Laser Scanning Versus Photogrammetry Combined with Manual Post-modeling in Stecak Digitization

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Abstract

Stecci (sing. stecak) are hand carved medieval Bosnian gravestones considered as valuable cultural heritage objects. One of the best ways for their preservation is digitization.

In this paper we compare digitization results and procedures for one of the most famous stecci – The Stecak from Donja Zgosca. The object was first digitized using a Minolta 910 laser scanner. Later we created the 3D model from photos using photogrammetry and improved it in 3ds max. We present advantages and drawbacks of these two procedures and characteristics of the obtained models. Results of this comparison will be used in future digitization projects.

Keywords: Laser Scanning, Photogrammetry, Manual Modeling, Stecak, Cultural Heritage, 3D Modeling.

1 Introduction

Cultural heritage within its set of materiality, traditions and knowledge helps us to better understand the past itself. Therefore it is very important to preserve these monuments in a way we see them now for next generations. Thus, new technologies can be very helpful. Today we are able to create virtual model of a real object using various techniques. We used two different techniques in our research, expensive technique of laser scanning and much cheaper, but also good technique for acquisition of 3D models from 2D images, photogrammetry. We also made a step forward and introduced some improvements of the model achieved using photogrammetry, as we will see in more details later in this paper.

Figure 1: The Stecak from Donja Zgosca

Stecci are hand carved medieval Bosnian gravestones. We applied both techniques on the Stecak from Donja Zgosca, and got some interesting results. This stecak originates from the second half of 14th century. It has a great importance for Bosnian history because it is assumed that the Bosnian king Stjepan II, who died in 1353, was buried under this stecak [1]. This monument is currently located in the botanical garden of the BH National Museum in Sarajevo (Figure 1).

In many cases, like with the Stecak from Donja Zgosca, the traditional modeling (for example manual modeling using 3ds Max or Maya) would require much more work and effort, and the final result would not be satisfactory. The model created using these methods would not be sufficiently accurate. It would not contain enough information about the real object. This is why we use methods such as 3D laser scanning, which produces a virtual model with high accuracy. In the first part of our research we used a Minolta 910 laser scanner (Figure 2), borrowed from our project partners, the University of Bristol, UK.

Figure 2: Scanning the stecak with a Minolta 910 laser scanner

In the second part of our research, we used photogrammetry technique for virtual reconstruction of the stecak. The basic principles of photogrametry are briefly presented in the Section 4. In this project we used the Photomodeler software for implementation of photogrammetry technique with manual approach of creating 3D model. The model was later improved in 3ds max software.

The paper is organized as follows: the Section 2 gives a short overview of the related work in similar projects, in the Section 3 we describe the laser scanning approach, applied on the stecak. In the Section 4 we describe the process pipeline of photogrammetry combined with manual 3D post-modeling of the model, and steps for its implementation. In the Section 5 we compare results achieved using these two approaches, and describe

advantages and drawbacks of both techniques. In the Section 6 we present conclusions based on our experience from this project, and illustrate reasons why to use one technique instead of another in future projects.

2   Related work

When creating 3D model of a real object, it is very important to choose the most appropriate technology and procedures that can create the best final output in accordance with the project's specifications and requirements.

Laser scanning shows its full potential in open pit mining environment application, where no rival technology comes close to matching the utility of a laser scanner, not even digital photogrammetry [11]. In project of recording 3D measurements from medieval castle of Haut-Andlau (Alsace, France) [12] laser scanning and photogrammetry were used. Application of each one of them resulted with similar level of satisfactory accuracy. Main difference between these two approaches is that laser scanning is focused on grid of points, without taking specific object structures into account, like corners or edges. On the other hand, photogrammetric measurements concentrate on object discontinuities and representative structures, even without generating dense point cloud [12]. If our method of improving the generated 3D model in 3ds Max had been used in this project, the achieved realism of the castle could have been even better and mainly flat surfaces could have had more details.

The accuracy of created 3D points in both techniques was compared in application on the ancient church of Pozzoveggiani, Italy [13]. Here the photogrammetry technique has given the similar or even better results than laser scanning technique, but for the best results author adviced using some combination of these techniques, as each one has attributes and elements that complement one another. In addition our method could be used for increasing geometry details on the model of the church created using photogrammetry technique.

Today's laser scanning technique offers a good way for 3D model acquisition, but also has a lot of issues which are preventing its wider use [4]. Some projects are introduced, which could boost the diffusion and evolution of 3D scanning technology [4]. New tools and solutions for improving these techniques are often introduced, such as TexAlign, which helps the user to improve image-to-image correspondences and it is presented and applied on the model of David's statue. Another example is a new solution for generating 3D models from high resolution photos, which is presented on the model of Arc du Triomphe, Paris, France [4]. This solution uses a special algorithm to calculate accurate surface details achieved by triangulation. Our method of improving the model by estimating surface details using object's textures is not that accurate.

3   Laser scanning

Laser scanners provide a method of capturing accurate information about object's surfaces. The stecak was scanned with a Minolta 910 laser scanner. It is a scanner for close range and indoor applications [2]. This scanner has accuracy of less than a millimeter.

The scanning is based on the principle of laser triangulation, Figure 3. The target is scanned with laser beams. The laser scanning mechanism characterizes each point on the scanned object according to its location in 3D-space by scanning the surface of an object with one focused beam, and recording the reflected light using CCD camera. Each point on the object is described by 3 numeric values which correspond to 3D coordinates X, Y, and Z.

The X coordinate of each point on the object is calculated from an accurate measurement of the position of the scanning mirror in the camera. The Y coordinate is calculated from an accurate measurement of the camera motion system (CMM). The Z, or range coordinate, is calculated through laser triangulation within the camera. Surface shape measurements of the object are obtained through triangulation, and then converted into a 3D polygonal mesh [3].

The scanner measures 640 x 480 points regions within one scan, simultaneously acquiring surface shape data and color image data.

After measuring the 3D depth data, the Vivid 910 uses its CCD to capture a 2D image in the same way as a digital camera. The CCD relies on ambient light to illuminate the target. The scanner software then matches points on the photograph to points in the surface mesh and exports the data as a CDM file which contains both the mesh and bitmap. In addition, a color image of the object can be also obtained by scanning the CCD through a RGB filter while the stripe light is not emitted. (A band pass filter is used when the stripe light is emitted.)
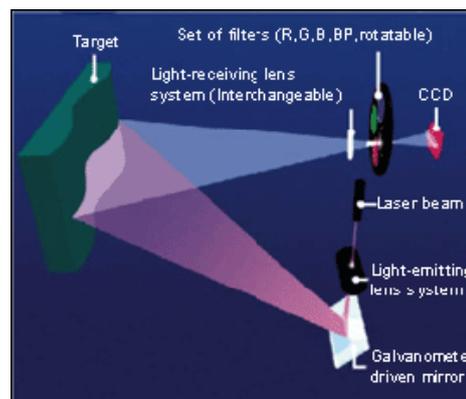

Figure 3: Minolta Vivid 910 measurement principle

Since the less illuminated scan areas produce better results, the model of stecak was scanned during the night because of the intense light in that part of the Museum's botanical garden during daylight. Given that, the textures produced were not satisfactory (Figure 4, left), so the

decision was made to continue without the original textures. Instead, the model was assigned with the appropriate textures later, during its reconstruction in Maya.
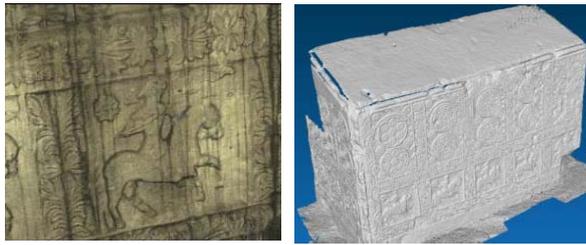

Figure 4: Texture of the model captured by the laser scanner (left); the stecak without textures. Multiple scans merged into a single using the Stitcher (right)

Individual scans, created by laser scanning method, were later connected together in a polygonal mesh by using the Stitcher software tool provided with the laser scanner (Figure 4, right). This software was used for editing captured scan data, merging scans into single "watertight" mesh, and then exporting .OBJ file to Maya.

The computer model of the scanned stecak was transferred from Stitcher to Maya. The size of the laser scanned model was so large that it needed to be reduced to 5% quality in order to manipulate it in Maya.

Maya has a function for reducing number of vertices of the model, optimizing it for easier use. Problem is that this function works only for models created in Maya, but not for polygon meshes generated by the scanner. The only suitable solution was to load the original scan file to Stitcher, and do all reducing there. After applying new modifications in Stitcher, reduced model was exported from there, and imported to Maya. Geometry of the stecak was here improved in some areas, and the damaged part in the lower corner was repaired (Figure 5).

Radiance – the physically based rendering software system was used for calculating light over the object. In Maya the new material was created with information about the object's radiance. That material was applied on the object.

The finished model's geometry was exported in an OBJ file, and TIFF texture file was created by the material conversion as well.

After that, we further optimized this model in

Figure 5: Comparison between raw model of the stecak before reconstruction (left); Final model of the stecak after repairing in Maya (right)

Meshlab tool [4, 5]. Results of comparison of various optimization methods are presented in Section 4.

The obtained model was used for creating the sun simulation animation [2] and in the online application "Virtual Sarajevo" [7]. We also used this model without optimization to introduce the archaeologists from the National Museum of Bosnia and Herzegovina with possibilities in virtual reconstruction of the cultural heritage objects, reconstructing the damaged part of the object in Maya (Figure 5).

4 Improved photogrammetry

Our goal in this phase of our research was to create a model of stecak which has the level of realism similar to the model created using laser scanning technique, using much cheaper equipment. The process of creating 3D model using improved photogrammetry consisted from three steps:

- Taking photos
- Creating model in Photomodeler
- Improving model in 3ds max

4.1 Taking photos

The first task that had to be done within the photogrammetry process pipeline was taking photos. It is very important to have knowledge about the photography technique and the camera parameters which are used in this process. To obtain high accuracy and reliability, the photos must be of the highest quality. The photos taken on the site are shown in Figure 6. We used Canon PowerShot Pro 1 camera for taking the photos.

Figure 6(a): The photos used to recover 3D

Figure 6(b): The photos used for capturing textures from the sides of the object

Figure 6(c): Additional photos used for obtaining more information from the top sides of the object

The photos must be taken in a precisely defined manner in order to be used later in a photogrammetry process.

Figure 6(d): Additional photos used for recovering textures and geometry from the damaged part of the object

This process requires that certain parameters of the photos remain unchanged. Focal length must be the same in all taken photos. Digital camera must have the option for manual adjustment of the focus or for locking the focal length. After adjusting the focus in a way that the image is sharp, the same focus value should be locked for every picture taken in the set.

Other parameters that must remain unchanged while taking photos are: image resolution, zoom, camera distance from the object, exposition. Brightness and possible shadows should be the same in all taken pictures in the set. If not, we can have problems in overlapping textures that look different when taken from different positions [4]. Flashbulb can be used, but we found that pictures look more natural when they are taken in daylight.

It is a good practice to take more photos from the same camera position, because it is not hard to do, and it can save our time if we find that some of the taken photos are not good enough. The tripod should be used if it is available.

Camera calibration is a procedure of taking photos of Photomodeler's calibration grid (Figure 7) with the same camera that was used for taking photos on the site. The final goal of camera calibration process is to introduce Photomodeler with internal camera parameters: focal length, format size of the sensor, image size or lens distortion. After taking calibration photos, they should be imported in Photomodeler and then automatically processed by this application. After successfully finished
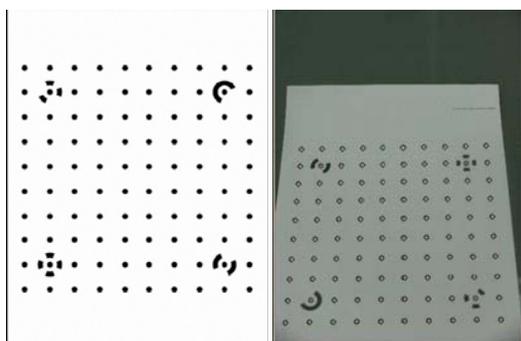

Figure 7: Photomodeler's calibration grid: Original paper (left); Photo with generated points after processing (right)

calibration process, Photomodeler will use internal camera parameters for later calculations of the taken pictures based on triangulation.

In this project we did not use camera calibration process because we wanted to see if it is possible to create satisfying model quality without it. We achieved almost identical results in this way as in a project where calibrated camera is used, because Total Error is very low indicating that estimated camera parameters are excellent.

4.2 Creating the model in Photomodeler

Model creation in Photomodeler is an iterative process. Each iteration consists of the following steps:

- Marking important elements on the photos
- Referencing elements between different photos
- Starting Photomodeler's automatic processing
- Drawing surfaces in 3D viewer

In the marking process we should mark the well visible elements (points, edges, curves, lines, etc.) that we can see at two or more photos. Every element must be marked in minimum two pictures in order to be processed and to reveal its 3D information. It is very important to have good quality photos with high resolution. Lower quality photos could lead to lower accuracy of the final 3D model.

Referencing step refers to connecting the same elements on different photos. In this way, Photomodeler "knows" that the same element is appearing in different photos. This information is used in automatic processing step in which 3D information can be calculated using triangulation.

After that, we can start Photomodeler's automatic process of calculating 3D data. If the processing step is finished successfully, the 3D model from given elements is created. We can make iterations of the process improving its elements until the Total Error is minimal (Figure 8). After the processing step, the 3D model is generated, and we can see it in the 3D viewer. In the 3D viewer we can also draw all surfaces.
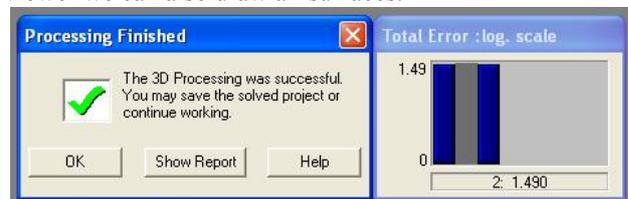

Figure 8: Notification for successfully finished processing. Processing was done in two iterations of improving data, with total error of 1.49

Now we can start with the next iteration of modeling by repeating these steps of marking and referencing elements, processing and drawing surfaces in the 3D viewer. We should repeat this cycle until we have generated the 3D model with desirable level of accuracy.

Without using calibration in the beginning, accuracy of our generated 3D model is very low. The software has no information about the camera parameters, thus 3D coordinates could be calculated in a wrong way (Figure 9).
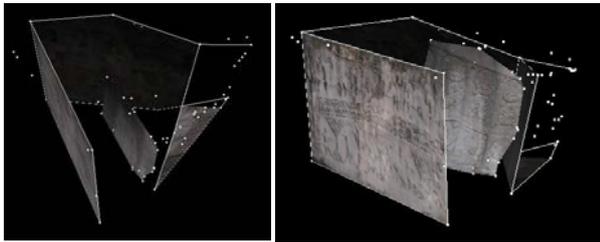

Figure 9: Due to the wrong calibration parameters and lack of marked information in the beginning, Photomodeler generated the wrong 3D information

In our example we have created a project with estimated camera parameters, which could be wrong, and we got poor results after processing. Lack of camera parameters information could be compensated by high quality photos, and well marked and referenced elements. In the beginning this can be very hard work that does not give us the results we expect.

The Point Table is used for approving overall accuracy of generated 3D information (Figure 10).

Figure 10: The Point Table in Photomodeler is used to find points that are not marked correctly

The Point Table holds all information of all points marked in our project. If we sort points by the "Largest Residual" value, points with largest value needs to be reviewed. Largest residual value is the difference between the position of the marked point, and the estimated position of that point calculated by Photomodeler.

At some point we found that our model is quite satisfying for our purpose (Figure 11). This model was exported in two files: .OBJ file that contains the stecak's geometry information, and .JPEG file with the stecak's texture information.
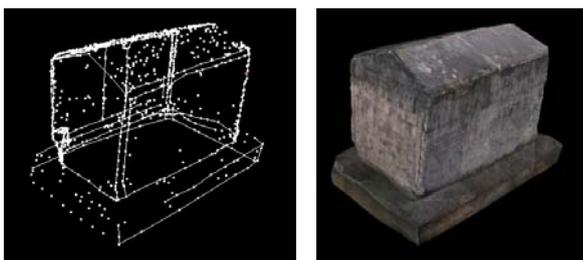

Figure 11: The final model of stecak in Photomodeler's 3D viewer

4.3 Improving the model in 3ds max

If we take a look at the previously created model in Photomodeler, we can see that its surfaces are mainly flat, and even if textures are fitting, we cannot see any relief of its surfaces.

In this paper, we introduce a new technique of improving models created in Photomodeler by photogrammetry technique using post-modeling in 3ds max software. We will modify its surfaces to obtain more relief.

The model is exported from Photomodeler as 3D Studio file (.3ds) with JPEG texture, and then imported in 3ds max. After importing, the model is converted to "Editable Poly", and we have applied three modifiers to it: Subdivide, Displace, MeshSmooth.

The first modifier we have applied to the model is Subdivide modifier. The main purpose of this modifier is to divide the object's surfaces in smaller parts, creating more faces. This modifier is used to prepare the model for the next modifier, and also for model optimization (Figure 12). We can optimize the model by selecting "Size" parameter value in Subdivide modifier.
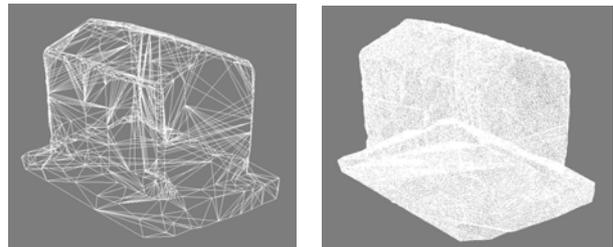

Figure 12: Model of the stecak before application of Subdivide modifier (left), and after

Subdivide modifier is used to prepare the model for Displace modifier. Purpose of using Displace modifier is to create relief on a totally flat surface based on the information from the texture map. Darker places in the textures will be pushed into the model, and lighter places will be pulled out of the model.

In our example, this technique of estimating relief proved as not so accurate, but it makes the model more realistic (Figure 13). We applied this modifier in the same amount on the whole object, but for getting better results, we could apply various amounts of this modifier to various parts of the object in different ways.

The last modifier applied on the model is MeshSmooth. This modifier smooths coarse, fragmented
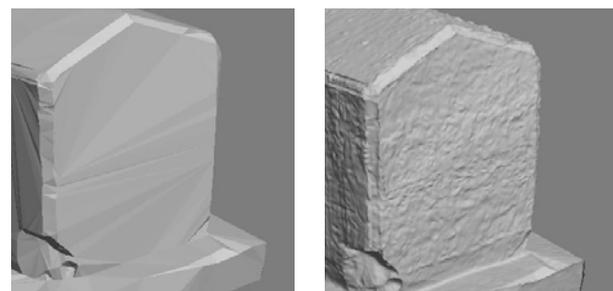

Figure 13: Model of the stecak before and after the application of Displace modifier

surfaces, and makes model surfaces to look more fluent (Figure 14).

After applying all mentioned modifiers, the model is exported as .OBJ file with additionally exported texture .JPEG file, and also in .WRL format, for usage on the web.
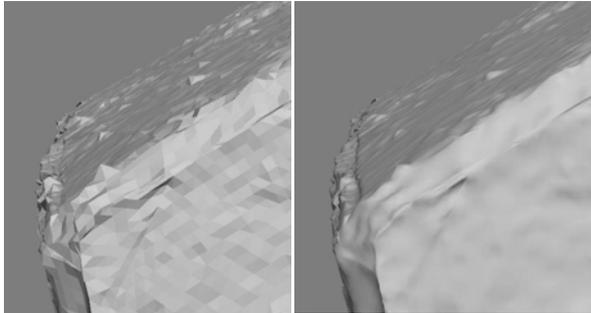

Figure 14: MeshSmooth modifier: The model before and after the application

We used the obtained model (Figure 15) as a part of our project "Digital Catalogue of Stecaks" [6].

Figure 15: The final model of stecak optimized for web

This project is a virtual museum of stecci from the collection of the National Museum of Bosnia and Herzegovina. The models created using photogrammetry combined with post-modeling work well considering all limitations of this online application.

5 Comparison of procedures

Laser scanning technique (LS) and photogrammetry technique combined with post-modeling (PP) are two completely different approaches for creating 3D models with high levels of realism. Both of them have some advantages and drawbacks which we will discuss in order to provide some recommendations for future projects of this kind. Results of this comparison based on our experience are presented in the following tables and figures.

We tested both techniques and compared their features. Results of this comparison are presented in Table 1.

Comparison of two techniques	LS technique	PP technique
Budget	High budget, expensive laser scanner	Low budget, cheap digital cameras
Geometry	High level of details	Low level of details
Textures	Problem with getting textures by night. Used only geometry, with radiance effects on the model's surfaces	Photo textures with high level of details
Operations taken automatically	The object's meshes generated using scanner	Automatic processing of marked data in Photomodeler software
Operations taken manually	Laser scanning. Editing and improving the model's meshes in Maya and Stitcher	Taking photos on site. Marking and referencing elements in Photomodeler
Accuracy level of model's geometry	High level of geometry details	Satisfying level of accuracy model in Photomodeler. Low level of estimated surface geometry details in 3ds Max
Optimizing	Not easy to optimize. For best results, hard work in manual optimizing is required	Easy to optimize. Models created in Photomodeler have very light geometry. Improved models in 3ds Max can be optimized easily in this software
Level of achieved realism	Geometry by itself offers good level of realism. In addition with good textures, the result is excellent	Very good level of photorealism. The model looks very natural to human eye
Human efforts	Overall small amount of included human efforts. If model's meshes have to be manually improved, human efforts can be much higher	Manual modeling requires a lot of human efforts in Photomodeler. Efforts in 3ds Max are usually low, but can be higher if high detailed mesh is needed
Required knowledge level	Laser scanning is not difficult to learn. Operator need to have earlier knowledge of 3D modeling and editing in order to know how to use similar programs. Editing model in Maya, requires essential knowledge of this software	Photomodeler is much easier to learn than programs like Maya or 3ds Max. Essential knowledge of calibration, marking and referencing can be achieved very quickly
Required experience level	Laser scanning process on site can be learned in a few hours. Experience of working in 3D CAD applications is desirable. Experience in working with Maya is needed	Only experienced operator can achieve well and accurate results in Photomodeler. Later improving in 3ds Max requires some experience of working in 3ds Max or similar CAD software

Table 1: Comparison of LS and PP techniques by various factors

The model created using laser scanning is optimized in several ways. Results are presented in Table 2.

Model ID	Description	Vertices	Faces	.OBJ size (KB)
LS_1^1	Non-optimized, 5% of the scanned quality	1.051.544	1.666.396	274.288
LS_2	Optimized using Meshlab	472.447	827.151	70.862
LS_3	Optimized for web using Meshlab	86.384	150.000	12.402

Table 2: The Models created using LS (LSx[1])

The model created by the Photomodeler and then improved using 3ds Max is optimized in several different ways. Achieved results are presented in Table 3.

Model ID	Description	3ds Max Subdivide modifier. "Size" parameter	Vertices	Faces	.OBJ size (KB)
P^2	Model, Photomodeler	-	657	1.299	211
PP_1^3	3ds Max optimized model	1,5	195.166	389.844	41.560
PP_2	3ds Max medium optimized model	1	440.466	880.140	95.770
PP_3	3ds Max maximum tested quality model	0,8	636.870	1.272.720	139.233
PP_4	3ds Max model optimized for web	4	37.838	75.456	7.826 (8.988 for .WRL)

Table 3: The model created using photogrammetry (P^2) and the models created using photogrammetry combined with post-modeling (PP_1^3-PP_4)

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[1] LSx - The model x created using laser scanning
[2] P - The model created using Photomodeler only
[3] PPx - The model post-processed in 3ds Max

As we can see, the optimization level of the final model created by PP can be easily adjusted using the "Size" parameter of Subdivide modifier. Optimization dependency of the parameter "Size" from Subdivide and number of vertices, number of faces and model's size (KB) is presented in Figure 16.
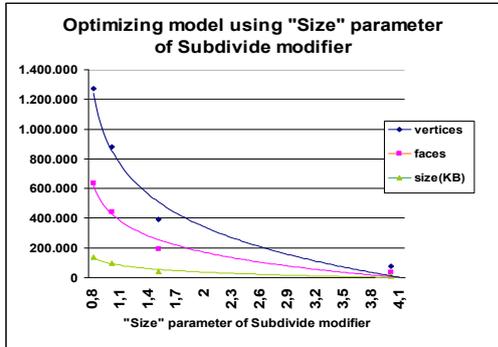

Figure 16: Optimization dependency of the parameter "Size" from Subdivide modifier and number of vertices, faces and size of model (KB)

Comparison of achieved photorealism in PP models is presented in Figure 17. These models are improved in 3ds Max and have various levels of quality, achieved using "Size" parameter of Subdivide modifier. In this way, we created a high quality model, optimized model and model intended for web usage (Figure 17).

Using MeshLab tools [5] we created from the laser scan the models with various levels of quality, Figure 18. Which quality of the model will be used depends of the project's requirements.
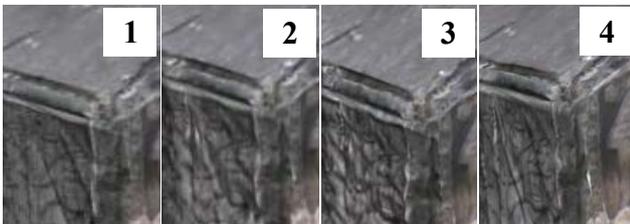

Figure 17: Comparison of models created by PP using Subdivide modifier: 1) created by Photomodeler (without post-modeling); 2) optimized with Subdivide "Size" parameter 1.5 (PP$_1$); 3) maximum tested quality - Subdivide "Size" parameter 0.8 (PP$_3$); 4) optimized for web - Subdivide "Size" parameter 4 (PP$_4$)
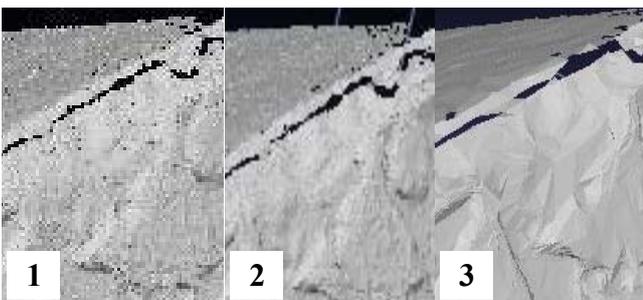

Figure 18: Comparison of various optimized LS models using MeshLab: 1) non-optimized model (LS$_1$); 2) optimized model (LS$_2$); 3) optimized model for web purpose (LS$_3$)

In our project we achieved various levels of geometry details in both techniques. Comparison of the highest and the lowest tested geometry quality is presented in Figure 19.
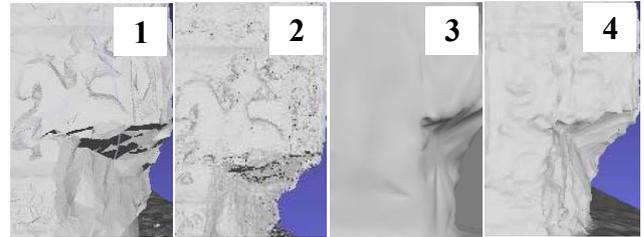

Figure 19: Geometry quality comparison: 1) optimized LS model for web purpose (LS$_3$); 2) non-optimized LS model (LS$_1$); 3) optimized PP model for web purpose (PP$_4$); 4) maximum quality PP model (PP$_3$)

5.1 Laser scanning advantages

The most important advantage of using LS is its accuracy. LS provided one millimeter accuracy in our example, and this should be more than enough for most of the applications. LS can be time saving. We can automatically generate 3D models using LS, and then optimize them using the software for automatic optimization in order to get good results. If we can extract textures from objects using this technology, then we can create models with high level of details, high accuracy, models that look very real.

5.2 Laser scanning drawbacks

LS is a very expensive technology. The raw scanned models usually have a lot of small mistakes that should be manually removed in order to achieve the high level of details. In our project we had problems with the laser scanner's daylight sensitivity, thus we scanned by night. Scanning by night caused another problem with textures, and we chose to exclude the scanned textures from the project. The optimization for web can be problematic because models created in this way consist of huge number of faces, and cannot be optimized for web without losing overall quality. Optimization can be very destructive on the models generated by LS. Still, we achieved very good results using MeshLab software tools [5].

5.3 Photogrammetry advantages

Photogrammetry is much cheaper than LS technique. If the budget is our main parameter, we should definitely choose photogrammetry. With this technique, we can also achieve very realistic models, especially if using photogrammetry in combination with manual post-modeling.

5.4 Photogrammetry drawbacks

This technique is time-consuming. It requires well experienced operator in order to achieve good results. If

we need high level of accuracy, then we should choose laser scanning. It is not completely impossible to improve accuracy of the model created by this technique, but it could acquire a lot of additional time to achieve that goal. This is still mostly manual technique that requires a lot of user interaction, but there are a lot of research efforts for achieving higher level of automation in photogrammetry [8] [10]. We can say that fully automated modeling using photogrammetry is still an ongoing research topic in this area of 3D modeling [9].

There are some common drawbacks in both approaches. Some objects cannot be captured with either of two techniques, for example objects made of glass, transparent, polished or mirrored and shiny materials [4]. Research is in progress to find solutions for these problems. Also, neither of these techniques is fully automated yet, in a way that manual editing is not needed at all.

6 Conclusion

In this paper we presented the procedures of laser scanning and photogrammetry combined with manual post-modeling applied for digitization of The Stecak from Donja Zgosca. The obtained results are used for comparison of these two techniques. Different ways of optimizing final models are also presented.

We introduced the concept of photogrammetry combined with manual post-modeling by improving our object in 3ds Max. This way we obtained more realistic surface details which were combined with high quality textures to achieve the satisfying quality of the model.

If we need to create a final model of the object with high level of realism, and we have a low budget, we should use some of photogrammetry based techniques. If we have requirements for creating a model with high level of accuracy, then we should use laser scanning technique which gives us more precise results. We can also use a combination of these techniques, photogrammetry for getting overall object geometry with realistic textures, and laser scanning technique for precise and accurate information of object's surface. The results obtained in this project can help us to decide which technique to use in our future projects.

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