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Protection of the city's cultural heritage also with the help of partial 3D models

Ondrej Takáč[1*], Ladislav Végh[1], Krisztina Czakóová[1], Daniel Dancsa[2] and Melinda Nagy[2]

[1]*Department of Informatics, Faculty of Economics and Informatics, J. Selye University, Slovakia*
[2]*Department of Biology, Faculty of Education, J. Selye University, Slovakia*

[*]*(takaco@ujs.sk) Email of the corresponding author*

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Abstract – In our paper, we will focus on the creation of partial as well as full 3D models of real objects in the context of cultural heritage protection. In the case of partial 3D models, we will focus on smaller objects that present the aesthetic aspect of everyday life captured in common building architecture. These are often already of significance to us today as cultural heritage. We value them for their age and as a legacy of past generations. We can read in them not only a way of life, but also their aesthetic sensibility, cultural atmosphere, social tradition and the so-called Genius Loci. It often happens, however, that in cities rich in historical architecture, modern sculptures or works of architecture by local artists begin to appear, set against the backdrop of the magnificent monuments of the past. These works are also an expression of the modern sensibility of ordinary citizens and deserve our attention. We will show 3D models of such sculptures as well, so full 3D models. In our paper we will show some of these monuments of the city of Gdańsk and around also pointing out not only the historical value of the 3D models, but also the typical statistical parameters describing the 3D models presented by us. In the conclusion of the paper we will offer a methodology for the creation of such models with the help of commonly available technical means of modern times, i.e. for everyone who has a mobile phone and access to the Internet.

Keywords – Cultural heritage, Photogrammetry, 3D models, partial 3D models, OPPO Reno 5z

I. INTRODUCTION

Close-range photogrammetry is a method based on the principle of photogrammetry, which is used to create 3D models of objects or environments using photographs taken from a close distance. This method is often used in fields such as architecture, archaeology and others. These photos are then processed using photogrammetry software. One of the few possibilities of creating 3D models of real objects in our everyday life and using commonly available technical means is the method of photogrammetry. It is as well applicable in the use of UAVs also as ground-based photogrammetry - the use of photographs obtained from the ground, in our case close photogrammetry. When creating 3D models of real-world objects using photogrammetry, we usually take into account several important conditions that are necessary for the creation of a high-quality 3D model. These include, for example, the use of calibrated cameras in order to reduce distortions and inaccuracies in the model, maintaining camera stability during photography in order to avoid the gain of incorrect textures and shapes, the use of high-quality light and colour balanced photographs, or the use of proper lighting and placement of light sources [1][3][4]. However, we often come across objects that usually catch our attention during our walks or we come across them completely by chance. In most of these cases, however, we cannot observe the above-mentioned conditions. We don't have professional photographic equipment but only an ordinary camera implemented in a mobile phone, and we can't influence the natural ambient lighting either. The solution is therefore 3D models created from a smaller number of photographs or partial 3D models. In our paper, we will focus on partial 3D models, such as reliefs, facades or parts of such objects, which, although not officially declared cultural monuments, had their architectural or aesthetic contribution to the culture of the local people. Often these small gems were part of people's everyday lives. We can also state that modern technologies of everyday use make it possible to obtain sufficiently high quality photographs and, together with the sufficient hardware and software power at our disposal, we are able to create such 3D models that will be beneficial in the preservation of cultural heritage [1][2].

Each 3D model can be described by various statistical indicators. Some of these include, for example 2D Keypoints parameters. 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. A 14MP image will generate between 5'000 and 50'000 keypoints per image. If the number of keypoints is less than 1000, the image may not have enough content to be calibrated. The minimum number of matches to calibrate an image is 25. The recommended number of matches is at least 1000 per image. We can also mention, for example The number of Automatic Tie Points. It refers to the number of automatically generated anchor points that the software identifies and uses to align and correlate different images when creating 3D models or maps. These locations serve as a reference for connecting images into a uniform spatial arrangement. A higher number of points generally means better coverage and more accurate results, but can also increase computational complexity and processing time. In practice, a balance needs to be found between the number of ATPs and available computing resources to achieve optimal results within the required parameters. In practice, Automatic Anchor Points (ATPs) are often displayed in the form of images or maps, which helps to visualize where these points are located on the images. This visualization is useful for quality control. This visualization is key because it allows users to identify and resolve potential issues with image overlap or detection errors. The 2D Keypoint Matches parameter refers to copying keypoints between different frames. The "2D Keypoint Matches" parameter therefore shows how many pairs of keypoints have been found and are usable for image processing. In these visualizations, key points are usually represented as dots or small crosses on the images, and the lines connecting them represent the correspondence between the corresponding points on the different images. If the visualization of the 2D keypoint pairing is dense, correctly covering the entire region of interest, this is a good indicator that the model will be accurate and reliable. Number of 3D Points Observed in N Images means that Each 3D point is generated from keypoints that have been observed on at least two images. Each row of this table displays the number of 3D points that have been observed in N images. The higher the image number on which a 3D point is visible, the higher its accuracy is. [6][7]

II. Materials and Method

As we mentioned above, our goal is to show the way of creating 3D models with the help of commonly available electronic means and at the same time to show some basic properties of 3D models by describing them with selected parameters. The entire process of creating 3D models can be divided into three stages. The first is to acquire photos, the second is to create a 3D model, and the third is to edit the model or texture file if necessary.

Photos form the basis of creating a 3D model. Although, as we mentioned above, we are not always able to meet the ideal conditions for obtaining photos, we must meet the minimum rules to create a 3D model. Photos must overlap. This overlap in both the horizontal and vertical direction must be at least 50%. Let's try to capture such colorful objects in the photos that are visible in several photos. Last but not least, we must keep in mind that high-quality 3D models can best be created from non-glossy objects that have a good texture. We also complied with these minimum conditions when obtaining our photos.

Subsequently, we will use photogrammetric software, with which we will create 3D models. In our case, it was Pix4Dmapper Pro v. 2.0.104 - 64 bit and Polycam Internet Platform - https://poly.cam. Pix4D can create point clouds and accurate digital surface and orthomosaic models [6]. It can process both RGB and thermal images, which can be very beneficial for some purpose-built models. Polycam is a convenient solution for home use or quick creation of 3D models.

We used the OPPO Reno 5Z mobile phone model CPH2211, with Dimensity 800U 8core processor, 8GB + 6GB RAM and ColorOS operating system to create all the following 3D models.

The photos intended for processing were in standard JPG format, with dimension 4000px x 3000 px and horizontal and vertical resolution 72 dpi. All photos had bit depth 24 bit and color representation sRGB at F-stop: f/1.7.

We present sample 3D models in tables number 1, 2 and 3. In individual lines we present previews of 3D models and other characteristics related to individual 3D models. In individual lines:

1. Preview of the 3D models themselves.
2. Link to the location of the 3D model on the sketchfab platform.
3. In column A are the corresponding parameters Number of 2D Keypoints per Image, i.e. Number of 2D keypoints (feature points) per image. In column B, the Number of Matched 2D Keypoints per Image, i.e. the number of matched 2D keypoints per image. A matched point is a feature point that was originally detected in at least two images (a 2D keypoint in those images) and has been identified as the same feature point.
4. Here we provide the Dataset parameter. There is no exact threshold, but 60% can be considered a breakpoint. 95% and more percentages can be considered very good.
5. The median of matches per calibrated image.
6. Number of 3D Densified Points – Total number of 3D densified points obtained for the project.
7. The number of Automatic Tie Points (ATPs)
8. 2D Keypoint Matches
9. 3D Points from 2D Keypoint Matches. Each 3D point is generated from keypoints that have been observed on at least two images. Each row of this table displays the number of 3D points that have been observed in N images. The higher the image number on which a 3D point is visible, the higher its accuracy is.

We could notice above that we used professional photogrammetric software to create the 3D models. But not everyone has such a tool and we can rightly ask ourselves, now that we have the photos, what next? Are there free solutions? Yes, there are, and there are online solutions, and we're going to show you one of them. For example, we can use the website https://poly.cam for processing. Creating a 3D model is really already very simple. The free version has a limitation on the number of photos. The minimum number is 20 and the maximum is 150. Once the photos are uploaded, the 3D model is automatically created. Most professional photogrammetry software allows you to create a 3D model from video instead of photos. This website also gives the possibility to do so. But the free version is limited to video lengths from 15 seconds to 3 minutes and video file sizes of 16 GB. It is possible to use .jpg, .png, .mp4, .mov or .avi formats. The free version allows downloading the 3D model in GLTF format. We can show the following example. In the following picture we can see the created 3D model from a total of 51 photos. In the left part using Pix4Dmapper Pro software and in the right part using Polycam tools, which is available at: https://skfb.ly/oTBUo.

Fig. 1 3D models created using Pix4Dmapper Pro software in left and on the right using Polycam tools. On the left, the camera locations during object capture are shown.

III. Results and Discussion

In table no. 1 we present examples of two monuments that weather naturally. On the left, you can see that the sculpture of the elephant is already significantly damaged. Probably, even the stone is already crumbling and may be permanently removed during the next reconstruction. Of course, our modern times reflect our culture and our standard of living, and we already have a different - more modern feeling when it comes to aesthetics. But in the form of a 3D model, even this monument can remain preserved even when it no longer needs to exist in reality. Monument in table no. 1 on the right is only a fragment, which was probably cleverly left and placed in the surrounding masonry. Although it is safe for now, the weather will slowly wear it down over time. In row number 7, we see that ATPs is very good for the left model, a bit weaker for the right, but still good. This is also clearly visible on line 8. In line 9, it can be seen that the dependence of the number of photos and the number of 3D Points Observed is represented by a power dependence. The graph also shows the equation with the parameter R^2. In table number 2 we present two examples of partial 3D models. In both cases, these are flat stone slabs. Although they are closer to 3D models in terms of their execution, surface three-dimensional details, bends and various smaller shapes can also be easily seen using 3D. Table number 3 shows two examples of more modern work by artists. These are complete 3D models, with a partially preserved environment in which they are placed. Of course, these models can also be viewed online. They are a typical example of the penetration of more modern elements against the background of historical monuments. That is why they are often placed on the periphery and are subject to damage and extinction more quickly. And that's why they deserve our attention.

Table 1. A sample of monuments that naturally weather

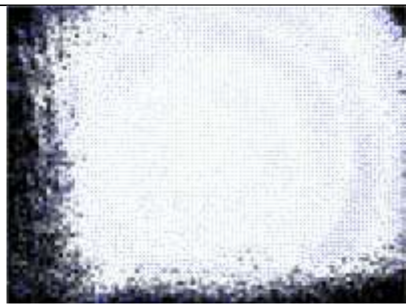
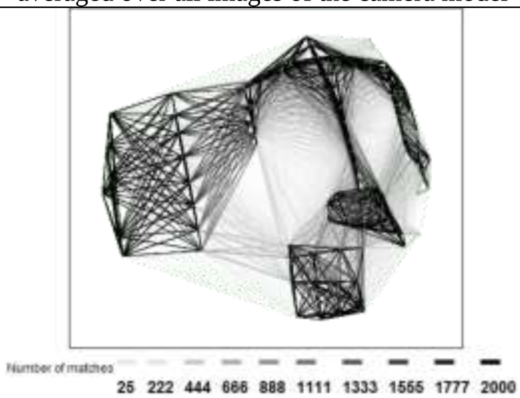
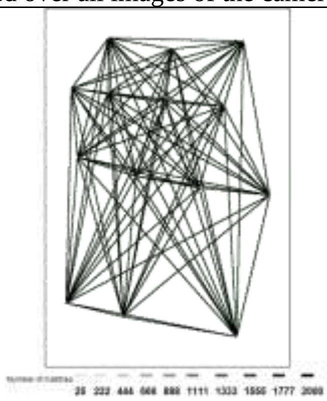
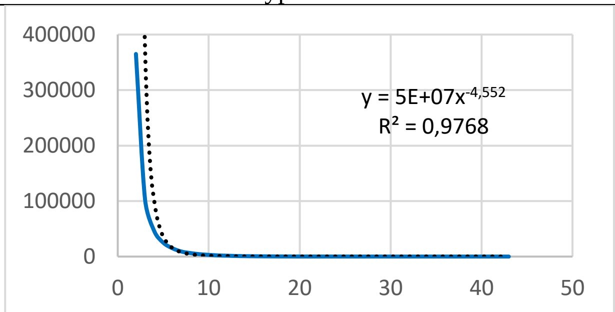
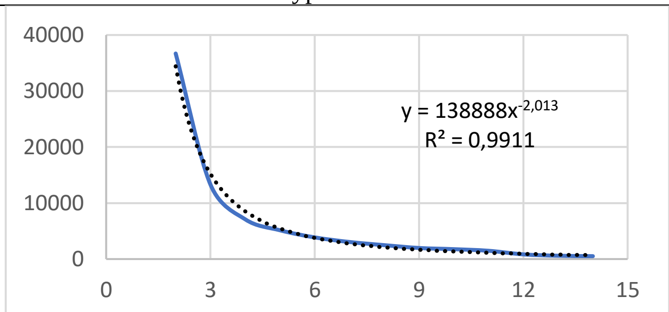
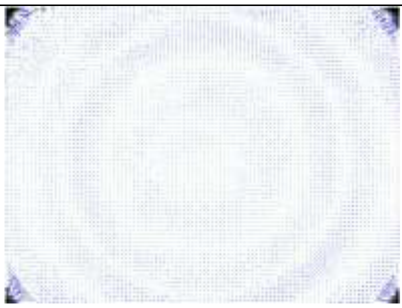
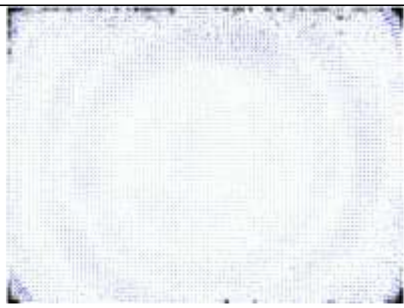
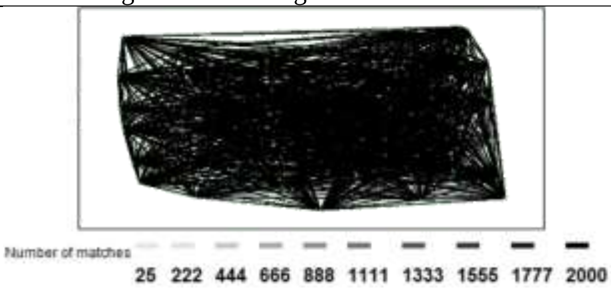
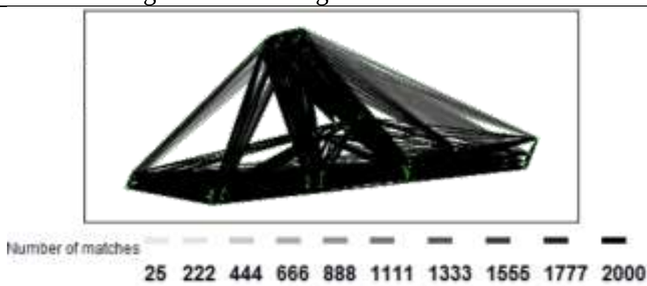
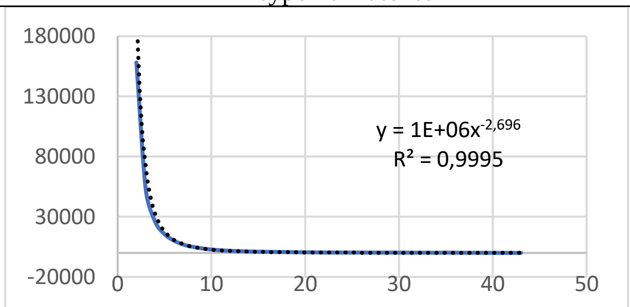
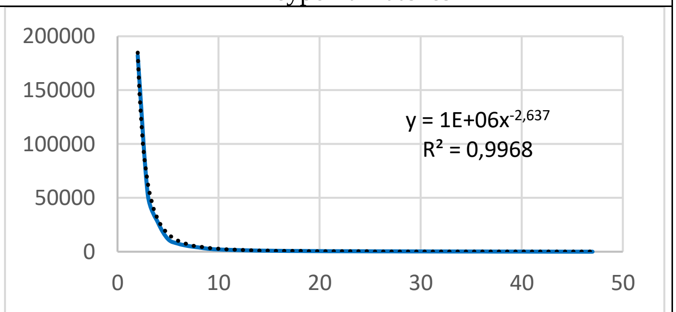
1		
2	https://skfb.ly/oTAyy	https://skfb.ly/oTAyz
3	A: B: Median 33463 16332 Min 16917 290 Max 56964 30562 Mean 33730 16657	A: B: Median 35555 21532 Min 31936 15794 Max 40846 26121 Mean 35743 22028
	A: Number of 2D Keypoints per Image;	*B: Number of Matched 2D Keypoints per Image*
4	104 out of 108 images calibrated (96%), all im. enabled	14 out of 14 images calibrated (100%), all images enabled
5	Median of 16331.9 matches per calibrated image	Median of 21532.1 matches per calibrated image
6	Number of 3D Densified Points 7292041	Number of 3D Densified Points 1416568
7	 The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model	 The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model
8	 2D Keypoint Matches	 2D Keypoint Matches
9	 x-axis: number of photos; y-axis: number of 3D Points Observed (blue)	 x-axis: number of photos; y-axis: number of 3D Points Observed (blue)

Table 2. Examples of partial 3D models

<table>
<tr><td>1</td><td></td><td></td></tr>
<tr><td>2</td><td>https://skfb.ly/oTAxO</td><td>https://skfb.ly/oTAxI</td></tr>
<tr><td>3</td><td>A: B:
Median 45306 27512
Min 24053 11191
Max 55957 32926
Mean 43992 26457
A: Number of 2D Keypoints per Image;</td><td>A: B:
Median 41718 23681
Min 34042 17265
Max 57636 31281
Mean 42018 23788
B: Number of Matched 2D Keypoints per Image</td></tr>
<tr><td>4</td><td>43 out of 43 images calibrated (100%), all images enabled</td><td>48 out of 48 images calibrated (100%), all images enabled</td></tr>
<tr><td>5</td><td>Median of 27511.9 matches per calibrated image</td><td>Median of 23680.6 matches per calibrated image</td></tr>
<tr><td>6</td><td>Number of 3D Densified Points 3364165</td><td>Number of 3D Densified Points 3768812</td></tr>
<tr><td>7</td><td>
The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model</td><td>
The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model</td></tr>
<tr><td>8</td><td>

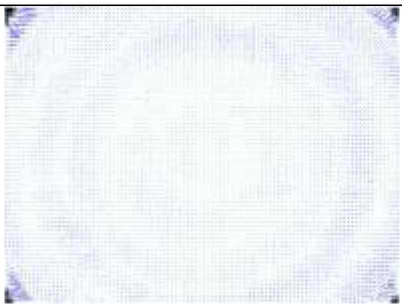
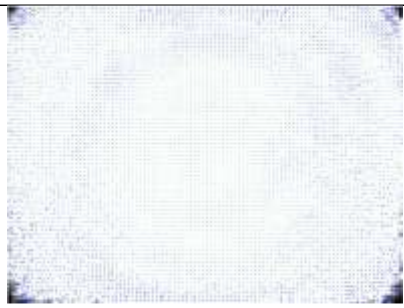
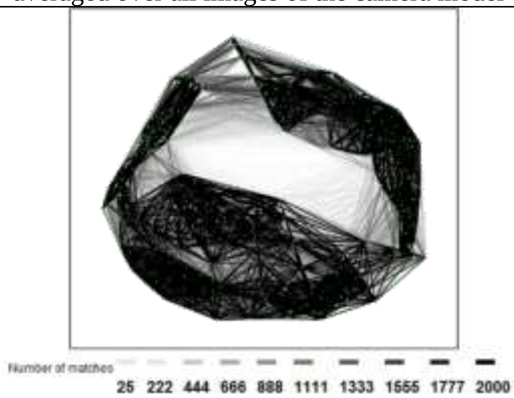
2D Keypoint Matches</td><td>

2D Keypoint Matches</td></tr>
<tr><td>9</td><td>

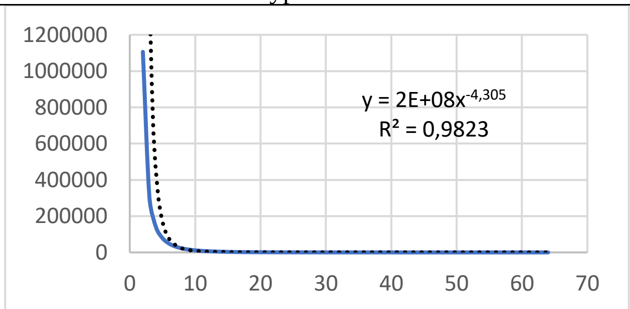
x-axis: number of photos;
y-axis: number of 3D Points Observed (blue)</td><td>

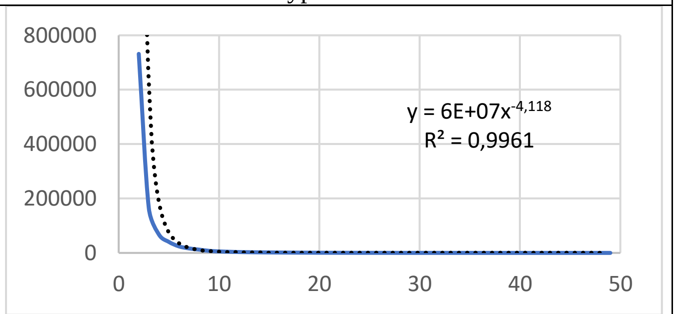
x-axis: number of photos;
y-axis: number of 3D Points Observed (blue)</td></tr>
</table>

Table 3. Examples of more modern architecture

<table>
<tr><td>1</td><td></td><td></td></tr>
<tr><td>2</td><td>https://skfb.ly/oTAxX</td><td>https://skfb.ly/oTAyr</td></tr>
<tr><td>3</td><td>A: B:
Median 69490 27711
Min 39688 9393
Max 79836 50903
Mean 66980 27713</td><td>A: B:
Median 53013 21689
Min 31398 11381
Max 72373 37940
Mean 52788 22690</td></tr>
<tr><td></td><td colspan="2">A: Number of 2D Keypoints per Image; B: Number of Matched 2D Keypoints per Image</td></tr>
<tr><td>4</td><td>203 out of 203 images calibrated (100%), all images enabled</td><td>143 out of 143 images calibrated (100%), all im. enabled</td></tr>
<tr><td>5</td><td>Median of 27711.2 matches per calibrated image</td><td>Median of 21688.5 matches per calibrated image</td></tr>
<tr><td>6</td><td>Number of 3D Densified Points 10328587</td><td>Number of 3D Densified Points 6939194</td></tr>
<tr><td>7</td><td>
The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model</td><td>
The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model</td></tr>
<tr><td>8</td><td>

2D Keypoint Matches</td><td>

2D Keypoint Matches</td></tr>
<tr><td>9</td><td>

x-axis: number of photos;
y-axis: number of 3D Points Observed (blue)</td><td>

x-axis: number of photos;
y-axis: number of 3D Points Observed (blue)</td></tr>
</table>

Finally, we can show one more example of a partial 3D model created using Polycam tools. It is also a partial 3D model because it is a monument, the top of which we have not seen. Even though Polycam has closed the model, it still has a lot of relevant information.

Fig. 2 Example of a partial 3D model created from 114 photos. On the right you can see that the top photos were missing. 3D model available: https://skfb.ly/oTC8C

IV. CONCLUSION

There are places that win us over with their atmosphere, history and cultural value. Michelangelo Buonarroti already said: Perfection lies in the little things, but perfection is not a little thing. Even great things hide their value in the little things. For example, railings, stone tablets depicting people's lives, their joys or sorrows, or small statuettes, various objects, ornament or details of architecture of buildings and structures. We must realize that many of these monuments or parts of monuments are being irretrievably lost, which also loses the meaning of a holistic image of culture and time. Often quite unintentionally, for example during renovations, modernizations, accidental damage, repairs to plasterwork and facades, or just naturally weathering and succumbing to the ravages of time. It is therefore very important to preserve for future generations not only the magnificent monuments of our culture, but also the small fragments of cultural heritage from our everyday life. After all, nowadays we too are eager to know the lives of our ancient ancestors.

In all of our examples, we collected photographs at random objects that caught our eye as we walked by them, not ones that we purposely searched for. Also, not all of the ideal and theoretical conditions imposed on the collection of photographs have been met, and yet we dare to claim that the 3D models produced are sufficiently accurate and good for their purpose. In this way we want to point to the fact that indeed the present time and its achievements are available for this direction of cultural heritage protection in our everyday life.

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