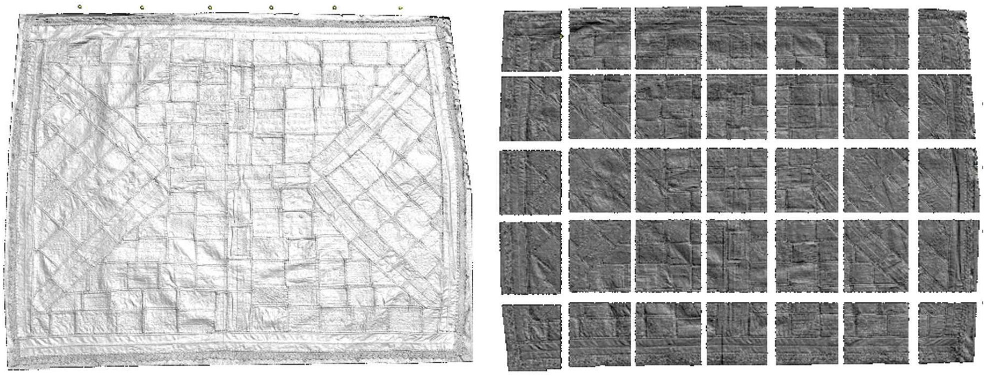

Fig. 4 - 3D digitized replica; left: the 35 main pieces to be prepared for 3D printing.

The 3D models of the cloth are representing only its surface. So it is actually a pixel thin sheet. In order to 3D print these thin pieces we must add a solid volume below the surface. One way to do this is to apply a thickness (by extrude method). In this case for pieces of 15 cm x 18 cm we chose a thickness of 10 mm. This step is done in the 3D printing preparation step. During this stage some errors usually occurs, like the gaps that are formed when the shells are not fully closed. These errors must be corrected before printing otherwise for the 3D printing software it would look like an empty object and it will be printed likewise.

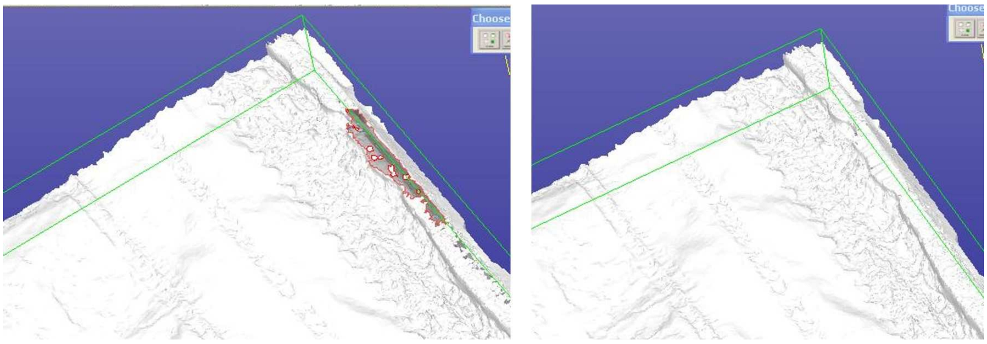

Fig. 5 - Gap errors fixed in the 3D printing preparation stage.

The prepared pieces were arranged together for each printing batch. A printing batch contained 6-7 pieces and took over twelve hours to print. Including the drying stage, cleaning and then the electrical heating in an oven (for strengthening the structure) the whole process took a week and a half of non-stop monitoring and changing batches.

2.4. Online publishing

The digital content was published online using a modern 3D publishing platform (sketchfab.com) that allows spatial manipulation of the 3D model and the visualization with or without a texture the surface. For this purpose we also processed the texture of the 3D model. The online published models contain the whole mesh and several details processed at higher detail with texture.

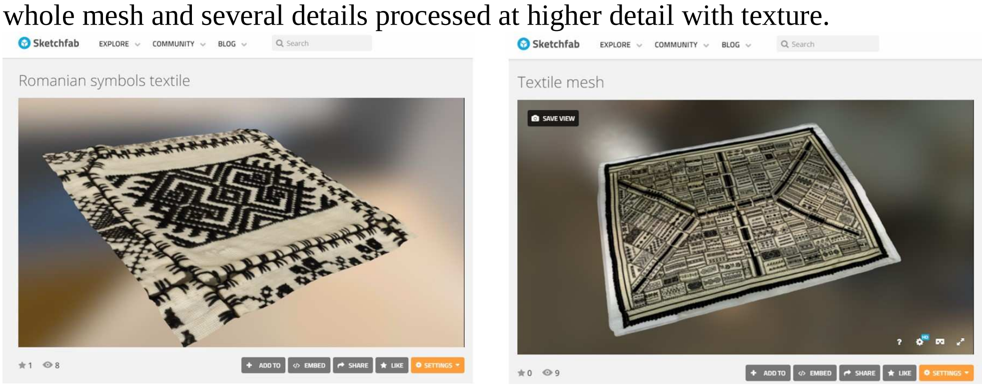

Fig. 6 - Online publishing using Sketchfab™.

3. RESULTS AND DISCUSSIONS

This project final results are on one hand the 3D digital replica of the textile traditional ornamental cloth and on the other hand the physical replica obtained by 3D printing the digital model. The digital replica was meant to be able to represent even the thinnest threads of the cloth which it does. The owner of the ornamental cloth didn't want a colored printing so the print was monochrome in the color of the printing material (white).

In order to be able to visualize and study the digital model on an average computer, the 1 billion polygon original model is not a viable solution [10]. Therefore a decimation to 1.8 million polygons for each working chunk was required (7,2 million polygons in total). Of course for certain details the surface can be cropped and the details could be studied at the original polygon count. For example, in Figure 8 the smallest detail in the original mesh measures around 0.3~0.4 mm, representing the thread thickness in the fabric.

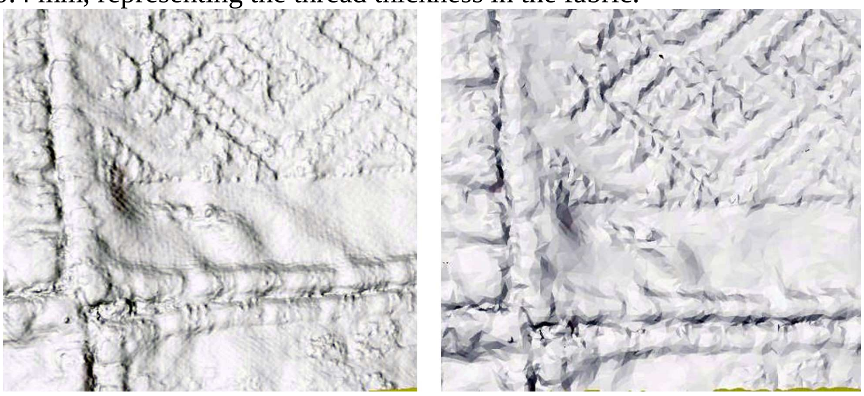

Fig. 7 - Left: original detail; Right: decimated detail (0.72%).

There were no problems in point detection so the acquisition process was correct. But an important fact is that we realized during the processing stage was that overlapping 3D meshes should be avoided in the future, especially when the mesh is intended for 3D printing. This is a problem we couldn't resolve so we had to work around a solution by using additional cuts of the central pieces. The limited timeframe for this project did not allow us to re-process the whole thing in order to avoid overlapping.

Fig. 8 - Final product: 3D printed replica.

4. CONCLUSIONS

In this paper we wanted to demonstrate a complete workflow for a three dimensional digitizing process for a textile cultural heritage asset. The method employed was photogrammetry, a cheap but laborious method with competitive results *versus* other methods, like 3D laser scanning [11].

A set of over 500 photos were taken with the same camera using the same parameters and light conditions. As a rule for photogrammetry a 40-70% overlapping was used for each adjacent photo on both horizontal and vertical axis. The great number of photos and the generous overlapping allowed the smallest cloth details to be recorded. Agisoft Photoscan was used for data processing and other 3D modeling software for additional editing of the final mesh. In order to be 3D printed, the mesh was split into 49 smaller pieces and then printed using a power based 3D printer.

This is an important achievement because it is one of the few attempts for 3D digitization of textile artworks. This type of artefact is very difficult to approach due to its malleability and fragility. A 3D digitization is as valuable as the smallest detail of the surface it can accurately offer. In textiles the smallest details are the threads in the fabric. You either try to obtain this kind of details or else you settle with a smooth model in which you try your best to compensate with high quality texture for visible impact. But the value of the information a 3D model can deliver stands in the level of details reported to the real object details.

ACKNOWLEDGEMENTS

This work has been realized within the Program Partnerships in Prioritary domains PN-II-PT-PCCA-2011-3.2-0356 wwwWATCH and through The Sectoral

Operational Program "Increase of Economical Competitiveness" Priority Axis 2 – CDI: Operation 2.2.1. Project "Multisite Infrastructure for the Increase of Research and Development Capacity in the Field of Optoelectronics and Analytical Instrumentation – INOVA-OPTIMA" (Contract 658/07.08.2014 – SMIS 49164).

We would also like to thank the Astra National Museum Complex for their trust and patience during these investigations and for all the support and information regarding the investigated object.

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