

## CREATION OF 3D MODELS OF REAL OBJECTS USING CLOSE-RANGE PHOTOGRAMMETRY IN EDUCATION

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**Abstract:** Nowadays, in a time of rapid development of many scientific disciplines, solutions are emerging that require knowledge from several fields. Promoting cross-curricular relationships is also becoming relevant. Its importance is also clear in higher education. It creates and deepens students' competences and enables them to take a broader view of related or underlying fields. 3D models are a very suitable tool to support cross-curricular relationships, where their importance is not only in the creation of the 3D model itself, but the results obtained in this way are also fully applicable in the educational field as a visualization tool. This is an interesting activity for students, but also the creation of models hides a number of possible complications that can complicate their creation and if the model fails, it can discourage the student. Therefore, it is important to be able to react correctly and choose the appropriate course of action. It is not necessary to obtain new photographs, but manual intervention in the creation of the 3D model is sufficient. The method of creating 3D models and their importance in the educational sphere have already been presented in several of our publications, for example [1-6]. However, practical implementations show that although students are very positive about this activity, they often encounter problems in post-processing. It is on post-processing procedures that we will focus in our paper. Using concrete examples, we will show the three basic editing methods we have proposed (adding manual tie-points; editing a meshed model by removing point clouds and properly removing the visible part of the model), which once mastered, students will be able to solve most problems in the creation of 3D models without deeper technical knowledge.

**Keywords:** Education, 3D models, Photogrammetry, Tie-points, Point-clouds, 3D model modification.

### 1 Introduction

Our previous work shows that 3D models are a very good tool for supporting intersubject relationships. Nowadays, thanks to modern technological solutions, they can be easily implemented in the teaching process, and both software and hardware tools for creating 3D models are available. Today, students already have a variety of tablets and mobile phones, the cameras of which are sufficient to take photos and create 3D models. [1-6] Realistic 3D models can be obtained in several ways. Currently, non-contact methods are divided into LiDar-type methods and photogrammetric methods. Of the photogrammetric methods, in the next text we will focus on close range photogrammetry. Photogrammetry obtains information about physical objects and environments from photographs. Basically, it's about creating 3D models from 2D photos or images. This method is often used in architecture, engineering, manufacturing, archeology and in the field of cultural heritage protection. Close range photogrammetry focuses on objects that are close and does not require the use of an aerial photogrammetry or UAV, which is used for example in the protection of cultural heritage. [7-9]

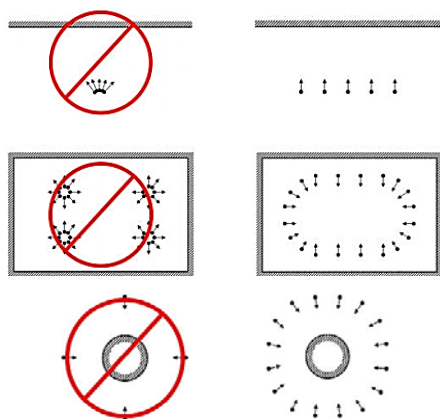


Figure 1 – incorrect and correct methods of obtaining photos according to the type of object. Above: facade, in the middle: interior, below: isolated object [10]

The basis for creating 3D models are photos of the scanned object. The correct method of photographing an object according to its shape is shown in figure number 1. When processing photographs, the so-called key points. They are well identifiable and recognizable points on several images. They are the basis for determining the position or movement of the camera and the arrangement of images relative to each other. Subsequently, the Tie points are determined, which are crucial for determining the mutual relations and orientation of the images, which enables accurate connection into one coherent 3D model. Those points do not yet carry any spatial information. Point Cloud is a set of points in 3D space, with spatial information - that is, they carry data about the position in the coordinate system. Each point in the cloud represents part of the surface of the object and together they form a detailed 3D structure of the model. Those points do not have to be present only on the scanned object, but also in its surroundings. This is clearly visible in picture number 2. The 3D model itself is created from the point cloud. This process transforms a set of points from a point cloud into a continuous surface grid (mesh) that represents the shape and surface of the object in three-dimensional form. Meshing connects points from a point cloud. In practice, the most widespread is the triangle mesh. [3-5,11-13]

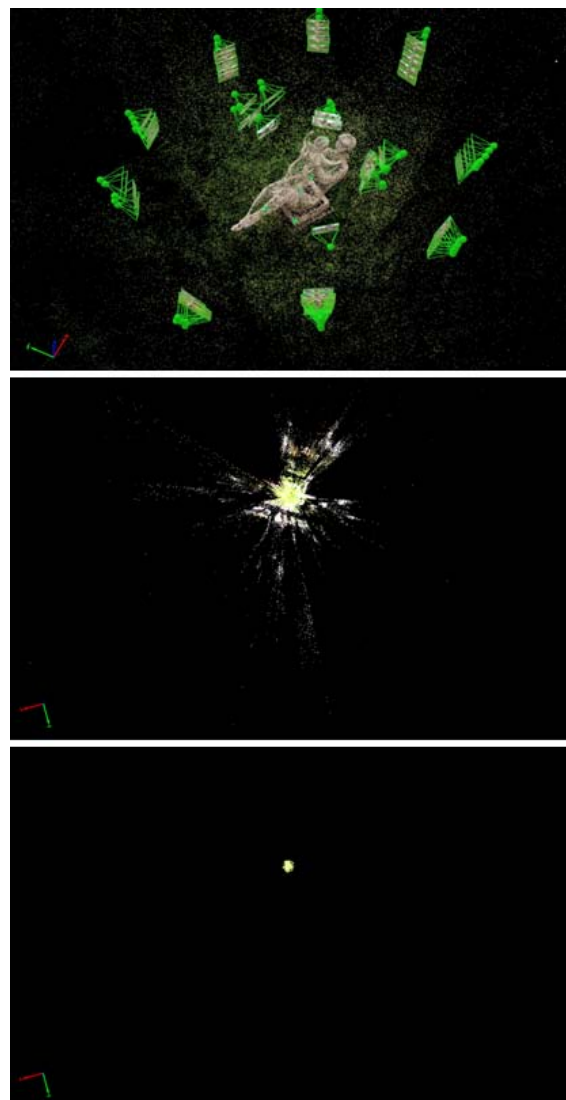


Figure 2 – Above: location of the cameras when obtaining photos, in the middle: Tie points of the object, below: Point cloud of the object while maintaining all the size parameters used in the image in the middle

## 2 Material and methods

We used the Pix4Dmapper Pro photogrammetry software to process the photos. It is a product of the Pix4D suite of products. Pix4D software uses imagery captured with drones, mobile devices, or planes to recreate scenes in 3D. It is characterized by high accuracy, automatic processing, supports the processing of RGB images, images from thermal cameras or multispectral images and, in addition to 3D models, it can also create digital maps. [14] All the models discussed in this article were created with the camera of the OPPO Reno 5Z mobile phone, with the help of a computer with the following parameters:

- Hardware: CPU: Intel(R) Xeon(R) CPU E5-1650 v3 @ 3.50GHz; RAM: 32GB; GPU: NVIDIA Quadro K4200 (Driver: 9.18.13.4121).
- Software: Pix4Dmapper Pro 2.0.104 – 64 bit; Windows 7 Professional, 64-bit.

Errors often occur when creating 3D models. It often happens that the created model is not a reliable image of reality, but contains several errors and inaccuracies. Some of them do not significantly affect the quality of the model (local texture color error, slight deformation of the surface), but others do (missing part of the surface, significant deformation, ...). These need to be removed and repaired. Especially in education, failure can easily cause demotivation. Therefore, it is necessary to control the subsequent processing and not to rely on success in the creation of a 3D model for the first time. From the post-processing processes, we will mention the use of manual Tie points, the correction of point clouds by removing them, and we will also focus on cropping.

## 3 Results

In Figure 2 we have shown the locations of the cameras, tie points and point clouds of the mother and child sculpture. We have chosen this statue also because it is a typical representative of the architecture of the former regime. It had its own character, but that is being lost by the automatic rejection of everything connected with the former regime. In Figure 3 we show the Point cloud of the sculpture (compared to Figure 2 it is more enlarged) and the resulting 3D model itself from the same point of view and the same position.

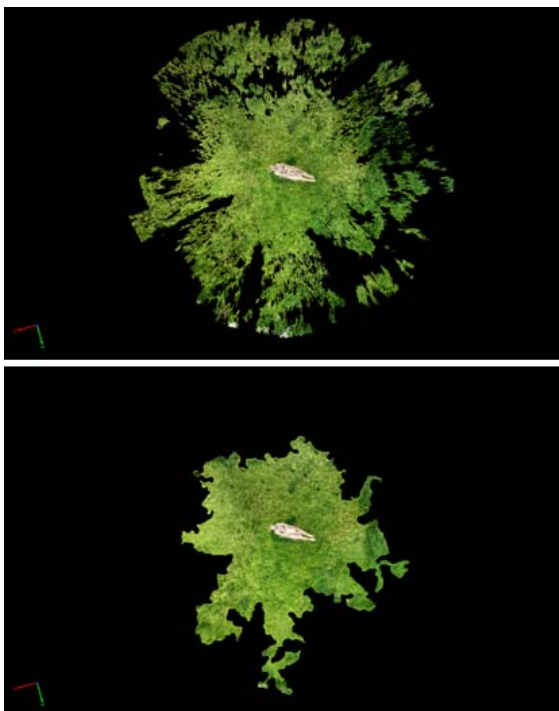


Figure 3 – Point cloud and 3D model of the statue

The resulting 3D model was not created the first time, but needed to be modified. In the automatic processing process, the software excluded almost half of the photos because it could not find enough points to pair them. Probably there was not enough overlap between some adjacent photographs. The 3D model created was therefore only partial. This condition is illustrated in Figure 4.

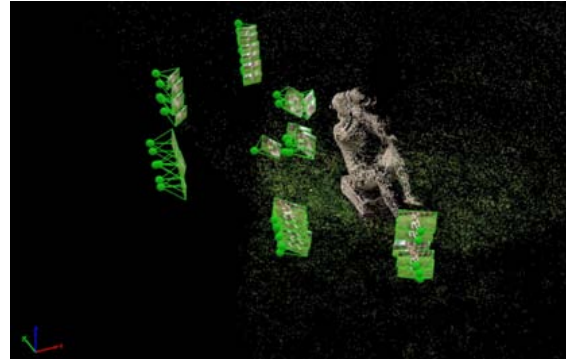


Figure 4 – Location of cameras and Tie points earned from them

We will use manual Tie Points to solve. These are selected so that they are visible in as many images as possible and so that they represent a distinctive point on the object. We show these in Figure 5. We chose the top of the leg crack, the child's toe, the two opposite edges of the pedestal, and the tip of the child's hair. Our aim was to find points that are evenly spaced on the object and are well identifiable. We manually add points by selecting one point and clicking on the "New Tie Point" button in the "Images" section of the window - the red arrow. We then start marking this point on other photos. After marking at least two photos, we can use the "Automatic making" button. If the software recognizes the point in the photos, it will mark it with a green marker. We use the yellow marker to mark the manual placement of manual Tie Points. Although it's not clearly visible in Figure 5, but by using the slider we can zoom in on the photos and thus pinpoint a particular point more accurately. Ideally, the centers of the green marks and the yellow marks are identical. However, this is not always possible to maintain and deviations can occur. In such cases, we try to use as many photographs as possible and pinpoint a specific point on them - down to a specific pixel if we can. The software starts to recalculate these positions and the centers of the marks start to converge. Here we have to point out a very common mistake. Users add points to individual photos but the accuracy does not improve. The reason for this is incorrect place marking. It sounds like a mistake of inattention, but it very often occurs especially in cases where the photos are quite homogeneous in color and many parts are easily confused (parallel grooves, regular inaccuracies, ...). When you have finished adding manual Tie points, start the reprocessing from the "Local processing" menu. If there is no change or only a partial change, we have to add a number of manual Tie Points. In our case, this number of points was sufficient and we included all the images as shown in Figure 2 for the camera placement. Of course, by exaggerating the manual addition of Tie points we can also damage the whole 3D model. When adding images cannot be achieved with 10 manual Tie points, it is a good idea to consider re-acquiring images of the object.

Thus, by manually adding Tie Points we can affect the dimension of the 3D model. This can be used, for example, in the case where we only have a small number of photos and can only create a partial 3D model. Such cases are, for example, when the object to be imaged is at height or in a dangerous environment and we can only obtain photos from one position with a range practically equal to the span of our hands. Even in such a case, we can create partial 3D models from the photographs, but it may happen that the desired part will not be part of the created 3D model. For example, bird nests, wood-boring fungus, etc. By manually adding Tie points we can achieve filling in the missing part. For more details, see [6].

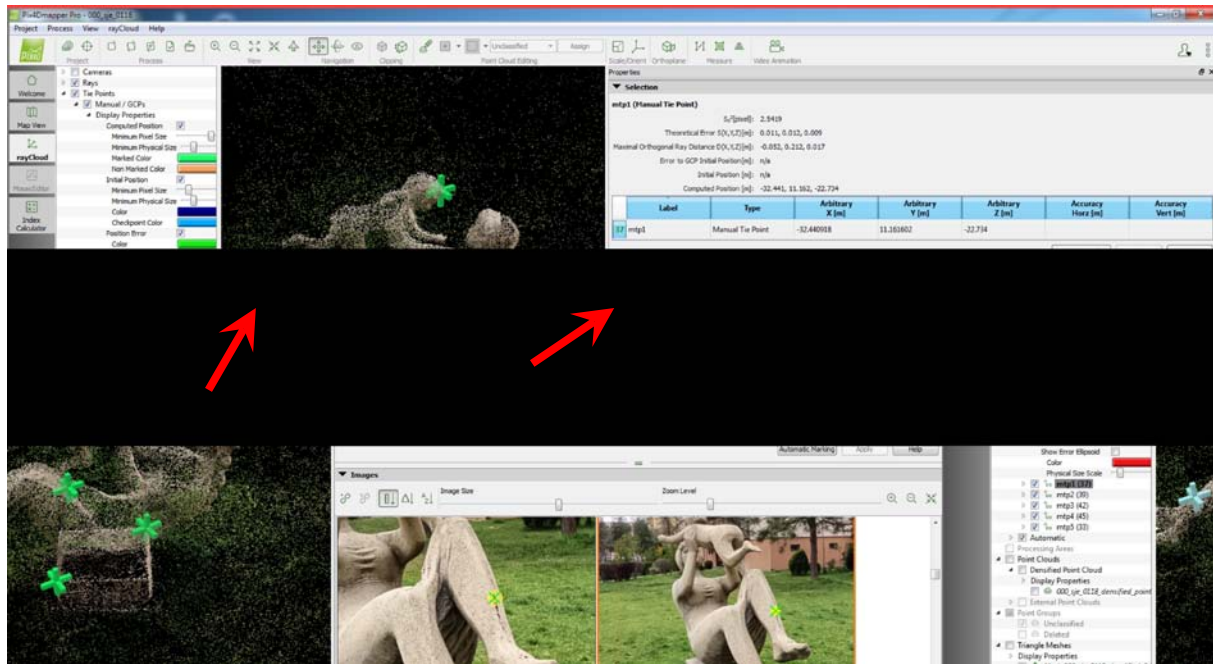


Figure 5 – Adding manual Tie points in Pix4Dmapper Pro

The aforementioned Tie point was marked on 37 photographs. The baby's thumb in 32 photos, the opposite edges of the base in photos 42 and 39, and the tip of the baby's hair in 45 photos out of a total of 80 photos.

It often happens that the created 3D model contains imperfections caused by incorrect determination of a point from the point cloud. In this case, we have to make the adjustments on the mentioned cloud of points. An example of such an error can be seen in figure 6 above. Usually the points outside the object are well discernible. We will remove all points that do not belong to the 3D model. Deleted points are indicated in red.



Figure 6 – Editing Point cloud

These errors were not yet visible when viewed from image number 3. The resulting 3D model after all previous adjustments is shown in image number 7. After removing the faulty points of the cloud, it is enough to run "Generate 3D textured mesh" from the "Process" menu.



Figure 7 – Final 3D model

One of the statistical parameters we monitor for 3D models (because they can give us an initial assumption about the quality of the 3D model) is 3D Points from 2D Keypoint Matches. The results can be presented graphically as well as in a table. Each 3D point is generated from key points that have been observed in at least two images. The first column of the table shows the number of 3D points that were observed in N images - the second column. The higher the number of images in which a 3D point is visible, the higher its accuracy. For our model, the table is as follows:

Table 1 – Number of 3D Points Observed

In 2 Images	408313	In 13 Images	151
In 3 Images	103706	In 14 Images	107
In 4 Images	38048	In 15 Images	79
In 5 Images	18545	In 16 Images	58
In 6 Images	10892	In 17 Images	57
In 7 Images	2906	In 18 Images	21
In 8 Images	1368	In 19 Images	7
In 9 Images	884	In 20 Images	10
In 10 Images	620	In 21 Images	2
In 11 Images	433	In 22 Images	4
In 12 Images	233	In 24 Images	1



In table no. 2 we present the 2D Keypoints Table. The 2D Keypoints Table displays some statistics of the keypoints and the matches of the project. Keypoints are points of interest (high contrast, interesting texture) on the images that can be easily recognized. Parameters number of matched 2D keypoints per image is a matched point is a characteristic point that has initially been detected on at least two images (a 2D keypoint on these images) and has been identified to be the same characteristic point.

Table 2 – 2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	41421	19386
Min	16024	1789
Max	60592	32400
Mean	41602	18730

Median of keypoints per image is 41421 at 11.41% relative difference between initial and optimized internal camera parameters. All photos were without location and GPS data. Number of Generated Tiles was 1 and Number of 3D Densified Points was 3270659. Camera model: OPPOreno5Z\_4.7\_4000x2256 (RGB). The total time required to create a 3D model consists of three times:

Time for Initial Processing : 6m:18s  
 Time for Point Cloud Densification : 8m:28s  
 Time for 3D Textured Mesh Generation : 2m:42s

For one Tie point which we mark on about 30 photos we can count on the time needed for processing 4-10 minutes. We also have to take into account the fatigue of the students and this time can be greater with a large number of Tie Points. In the following figure we present Number of Automatic Tie Points. The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Average direction and magnitude of the reprojection error for each pixel indicated by the blue lines. Vectors are scaled for better visualization. [14]



Figure 8 – Number of Automatic Tie Points for our object

In general, it can be argued that as long as this characteristic for any object is white at least in the object region, it indicates that a 3D model can be created and will be of sufficient quality.

For the sake of completeness, we can mention the following three characteristics:

- Number of 2D Keypoint Observations for Bundle Block Adjustment: 1498422
- Number of 3D Points for Bundle Block Adjustment: 586445
- Mean Reprojection Error [pixels]: 0.207682

We can also use manual Tie points to solve the problems shown in Figure 9. In this case, we can see that the software has created

Automatic Tie points for different sizes of the same monument. The reason for this can be the acquisition of photographs from significantly different distances, different values of F-stop, blur or focal length, the use of different cameras with different parameters, etc. The green markers show manual Tie points.

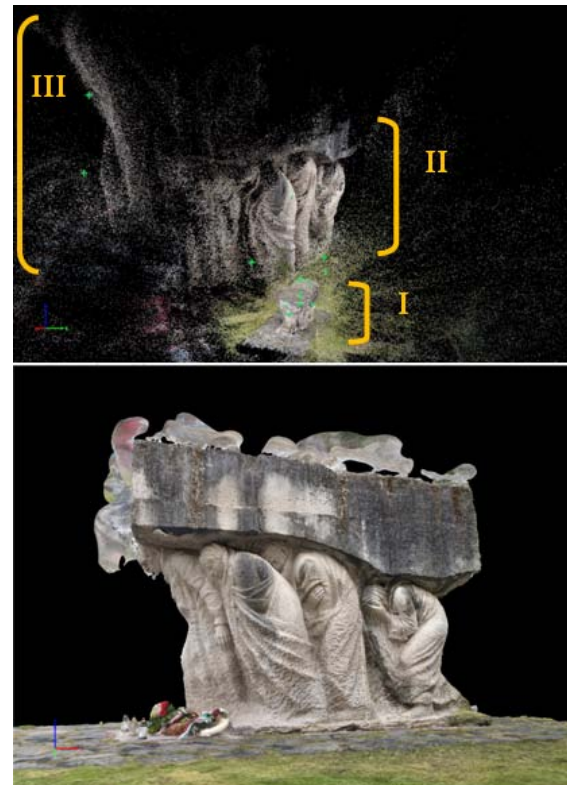


Figure 9 – Tie points of non-uniform size of the same object and the 3D model after adding manual Tie points below

In the creation of 3D models, it sometimes happens that although the camera positions are correct, neither Tie Points nor Point Cloud show significant flaws and the resulting 3D model is created, but without the desired object. This happens especially when the background occupies a larger area in the photographs and not the object to be captured. The case is illustrated in Figure 10. At the top, you can clearly see that the object being imaged is part of the 3D environment formed by the point cloud points, but is missing from the scene after the 3D model has been created - the image in the middle. Note that the sensed object is isolated, so it is not part of the background. The software tries to create only one model and therefore creates a background model. The solution in this case is that we remove all points of the point cloud except the points of the scanned object. When the model surface is recreated, the background will no longer be present but only the sensed object. We can see this in figure number 10 below.

#### 4 Discussion

In teaching it is important that the 3D model is successful and that students are motivated by their work and not discouraged from further activity. Therefore, it is good if their first models succeed even on the first attempt. The basis of creating 3D models using the photogrammetric method is the acquisition of image data. These can be obtained in two ways - photographs or video. When acquiring photos or video, we have to follow certain rules so that the photogrammetric software can correctly create the 3D model. Therefore, based on our experience, in addition to the above mentioned, we also recommend observing the following points, which have a significant impact on the creation of a 3D model without the need for post-processing:

- Even lighting - lighting should be even where possible, with no strong shadows, and we also avoid shooting

against the sunlight. We must also be careful of moving shadows, such as the movement of the sun during the day or the change of lighting source in laboratory conditions. This means that in nature, we only take photographs once during the day and do not add to the photographs. If necessary, we repeat the whole acquisition once more.

- Sufficient overlap - the currently captured photo should be with the previous photo at 60 - 80% in overlap. Our experience tells us that this overlap is good to maintain in both horizontal and vertical directions. The better the overlap the better the result. But there is a certain limit, after crossing which the 3D model will not gain in accuracy or quality, but on the contrary, it may cause damage. For an object with dimensions of approximately 30-30-30 cm, no more than 200 photographs are needed.
- Resolution and photo quality - the higher the resolution, the more detail the photos capture. The resulting 3D model will be all the more detailed. However, some software has some limitations on the maximum resolution which we have to accept.
- Motion minimization - objects that move between shots can cause reconstruction problems. Therefore, avoid such shots as they can cause inaccuracies in the 3D model. Such as moving cars in photographs, movement of people, etc.
- Angle of view - we shoot the subject from different angles, approximately equidistant, and try to cover the entire subject so that each part of the subject is clearly visible in multiple frames.
- Glossy surfaces - Glossy or reflective surfaces can interfere with the photogrammetry process as they can distort texture information but can also affect the formation of Tie-points and thus have a direct effect on the quality of the resulting model. Gloss is also caused by painted or dyed objects.
- Object texture - to properly create a 3D model, it is important that the subject is not only well lit, but also has a good texture. Such objects include natural non-glossy stone, natural wood, leather, paper, etc.
- Size of the subject - when photographing, we must also try to make sure that the subject is dominant in the photographs and occupies a large enough space in the photo. Otherwise the software will create a 3D model of the background and not the subject.
- Background in lab conditions - when possible, we use a simple and consistent background so that the software can more easily identify and model the main object.
- Manual settings - we use manual camera settings when taking photos to ensure that each photo is sharp enough and of good quality even if the distance from the camera changes. Blurry shots are not usable and are often discarded from processing by the software.
- Post-processing - some literature sources also mention the possibility of editing photos before the actual creation of the 3D model. However, we do not recommend such editing but rather discard inappropriate photos. By processing the colors in the photos, the edges may also change which may adversely affect the quality of the 3D model.

Probably the most common issue when implementing it in the classroom will be the time it takes to create a 3D model. From our previous studies [1-6], we venture to say that there is little correlation between the number of photos and the processing time. However, there is a correlation between the number of points processed and the time to create a 3D model. This is logical because we do not know in advance how many key points and tie points the software will find. The processing time is difficult to predict and hence the number of teaching hours is difficult to determine. We propose to schedule the creation of the 3D model for 3 lessons with 45 minutes of each lesson. We also have to account for post-processing. One lesson should be sufficient for post-processing, but this is very subjective. Some pupils are smarter, others are not. Some have the opportunity to work on their projects during their free periods, others only in computer science classes. The post-processing time depends on the number of photos that need to be processed. In some cases,

less precision is sufficient - in that case we can move faster, while other times we try to process as much as possible from the details. The precision of the post-processing therefore also has an impact on the overall processing time.

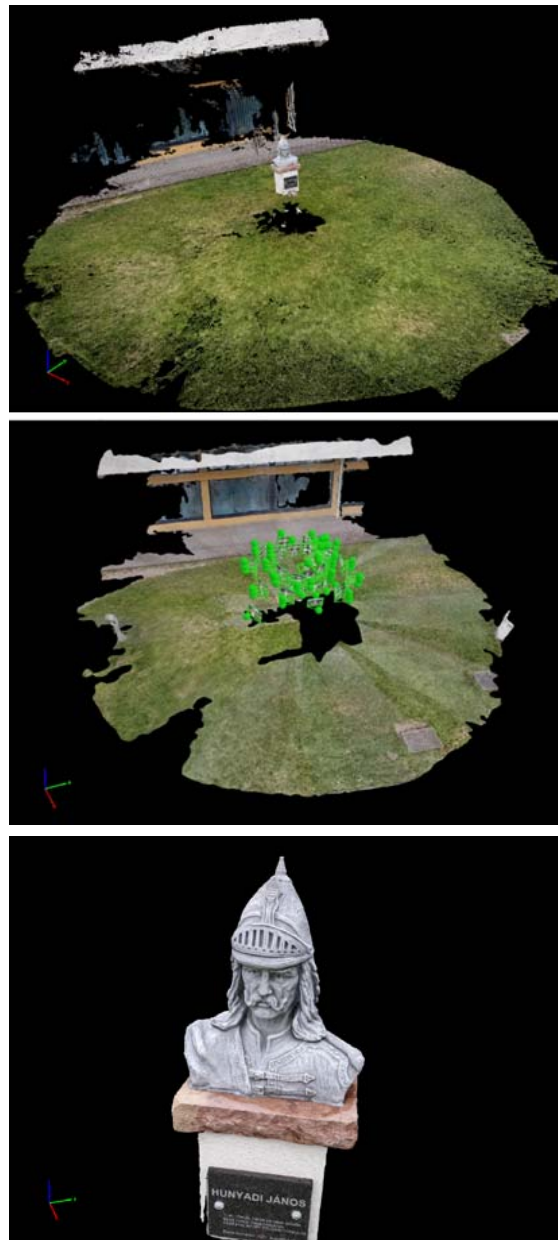


Figure 10 – Above: cloud of points also with object scanning, in the middle: created 3D model with the position of the cameras during photo acquisition, below: desired part of the 3D model

The creation of 3D models has indeed become available these days, and we are increasingly seeing that it is also being implemented in the educational field. Until now, students did not have such a rich technological background that the creation of 3D models could become available on a daily basis. We must also mention that this is an interesting and motivating activity for students. It deepens interdisciplinary relationships with many subjects such as mathematics, physics, but also geography, history and the like. Indeed, it belongs to the few practices that have such a broad interdisciplinary scope. For the teacher, these procedures can be interesting, especially from the point of view of repeatability. Thus, proven sets of photos can be repeatedly used in several years. The hardware requirements are also no longer enormously high. Of course, more powerful computers will significantly reduce the processing time, but even not the most powerful computers can also handle these tasks. If we care about the processing time, the negative can be the price of the

hardware but also of the software. Of the many, we can mention a few of the most widespread: Agisoft Metashape (formerly PhotoScan) - one of the most popular commercial software. It is paid, but according to several sources it is currently the best. Pix4Dmapper – commercial software often used in UAV technology and near photogrammetry. MicMac - Free and open-source photogrammetry tool. Regard3D is similar. Nowadays, there are indeed many software designed for different platforms. From the point of view of use, we can boldly claim that a 3D model created from a real object is much better than a 3D model of ideal clothes. Real 3D models preserve all the parameters of the object, both color and size, and are very valuable in the educational process. In addition, the 3D model is not subject to decay, decay or the ravages of time. It can be viewed at any time - even from the comfort of your home, it is not tied to seasonality, provides better visualization than a photograph and is also suitable for external study.

## 5 Conclusion

We have tried to choose a typical example and typical problems that can be encountered in common practice when creating 3D models in computer science lessons. We pointed out the most common problems in creating 3D models that we have encountered and caused problems during our practice. We also tried to point out the basic statistical characteristics of 3D models and methods of obtaining photographs, in order to limit the negative effects on the creation of 3D models. We firmly believe that this information will be helpful to many who encounter similar problems, whether in teaching or non-teaching fields.

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## Primary Paper Section: I

## Secondary Paper Section: AM