

Evaluation of the 3D Reconstruction Performance of Objects in Meshroom: A Case Study

By Indrit Enesi* & Anduel Kuqi[±]

3D reconstruction of objects is with interest nowadays, mainly in production industry. The field of photogrammetry realizes the 3D reconstruction of objects through 2D photos. Different software, free or non-free exist, providing different quality and performance. Accurate 3D reconstruction is important in cloning objects, especially in the industry of spare parts or in the production of prostheses in medicine, etc. Determining accurately the sizes of the object, especially those with complex geometric shapes is very important in the 3D printing process. The purpose of this paper is the analysis of the accuracy of 3D reconstruction of objects against the number of its photos and the time evaluation of this process. The 3D reconstruction will be performed by free Meshroom software, measurement will be done in MeshLab one. Experimental results show that quality and performance of 3D reconstruction depends on the number of photos of the object, concluding in finding the optimal balance between these parameters.

Keywords: Meshroom, MeshLab, 3D reconstruction, sizes accuracy, time analysis

Introduction

Undoubtedly the use of 3D computer vision finds massive use in many different fields, such as archeology, 3D printing etc. As a result of the massive uses of today and the premises for the future, research in this field can be a valuable asset for improving the future vision for new applications in computer vision or even for improving existing ones.

The work here deals with the study of a software that serves for the reconstruction of 3D objects from images taken with cameras of different types. The software used in the paper is Meshroom. Meshroom is a free, open-source 3D reconstruction software based on Alice Vision framework. Alice Vision is a Photogrammetric Computer Vision Framework which provides 3D reconstruction and camera tracking algorithms. Meshroom software is designed as a nodal engine. It is developed in Python while Alice Vision framework is developed in C++ (Alice Vision Inc 2021). What makes this software very special both in terms of research and in terms of practical use is the fact that the parameter configurations can be changed in each of the nodes. The nodes can be added or removed from the pipeline regarding the type of processing. The aim of the paper is the visual quality

*Professor, Polytechnic University of Tirana, Albania.

[±]Assistant Lecturer, Polytechnic University of Tirana, Albania.

and the processing time of the reconstructed object from its images taken from a usual camera.

Different sets of photos of the same object will be used as input in the Meshroom software, for each set, the quality and processing time of the reconstructed object will be evaluated. Measurement of object sizes will be determined in Meshlab software (Meshlab 2021).

The object rebuilt in Meshroom from sets of photos, will be extracted in MeshLab software to determine its sizes. MeshLab is a software that serves for processing and editing messages. It is an open source and offers various edited tools (Meshlab 2021).

Methodology

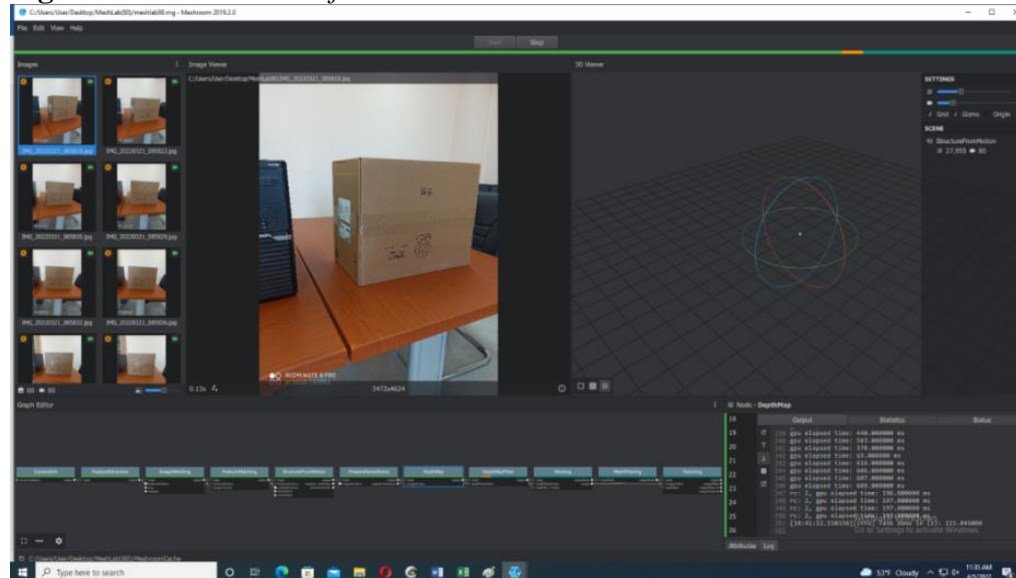
Photogrammetry

Photogrammetry is the process of creating 3D models from images taken from real-world objects in different positions and different angles. Reconstructing 3D objects from its photos would require a huge work if modern software did not exist. In the paper a combination of software's Meshroom and MeshLab will be used and evaluated.

Meshroom Software

The Meshroom interface is shown in Figure 1.

Figure 1. Meshroom Interface



The inputs are located in the upper left part, and right part serves to show the reconstructed 3D object, the output of special nodes such as meshing, or structure

from motion stands in the right part of the workspace. The left-bottom part is the actual nodes that will take part in the execution flow. Nodes can be easily configured, giving Meshroom a lot of flexibility. The photos for the implementation and testing are taken through the Xiaomi Redmi 8 Pro mobile phone.

The implementation consists in measurement and analysis of five cases, in case one a set of 100 photos is taken, the 3D object will be created based on the set and the dimensions of the object are measured and analyzed, in case two 80 from 100 photos create the set 2, in case three 60 from 100 photos create the set 3 and respectively 40 and 20 out of 100 photos creates sets 4 and 5.

In set 5, one out of five photos are chosen, it consists in photo indexes: 1,5,10,15,20,25,30,35,40,45,50,55,60,65,70,75,80,85,90,95. In set 4, one out of five photos are chosen, practically the photo indexes are: 1,2; 5,6; 10,11; 15,16; 20,21; 25,26; 30,31; 35,36; 40,41; 45,46; 50,51; 55,56; 60,61; 65,66; 70,71; 75,76; 80,81; 85,86; 90,91; 95,96. Increasing by one the number of samples creates set 3, 4 and 5. On every case, object dimensions are obtained and compared with the real ones.

Finally, a comparison between the five cases is made in terms of processing time, the quality of the reconstructed object as well as the accuracy of the measurements.

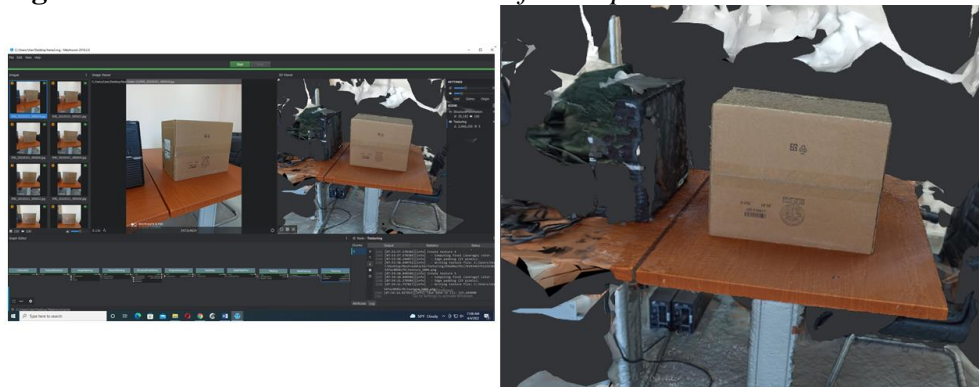
MeshLab Software

Meshlab is an open-source software for 3D image processing and preparing models for 3D printing. It works based on point clouds or in meshes. A set of tools are provided from Meshlab software as rendering, meshes, texturing, measurement of distances, cleaning, healing etc. (Meshlab 2021).

Case A

This case consists of a set with 100 photos. The workspace in Meshroom is given as illustrated in Figure 2.

Figure 2. 3D Reconstruction Based on Default Pipeline



In this case the default nodes of the Meshroom are used, which are camera initialization, feature extraction, image matching, structure from motion, depth map, depth map filter, meshing, mesh filtering and texturing. Camera Init loads

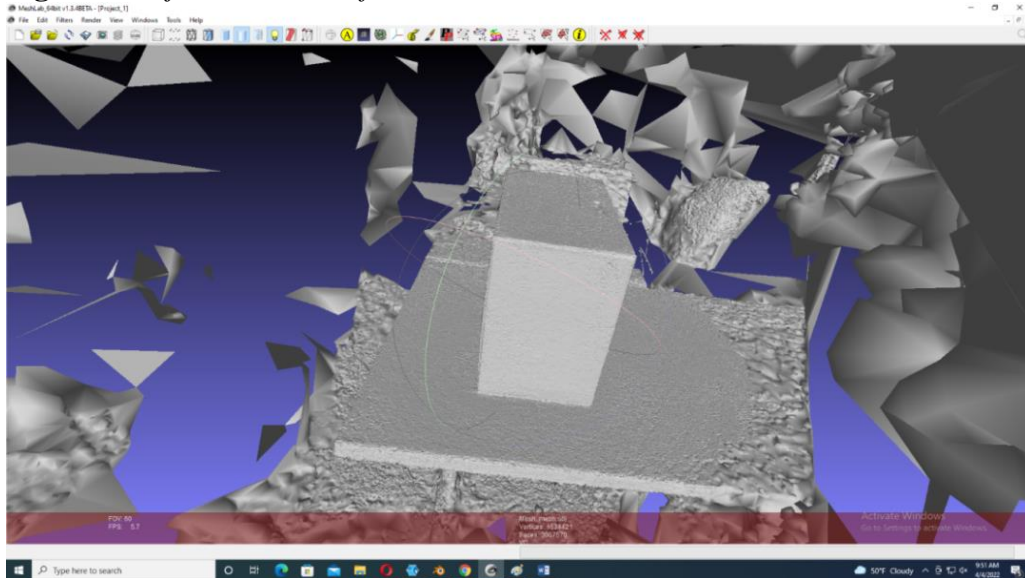
image metadata, sensor information and generates viewpoints.sfmcameraInit.sfm (Alice Vision Inc 2021). Feature Extraction extracts features from the images as well as descriptors for those features (Alice Vision Inc 2021). Image Matching is a processing step which figures out which images make sense to match to each other. Feature Matching finds the correspondences between images using feature descriptors (Asadpour 2021). Structure from motion will reconstruct 3D points from the input images. Depth Map retrieves the depth value of each pixel for all cameras that have been resolved by SFM (Alice Vision Inc 2021, Shilov et al. 2021). Certain depth maps will claim to see areas that are occluded by other depth maps (Stark et al. 2022, Berio and Bayle 2020). The Depth Map Filter step isolates these areas and forces depth consistency. Meshing generates mesh from sfm point cloud or depth map. Mesh Filtering filter out unwanted elements of your mesh. Texturing projects the texture, it changes the quality and size/file type of texture (Matys et al. 2021, Lee and Yu 2009).

As can be seen from Figure 2, the quality for the target object is at a good level, but the processing time of the nodes for this set and for the total time of the object generation process is quite high, the total processing time is 120 minutes (2 hours). Details of the time processing are given in the summary table 1.

The actual dimensions of the object are width = 27.5 cm, length = 48.5 cm and height = 39.5 cm (in MeshLab the width is referred to the x axis, length is referred to the y axis and height is referred to the z axis).

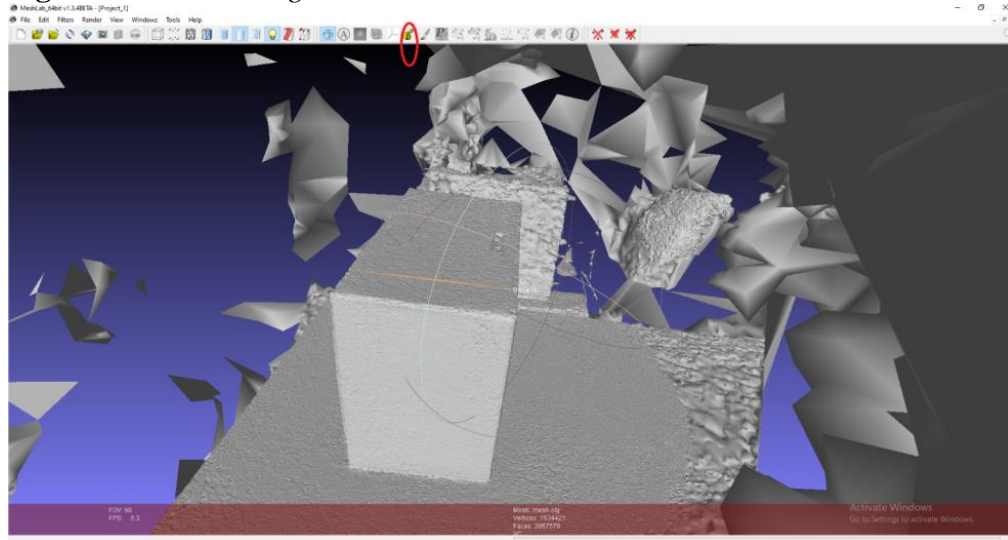
To find the dimensions of the reconstructed 3D object, MeshLab software will be used. The meshing generated by Meshroom software will be exported to MeshLab (Alice Vision Inc 2021, Berio and Bayle 2020). The workspace in MeshLab is illustrated in Figure 3.

Figure 3. Object in Meshlab for Measurements

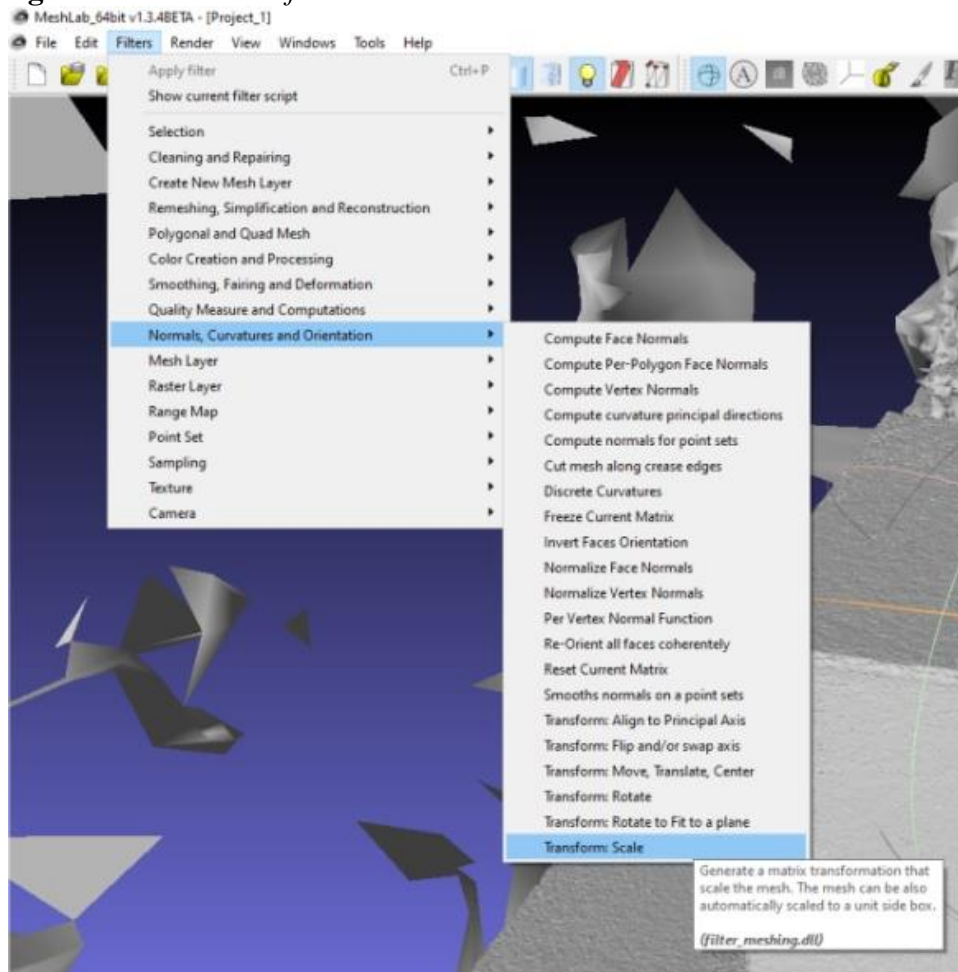


The target object, as can be seen from Figure 3, is complete, it is in the same condition that was generated in the Meshroom. MeshLab in addition to sizing can also serve to eliminate the parts of the background that as noted from Figure 3 are in a large quantity, but this is out of our focus since it is done in the Meshroom software. Therefore, in this paper, MeshLab will be used only to determine the dimensions of the object.

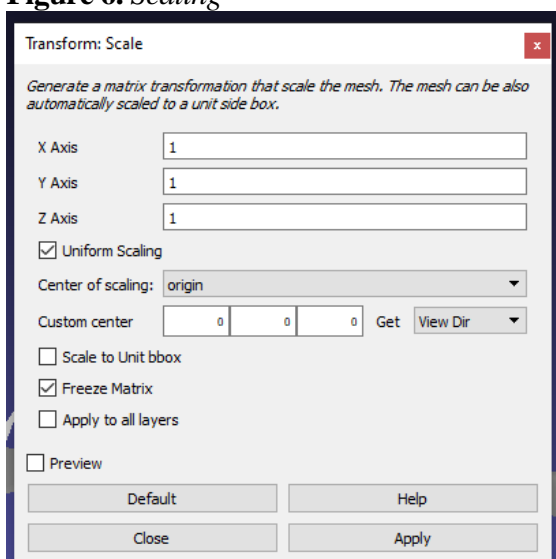
Figure 4. Dimensioning Procedure



To determine the object sizes, the box marked in red will be checked, as shown in Figure 4, it stands for the measurement option. To find the object dimensions, two points, for which the distance is needed, are specified, it is illustrated by the orange line in Figure 4. The result is around the value of 0.55 but nothing is specified if this unit belongs to meters, centimeters, millimeters, etc. The scaling information is missing. One way to convert it to real world measurement units is: knowing the dimensions of the real object that corresponds to the two ends of the orange line, then the real size of the object is divided by the value generated by the orange line above, their ratio is calculated. The result that is obtained is exactly the value of the scale. This value replaces the corresponding parameter that corresponds to the real distance between two points, so it can be in the x plane, y plane or z plane. The Transform: Scale is filled with the calculated value, as shown in Figure 5.

Figure 5. Conversion of Units into Real Units

Scaling parameters window is shown in Figure 6.

Figure 6. Scaling

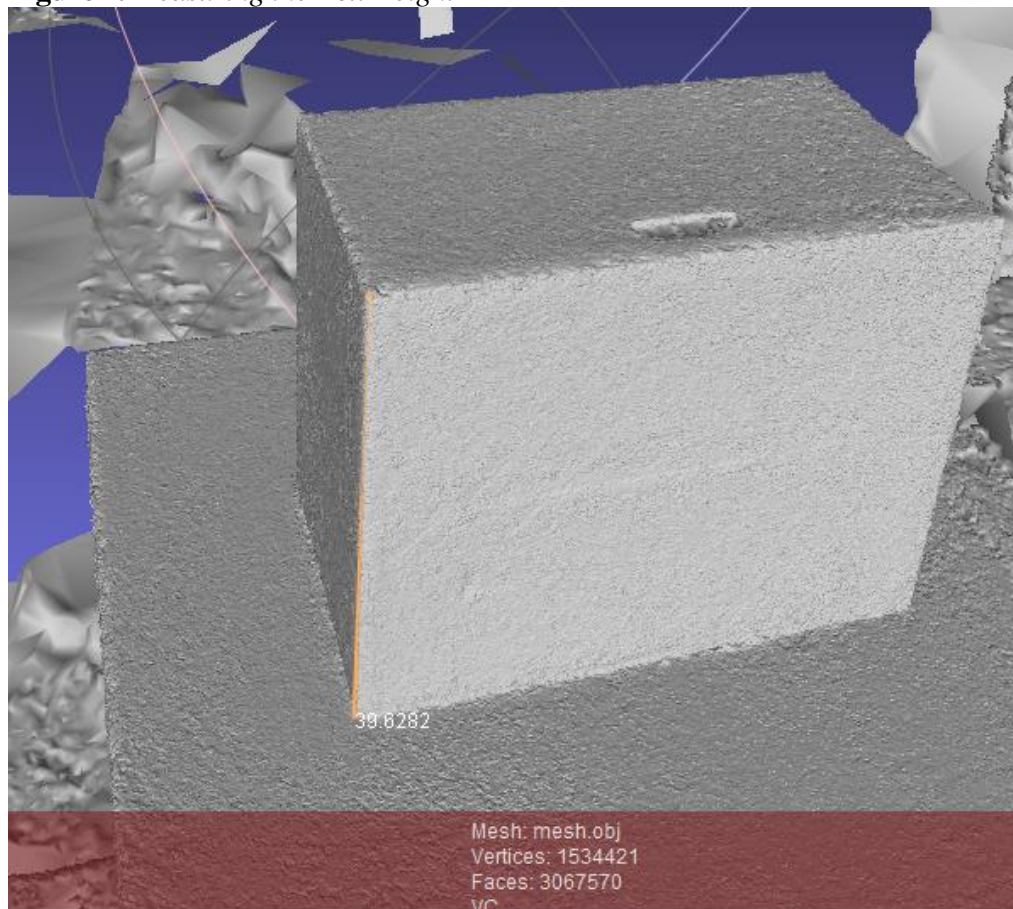
The values x, y and z will be set exactly the new values as indicated in Figure 6. Measuring only the width corresponds to the x coordinate, only the x value will be changed, it is the same for the other two coordinates.

Based on the real values and the measured ones, the scales will be determined. For X dimension, the ratio is calculated as $27.5 / 0.575 = 47.8$, where 27.5 cm is the real size of the width of the box, 0.575 is the number that was generated from the initial measurement of the width of the box in the meshing (inside MeshLab) and 47.8 is the new value of scale to be set for X.

For Y dimension, the ratio is $48.5 / 1.01 = 48.01$, where 48.5 cm is the real size of the box width, 1.01 is the number generated by the initial measurement of the box width in the meshing (inside MeshLab) and 48.01 is the new value of the scale that will be set for Y.

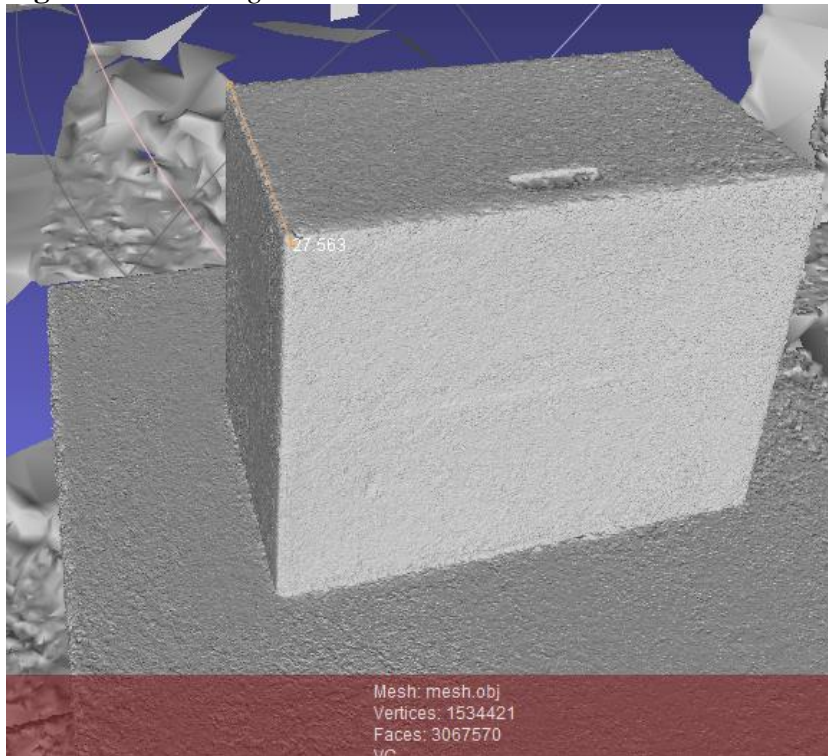
For Z dimension, the ratio is $39.5 / 0.82 = 48.17$, where 39.5 cm is the real size of the width of the box, 0.82 is the number that was generated from the initial measurement of the width of the box in the meshing (within MeshLab) and 48.17 is the new scale value to be set for Z. The three new values in X, Y and Z are replaced in Transform: Scale. The dimensions that will be measured in the target object will be of the same unit as those of the real object.

Figure 7. *Measuring the Box Height*



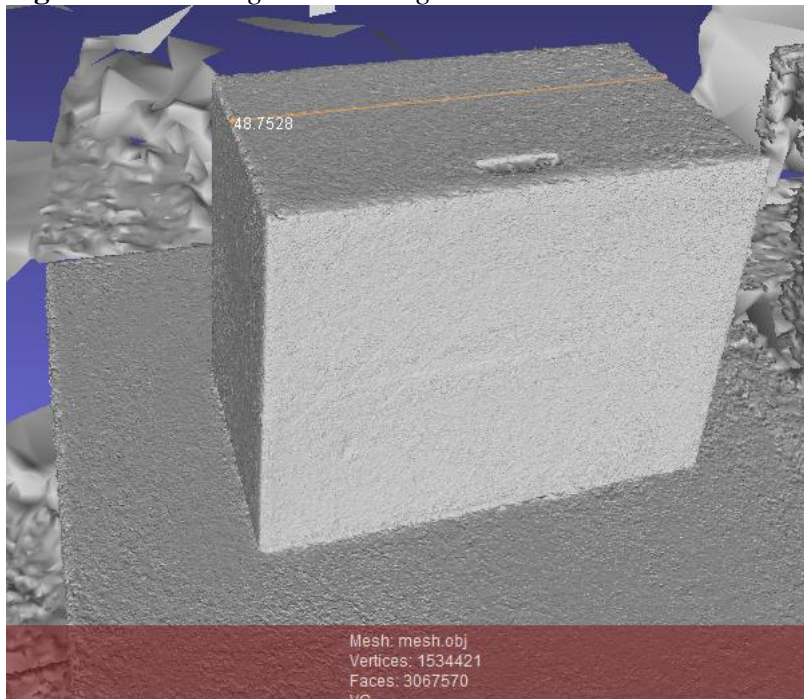
From Figure 7 it is noticed that the height is 39.6282 cm.

Figure 8. *Measuring the Box Width*



From Figure 8 it is noticed that the width is 27.563 cm.

Figure 9. *Measuring the Box Length*

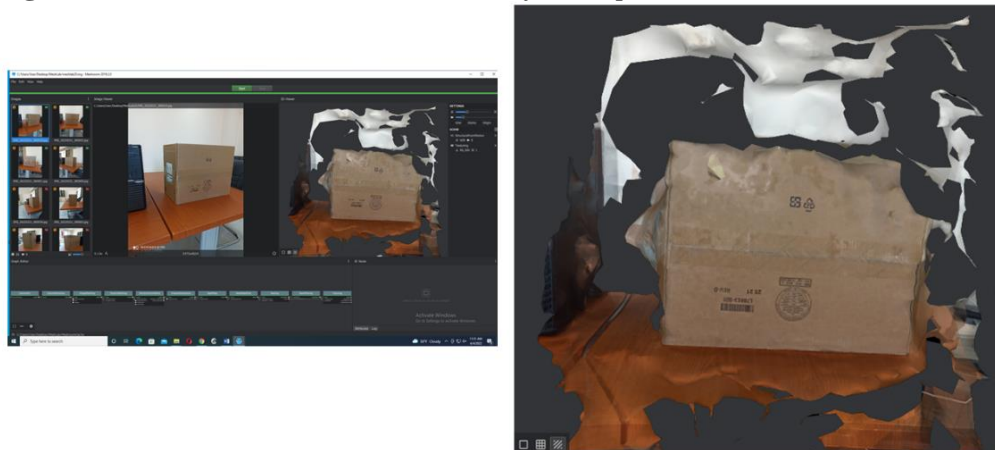


From Figure 9 it is noticed that the length is 48.7528 cm. From measurement results that the width is 27.573 (x axis), the length is 48.7528 (y axis) and the height is 39.6282 (z axis). A very accurate precision has been achieved for the width, for the length an error of only 0.25 mm and for the height an error of only 0.12 mm.

Case B

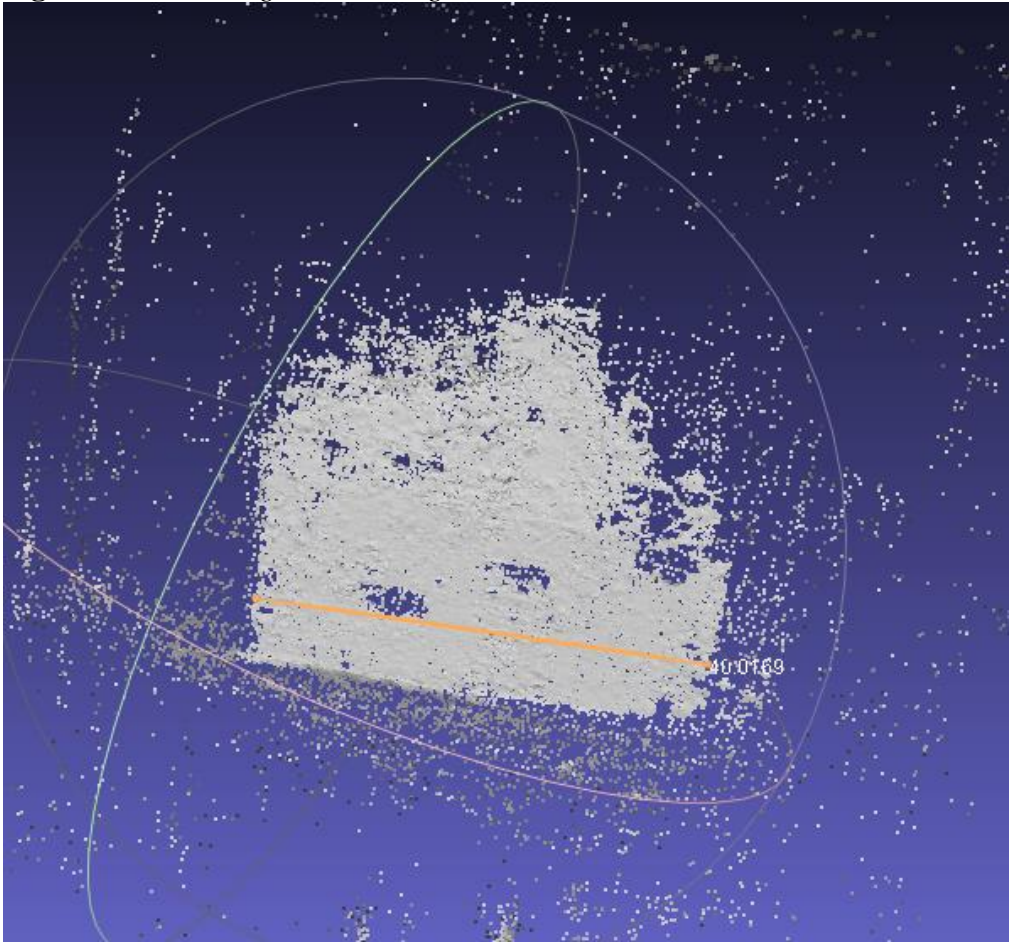
The set with 20 photos is used, within the initial set with 100 photos according to the rule: choose the photo with index 1, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90 and 95. The proposed procedure is performed again and the result in Meshroom is obtained as shown in Figure 10.

Figure 10. *3D Reconstruction Based on Default Pipeline*

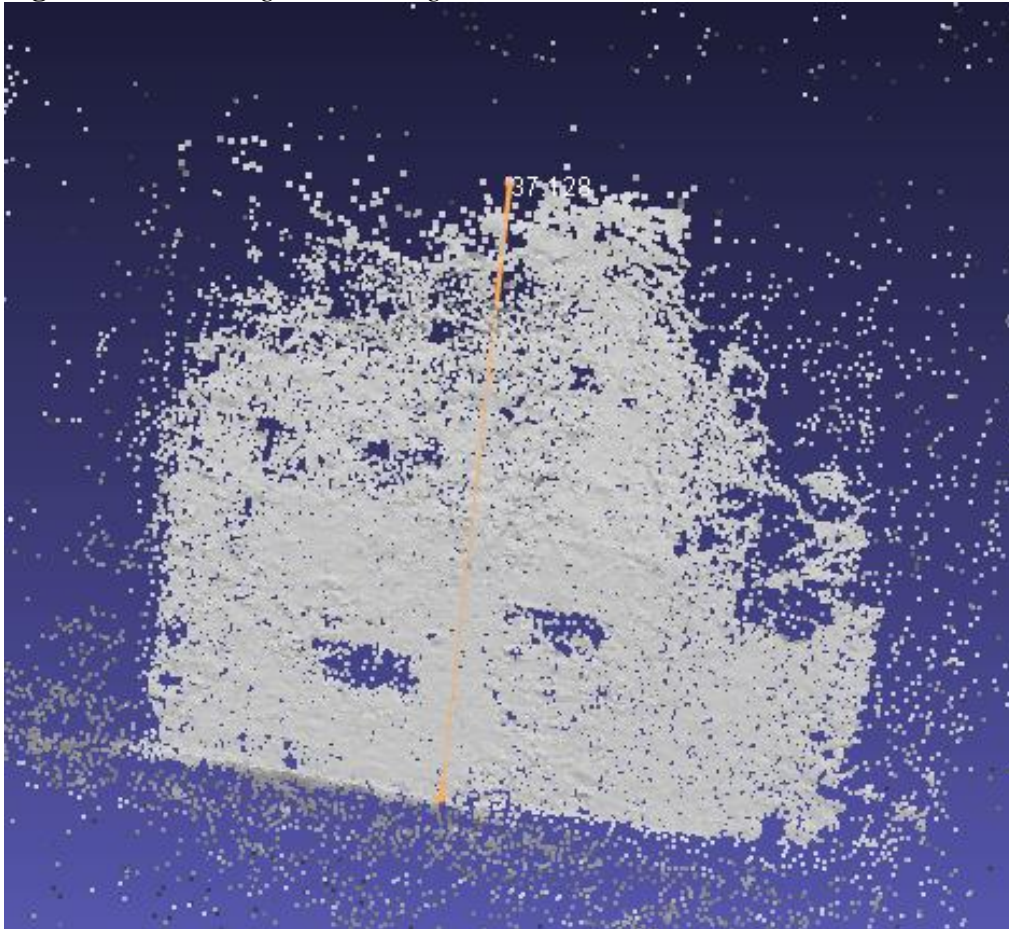


The 3D object reconstructed with this selection of photos has many shortcomings in terms of quality, which can be seen from Figure 10, where the biggest problems are seen in the contours. The number of photos is relatively enough to generate a 3D object more complete than the obtained results, but the selection of photos according to the specified rule led to the conclusion that out of 20 photos as input only 5 of them are recognized and processed further in subsequent nodes to generate the 3D object. In terms of time the result is generated for about 2 minutes. Details of the processing time are given in Table 1.

To determine the dimensions of the reconstructed object, the meshing generated by Meshroom software for the set of 20 photos will be exported to MeshLab. The result is shown in Figure 11.

Figure 11. *Measuring the Box Length*

The width, as it is seen from Figure 11, is 40.01 cm, about 8.5 cm less than the real width of the object.

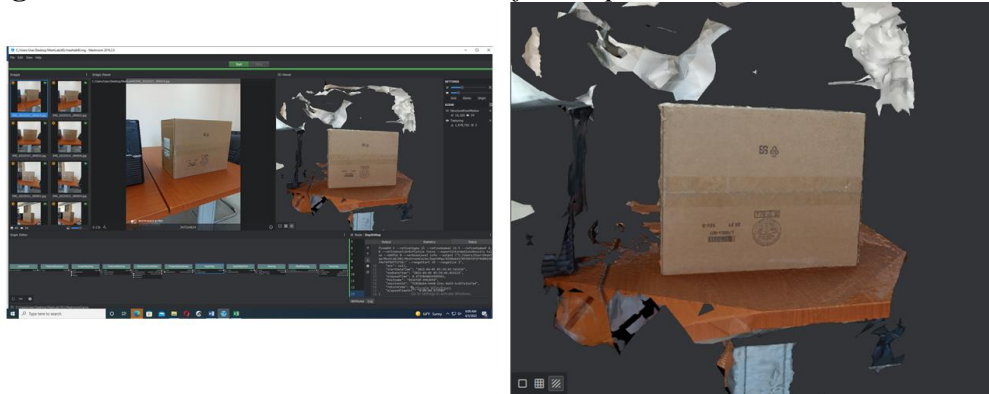
Figure 12. *Measuring the Box Height*

As indicated in Figure 12, the height results about 37.12 cm at the farthest distances between the two points. This distance is in the center of the object, but the rest of the object is incomplete so a fixed value for the height cannot be determined. But even the value 37.12 is 2.4 cm smaller than the real size of the object.

The depth of the target object is not possible to determine since many parts are missing from the side and rear views.

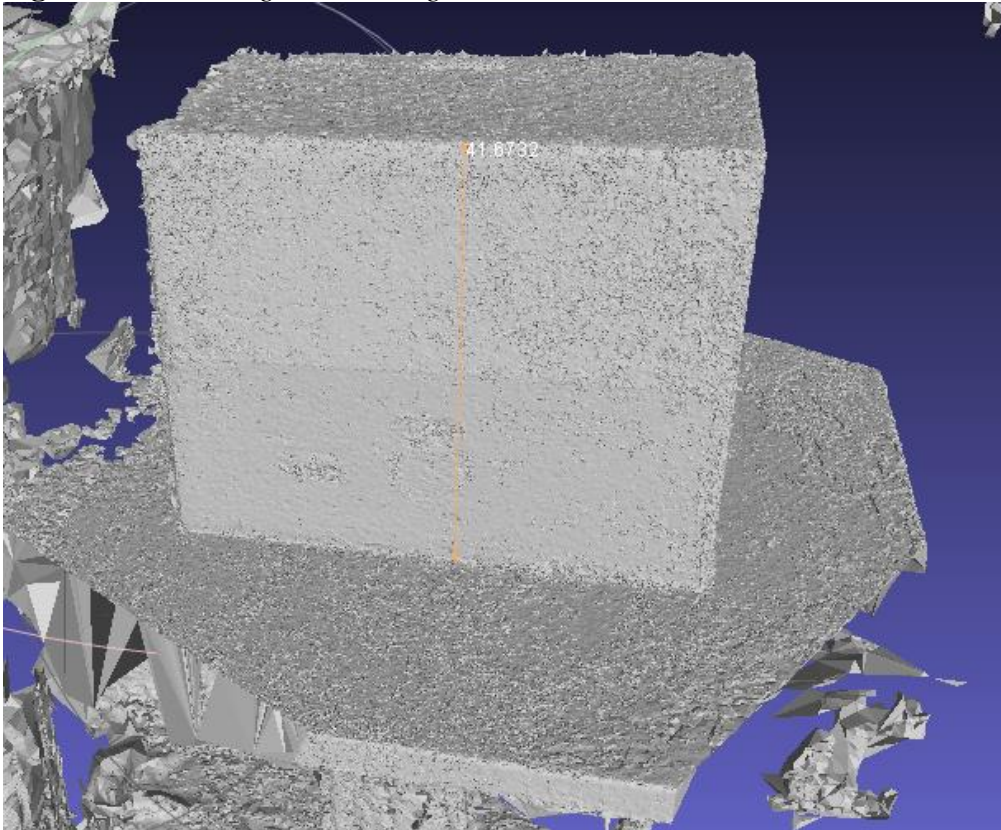
Case C

The set with 40 photos is chosen, the photo indexes are: 1,2; 5,6; 10,11; 15,16; 20,21; 25,26; 30,31; 35,36; 40,41; 45,46; 50,51; 55,56; 60,61; 65,66; 70,71; 75,76; 80,81; 85,86; 90,91 and 95,96. The proposed procedure is repeated and the result in the Meshroom software is shown in figure 13.

Figure 13. 3D Reconstruction Based on Default Pipeline

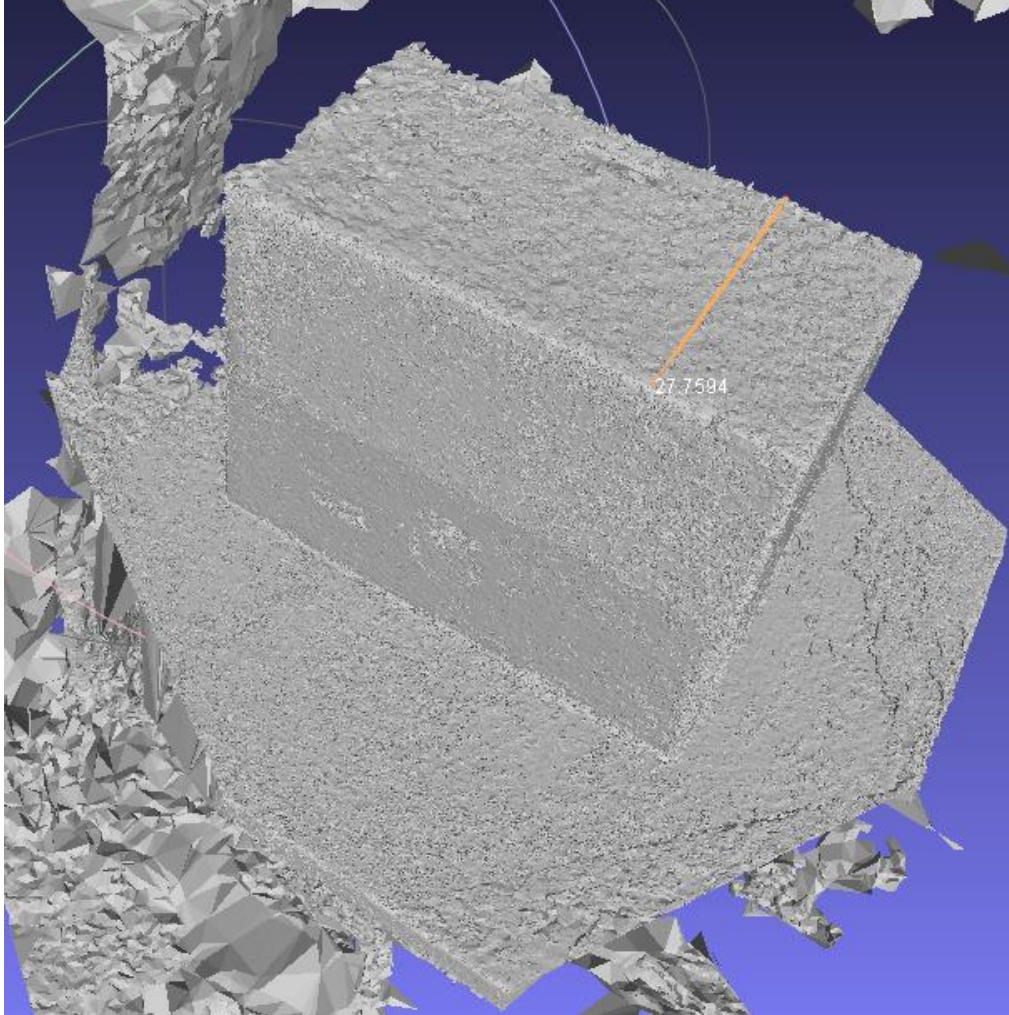
From the set of 40 photos, 34 of them are recognized for further processing. After the processing in the Meshroom pipeline, the 3D reconstructed object is obtained in a good quality, as shown in Figure 13. The object is visually clear, the contours are also quite clear and the content part is complete from all sides. The total processing time to generate the 3D object is about 32 minutes. Details of the time processing are given in Table 1.

To find the dimensions of the reconstructed 3D object, MeshLab software will be used. Meshing generated by Meshroom software will be exported to MeshLab. Result from the MeshLab measurements are shown in Figure 14.

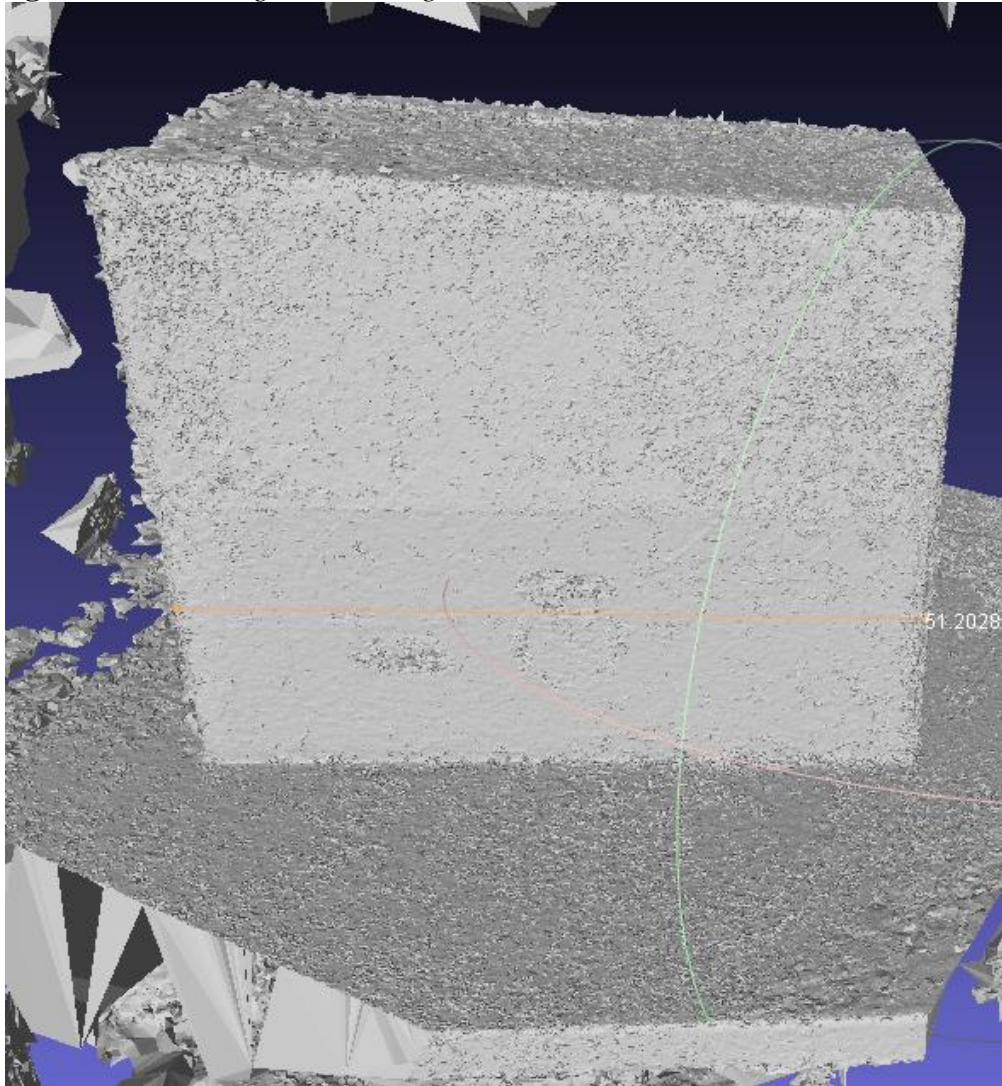
Figure 14. Measuring the Box Height

The measured height for the reconstructed object, as shown in Figure 14, is 41.67 cm. Comparing it with the height of the real object, which is 39.5 cm, yields a measurement error of 1.17 cm.

Figure 15. *Measuring the Box Width*



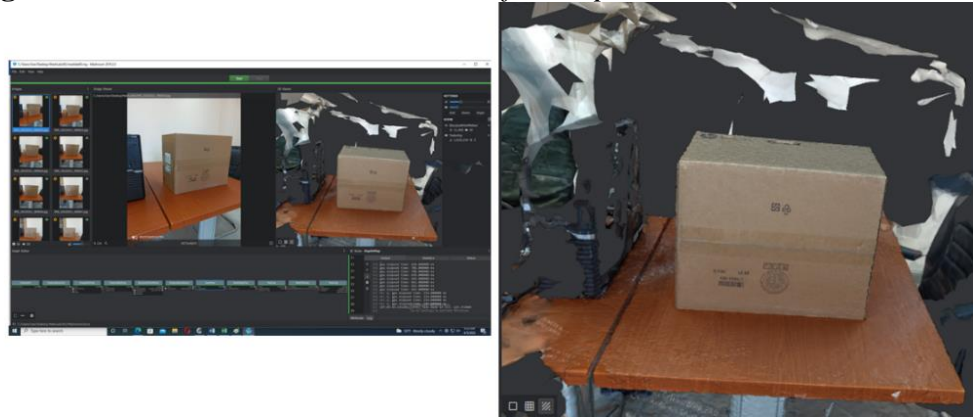
Regarding Figure 15, the measured of the width of the reconstructed object is 27.75cm, while the width of the real object is 27.5 cm. The error is very small, only 2.5 mm.

Figure 16. *Measuring the Box Length*

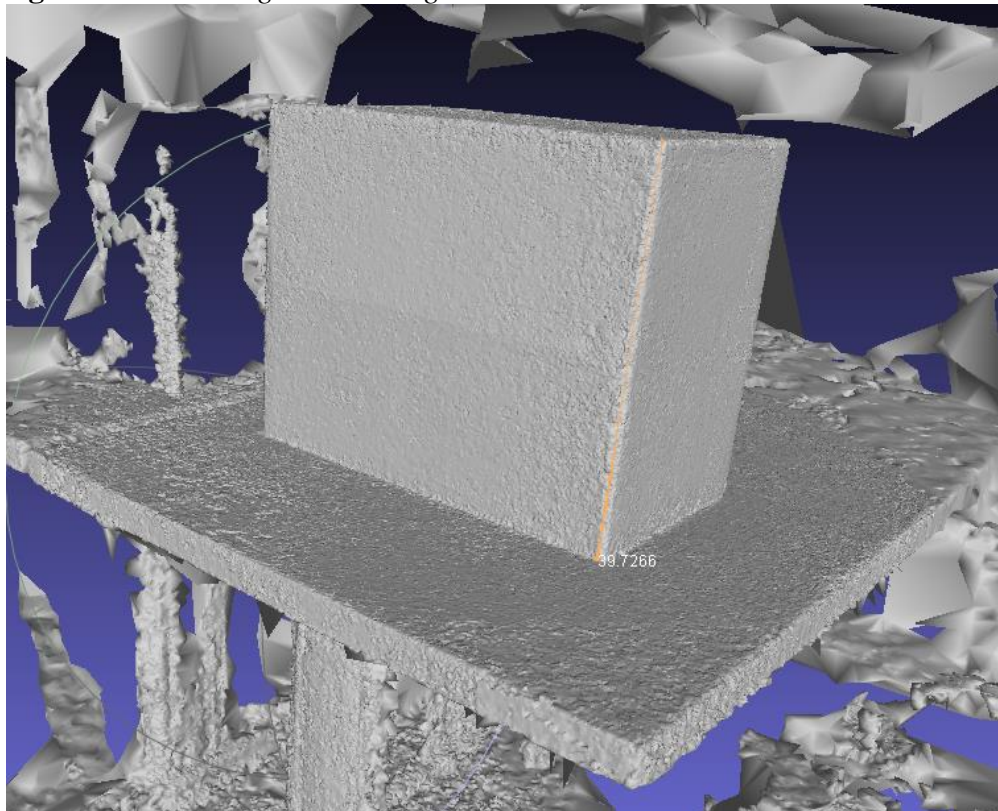
Regarding Figure 16, the measured length for the reconstructed object is 51.2 cm, while the width of the real object is 48.5 cm. The measurement error is about 2.7 cm.

Case D

The set with 60 photos is chosen, the photo numbers are: 1,2,3; 5,6,7; 10,11,12; 15,16,17; 20,21,22; 25,26,27; 30,31,32; 35,36,37; 40,41,42; 45,46,47; 50,51,52; 55,56,57; 60,61,62; 65,66,67; 70,71,72; 75,76,77; 80,81,82; 85,86,87; 90,91,92 and 95,96,97. Repeating the procedure, the result in the Meshroom software is given in Figure 17.

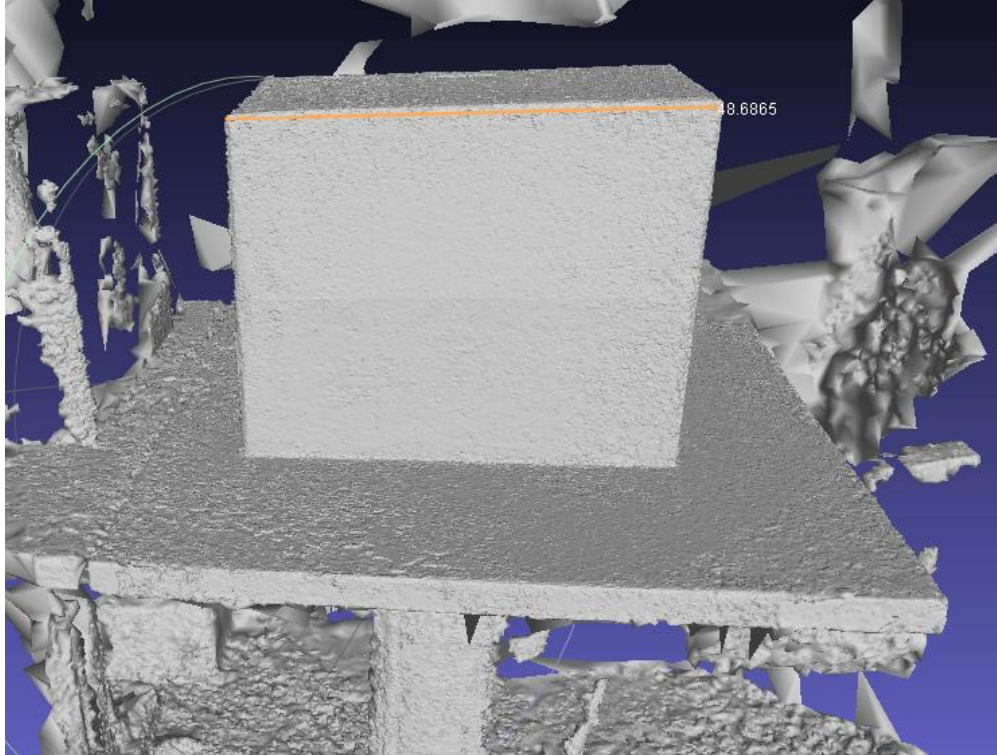
Figure 17. 3D Reconstruction Based on Default Pipeline

Regarding Figure 17, the reconstructed 3D object is in the same quality as the reconstructed object with the initial set of 100 photos, the contours clear, the content part has no shortcomings and is visually very clear. From the input of 60 photos, 59 of them were recognized for the processing and the total processing time in the default pipeline nodes of the Meshroom software (given as the sum of processing time in each node) is about 97.6 minutes. Details of the time processing are given in Table 1.

Figure 18. Measuring the Box Height

The dimensions of the 3D reconstructed object will be measured. The height, as can be seen from Figure 18, results 39.726 cm, while the real dimension of the object is 39.5 cm. The measurement error is only 2.26 mm.

Figure 19. *Measuring the Box Length*

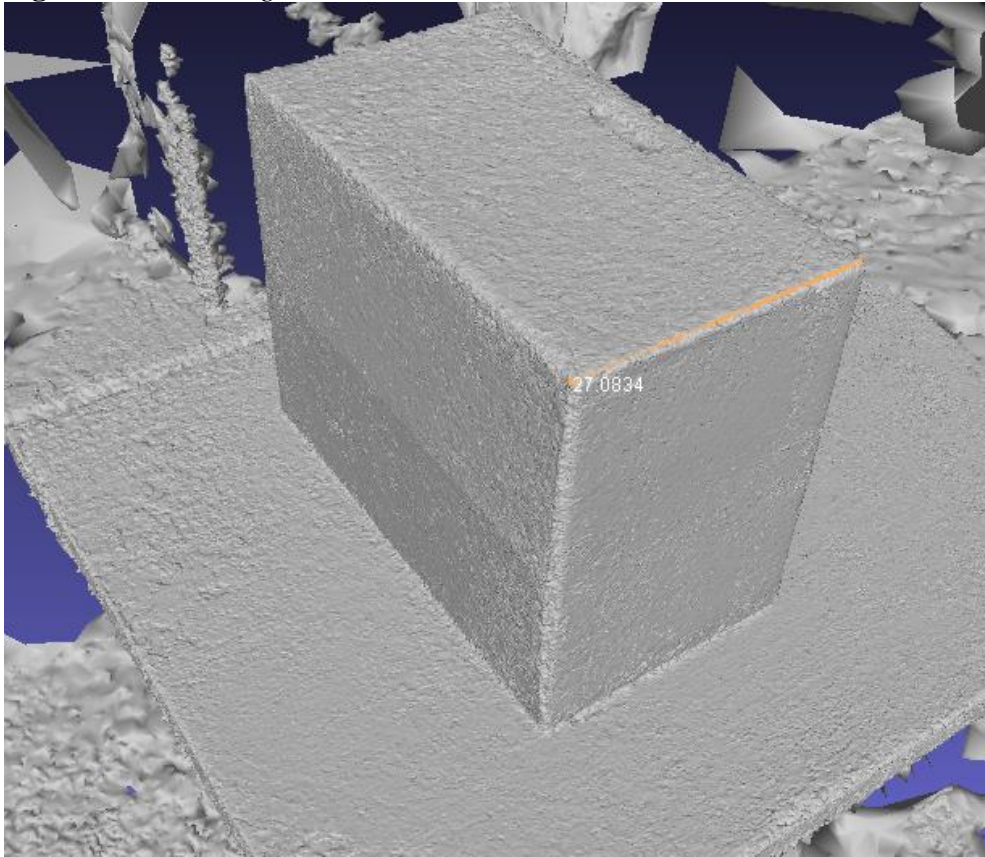
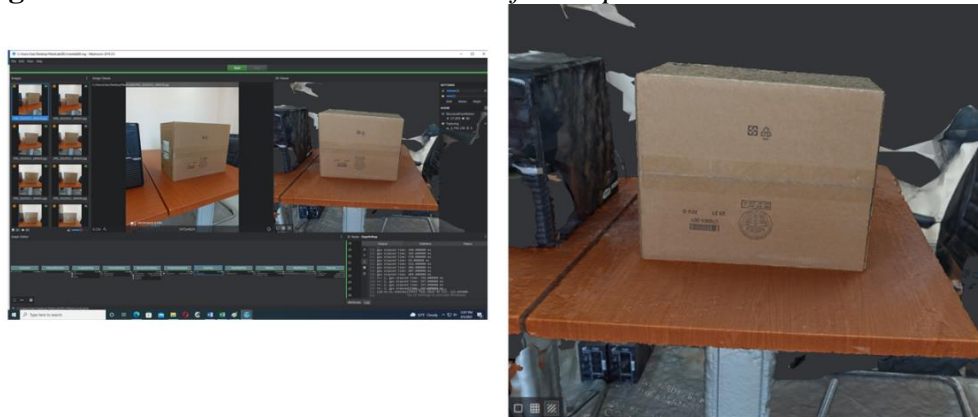


Regarding measurement shown in Figure 19, the length resulted 48.68 cm, while the real value is 48.5 cm. The error is only 1.8 mm.

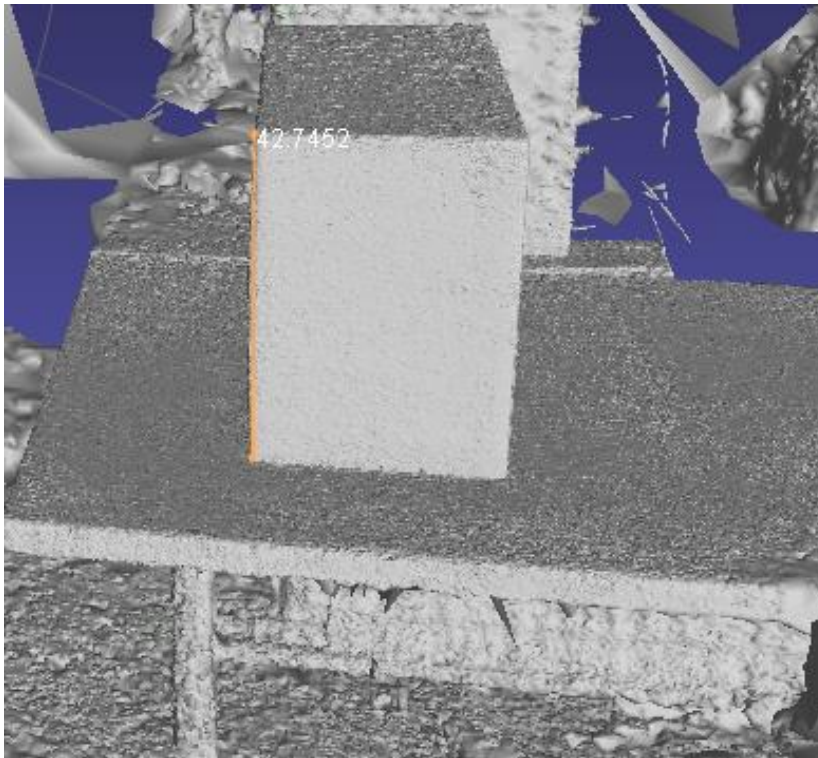
As indicated in Figure 20, the width of the reconstructed object resulted in 27.08 cm, while the real width of the object is 27.5 cm. There is an error of 4.2 mm.

Case E

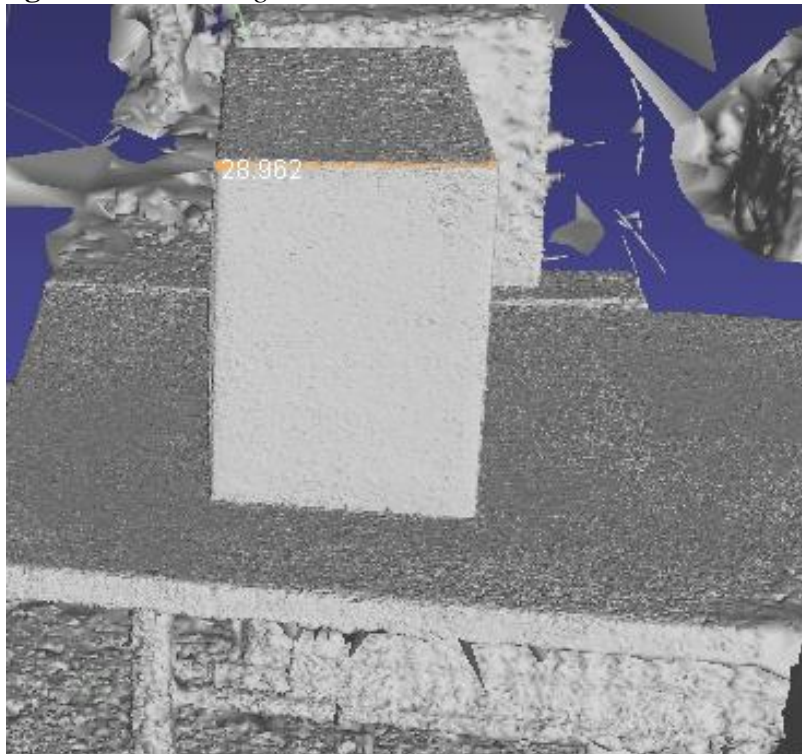
The set with 80 photos is chosen, the photo indexes are 1,2,3,4; 5,6,7,8; 10,11,12,13; 15,16,17,18; 20,21,22,23; 25,26,27,28; 30,31,32,33; 35,36,37,38; 40,41,42,43; 45,46,47,48; 50,51,52,53; 55,56,57,58; 60,61,62,63; 65,66,67,68; 70,71,72,73; 75, 76,77,78; 80,81,82,83; 85, 86,87,88; 90,91,92,93; 95,96,97,98. The procedure is repeated and the result in the Meshroom is shown in Figure 21.

Figure 20. *Measuring the Box Width***Figure 21.** *3D Reconstruction Based on Default Pipeline*

Regarding Figure 21, the reconstructed 3D object is in the same quality as the reconstructed object with the initial set of 100 photos, the contours are well reconstructed, the content part has no shortcomings and is visually very clear. From the input of 80 photos, all were recognized for processing and the total processing time in the default nodes in Meshroom software (given as the sum of processing time in each node) is about 84 minutes. Details of the time processing are given in Table 1. The dimensions for the generated object will be measured.

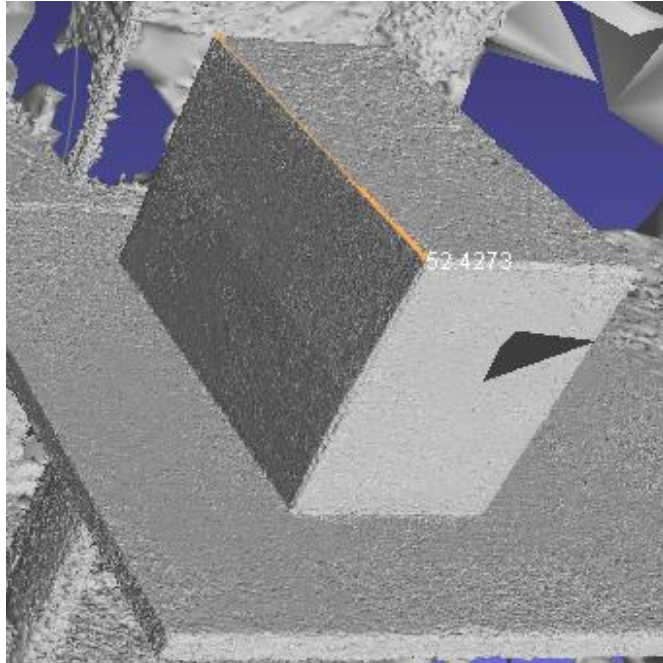
Figure 22. *Measuring the Box Height*

The height as indicated from Figure 22 is 42.74 cm, while the real value of the object is 39.5 cm. The measurement error results in 3.2 cm.

Figure 23. *Measuring the Box Width*

Referring to Figure 23, the width of the reconstructed object resulted in 28.962 cm, while the real width of the object is 27.5 cm. There is an error of about 1.46 cm.

Figure 24. *Measuring the Box Length*



Referring to Figure 24, the length is 52.427 cm, while the real value is 48.5 cm. It resulted in a measurement error in the value of about 4 cm.

Time processing results for each case is shown in Table 1.

Table 1. *Results of Processing Time Measurements for Each Case*

Processing statistics											
Test	Input images	Camera calibrated	Camera init	Feature Extraction	Image Matching	Feature Matching	Structure from Motion	Prepare Dense Scene	Depth Map	Depth Map Filter	Total time (seconds)
1	100	100	0.21	94.37	0.2	165.76	83.17	35.37	4697.83	511.5	7207.85
2	80	80	0.21	33.34	0.3	103	103.1	30.84	3250	390	5038
3	60	59	0.21	36.34	0.19	68.1	73.75	47	3776	473	5861.8
4	40	34	0.19	36.63	0.33	22.07	31.04	28.28	1284	168.83	1920
5	20	5	0.19	19.39	0.3	7.84	3.11	5.02	52.54	11.36	135

As indicated in Table 1, case 5 gives the best result for processing time. Performance comparison for each case is shown in Table 2.

Table 2. *Performance Comparison*

Experiment	Processing time	Quality	Size measurements
Case 1	5	1	1
Case 2	3	3	4
Case 3	4	2	2
Case 4	2	4	3
Case 5	1	5	5

Regarding results shown in Table 2, the reduction of the number of photos from 100 to 60 (case 3) yields the optimal performance in terms of visual quality and processing time.

Cignoni et al. (2008) deal with the strategy and support for development and the capacities offered by the proposed system, but not the measurement of the size of the objects and the accuracy in the measurement. Sá et al. (2019) proposed a methodology for replica of public sculptures of modern period. In this work discussion is presented about various options for access, augmented reality applications and 3D printing of replicas. The proportions of the components of the objects under consideration are analyzed, but not their measurement and accuracy. In the article of Djuric et al. (2021) the results of the 3D reconstruction in the open-source software Meshroom and the commercial one Agisoft Metashape are compared, highlighting the advantages of the commercial software and the level of accuracy obtained from the open-source software, in this case Meshroom.

Conclusions

In this paper the trade-off between number of photos and processing time in the 3D reconstruction is analyzed. Meshroom software is used for reconstruction and Meshlab is used for dimensioning. The full quality is obtained from input of all the photos, but processing time is too large. Five cases are considered, with 100, 80, 60, 40 and 20 photos, quality of reconstruction and time processing are analyzed for each case.

Experimental results show that reducing the number of photos decreases the processing time but at the same time also the quality of the reconstructed object. On the other hand, a very large reduction of photos can give a poor quality, as demonstrated in the case five with the set of 20 photos, only 5 of them were processed by the nodes.

Based on the experimental results it is concluded that the optimal case in terms of quality and processing time is the case three, where the number of photos is equal to 60. The processing time is 97.6 minutes and the dimensions accuracy is about 1-2 mm.

Acknowledgments

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