Retention of cultural heritage with the help of innovative technologies

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***Abstract* - "The heritage of our fathers, preserve to us, oh Lord", are the words of one prayer in Slovakia. However, this is not always possible, especially with cultural monuments that have already been stricken by the ravages of time or natural disasters. Current advanced technologies such as photogrammetry, laser scanning, reverse engineering and visualization applications allow us to monitor the current state of monuments, their intermediate steps of possible reconstruction and the final state. In this way, the cultural heritage will be preserved for future generations. This paper presents usage of progressive technologies as a tool for retention and digitization of cultural heritage.**

Keywords – cultural heritage, laser scanning, photogrammetry, visualization, BIM

I. Introduction

Cultural heritage shapes human´s everyday life in Europe, we are surrounded by it on our life journey: in the architecture of cities and towns, in literature, in music, in the fine arts, in crafts or in the stories we tell to our children, in food, in films, in folk traditions, etc. It is defined as a set of tangible and intangible documents of human creative activity and the development of human society from ancient times to the present. It is important to be aware of the historical and cultural-social value of the documents.

The intangible cultural heritage consists of: traditions, folklore, songs, poems, legends, musical works, rituals, social customs, knowledge and experience related to nature and the universe, or knowledge and skills necessary for traditional crafts.

We can include various buildings such as castles, chateaux, statues in the material cultural heritage. This includes open-air museums, or even entire villages, as well as old books or objects, which may not be exceptional for the nation, but only for one family left behind by its ancestors. There are many material cultural monuments that are also included in the UNESCO World Heritage Site.

More attention is required by historic buildings. In order to preserve them for future generations, we need their maintenance or conservation, which will protect them from various weather influences, but also from the ravages of time. However, there will be times when, from a financial point of view, it is not possible to stop the gradual destruction of a cultural monument. Then it is possible to reach for innovative technologies, which can be used to document the current state of the monument, create its digital twin and thus preserve it for possible later reconstruction.

Only a small percentage of historic buildings have drawing documentation. These are the maximum old drawings. It is desirable to create virtual 3D models together with drawing documentation. If an unexpected situation occurs (lightning strike, hail, earthquake or fire) and massive damage occurs to the building, its exact reconstruction will be possible in the future. Documentation is a very complicated process, because it includes not only the geometry of the building, but also other parameters that make the monument unique and create architectural, artistic, historical, scientific and social values. The following paragraphs will describe the innovative technologies we used to create the 3D virtual model of the historic building – Castle Kunerad.

II. 3D laser terrestrial scanning

Terrestrial laser scanning (TLS), also referred to as terrestrial LiDAR (light detection and ranging) or topographic LiDAR, acquires XYZ coordinates of numerous points on land by emitting laser pulses toward these points and measuring the distance from the device to the target.

Laser scanning provides high-precision in a recording of real world objects. The result of the scan is a point cloud which represents a three-dimensional image of the scanned objects. This technology is widely used to measure various objects such as buildings, production halls, machines, facilities, engineering networks as well as cultural monuments or sculptures [1].

The resulting data from the exterior scan are largely dependent on the material composition from which the scanned objects are made. The weather is also affected by the data: the level of sunlight and wind. The data collection method used also affects the occurrence of different types of scanning irregularities.

Authors [2] describe the following scanning irregularities:

- Physical limitations of the sensor will cause noise in the captured data. Recorded points can also be damaged by quantization levels or moving objects. This happens if the scanned object moves during data capture. This is mainly the case for scanning humans or animals.
- Multiplex reflections and strong noise can cause formation of additional surface points. These

points do not actually exist their creation was enabled when the laser beam passed through transparent objects such as windows.

- Additional gaps and insufficient surface sampling of the model will appear due to occlusion, critical reflection properties, limitations in the scanning path, or the range of sensor resolution. These gaps also appear under the device itself.
- If the scanned object has a texture, many scanning devices create additional phantom geometry.

We used terrestrial laser scanner with possibility of scanning to a distance of 330 meters with an accuracy of 2 mm. Integrated GPS receiver enables scanner to coordinate and harmonize separate scans in post processing. Scanning of the building exterior took us about 5 hours (weather conditions were suitable), because the building is large and has many niches and parts destroyed by fire. We had to use reference balls and reference labels. These are used later in the data processing process for the software to automatically recognize reference elements and automatically combine scans from multiple viewing angles to create a complex point cloud image of the scanned object. We faced these irregularities: reflection of objects on the building walls, duplicated points and dark scan points. At the figure 1 you can see one partial raw (noised) pointcloud of one part of the building.

The next step is scan registration. All scans are downloaded and imported to software, where they are connected to one big pointcloud. Later is the scene cleaned of noise and filtered. The most common filters are:

- Smooth filter - the filter smoothes the acquired data. The principle is as follows: the captured spatial point is adjusted to the mean value of the neighboring point. The filter does not allow you to delete individual points and adjust the values leading to smoothing.
- Stray Filter - the filter requires the removal of points that are outside the desired area and are based on the definition of the distance of the points. Used at borders. Because it is based on distance, it balances those bodies that do not meet the required quality, minimum and maximum distance.

Figure 1. Raw pointcloud of one building side

Figure 2. Denoised and filtered pointcloud of one building side

- Outliers filter - filter removes points that are outside the selected area. It is not recommended to use this filter near the edges.
- Combination of various filters

After removing duplicate points, unwanted points, reflected points on the building facade, unwanted objects and application of filters, we got a pointcloud, which is ready for further operations, e.g. texturing, export to other software where volume models or drawing documentation are created using reverse engineering method. Denoised part of building is shown on figure 2.

III. Photogrammetry

Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena. [3]

Photogrammetry has long been used as a tool to gather various (3D) object information as well as texture information. In the last decade, the development of electronics has been advancing very fast. Computing devices are gaining great performance and thus open up new possibilities in the field of photogrammetry. Increasing CPU and GPU performance allows for the high development of photogrammetric products that can turn photos of an object, such as a building, into a 3D model. These software products can also compete with laser scanners, which are very often used at work for photogrammetry, such as buildings and ground infrastructure. The main advantage of photogrammetry is its high presence and low time required to obtain high quality input data in a short time.

We used terrestrial (ground) and aerial photogrammetry to create photogrammetric data of the historic building.

A. Terrestrial (ground) photogrammetry

Terrestrial (ground) photogrammetry deals with determining the dimensions, position and properties of objects and phenomena in photographic images. Pictures are taken from a fixed position on the ground. The images have secured elements of internal and external orientation, which allow to determine the spatial position of each point measured in the image [4]. The creation of images is

Figure 3. Terrestrial (ground) photogrammetry

carried out from distance of centimeters to 150 meters from the object. Thanks to the shorter distances and high resolution of today's digital cameras, high accuracy can be achieved when creating 3D models. Compared to TLS, photogrammetry gives the model a photorealistic look (texture), making the object a true copy of the real object. There are many options and variations of digital SLR manual settings, so each situation requires a different approach.

You can ground in with manual settings for digital SLR in [5], [6]. However, the most important factors are ISO, iris and shutter and we set all needed settings according recommendations in [7].

We used a digital SLR camera, where the lens has a focal length range of 27 - 136 mm at 35 mm format, 3-step image stabilization and a maximum iris of 1.4f – 2f, which is also suitable for shooting in low light conditions. We created about 1,500 photos. On figure 3 is shown one side of the castle.

B. *Aerial photogrammetry*

Aerial photogrammetry deals with the interpretation of measurement images taken from aircraft or other flying bodies and their evaluation. Aerial photogrammetry is not limited by terrain conditions, it is today the main focus of photogrammetry. It is used for mapping and survey of larger territorial units. With the development of unmanned aerial objects (UAV), aerial photogrammetry has become financially viable and is used primarily to map smaller areas, e.g. cultural monuments.

Terminology UAV photogrammetry [8] defines a photogrammetric measurement platform, which operates remote controllably and is semi-independent or

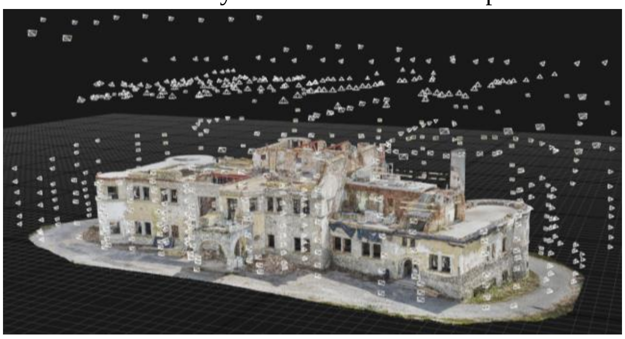

Figure 4. Aerial photogrammetry

Figure 5. Denoised and filtered pointcloud connected with terrestrial and aerial photogrammetry

independent, and in which there is not any pilot. Platform was equipped by photogrammetric measurement systems. This also includes small or medium sized fixed video or video camera, thermic or infrared camera systems, and aerial LIDAR systems. The existent standard UAV enables to monitor the record and position and the direction of sensors applied in a local or local coordinate system. Hence, UAV photogrammetry can be understood as a technique that makes photogrammetric measurements with the help of an unmanned aerial vehicle

We used a UAV with a camera whose lens has a focus of 24 mm. Photos have a resolution of 20 Mpix. The iris can be adjusted from 2.8f to 11f. Video transmission is possible up to a distance of 8 km. We created about 650 photos at different heights and angles. On figure 4 is shown the whole aerial photogrammetry.

IV. Data connection from terrestrial scanning, terrestrial photogrammetry and aerial photogrammetry

Linking the 3D laser scan model to photogrammetry model delivers a high quality and accurate model. It is a connection of very high measurement accuracy with photography. The output thus obtained, which connects the scan outputs and photos, gives the opportunity to look at the flawless model, obtained in real time. Another advantage of photogrammetry is that the actual laser scan output, thus the finished 3D model, also has so-called dead spots. These are places where the scanner beams cannot reach at a certain angle, and the model loses quality which, however, can be supplemented by photogrammetry. The procedure in software is to detect common points and then the photos overlap the unscanned areas from the laser scan. Then resulting 3D model meets all the demanding criteria for output quality requirements such as dimensional accuracy, color and model will thus become the digital twins of the real object as shown on figure 5.

V. Visualization application

Building Information Modeling (BIM) is a process that begins with the creation of an intelligent 3D model and enables document management, coordination and simulation during the entire lifecycle of a project (plan, design, build, operation and maintenance).

Figure 6. The process of BIM [8]

BIM is used to design and document building and infrastructure designs. Every detail of a building is modeled in BIM. The model can be used for analysis to explore design options and to create visualizations that help stakeholders understand what the building will look like before it’s built. The model is then used to generate the design documentation for construction [9]. The process of BIM is shown on figure 6.

When creating a new building, the BIM model carries all the information, such as the used materials and their physical properties, as well as any modifications. For the investor, one of the key pieces of information is the price, which can be determined quickly at BIM.

However, in order to create a model of an existing object, information about the shape of the building and dimensions is needed in the first place. When creating such a BIM model, it is important to collect data where the SCAN to BIM method was used.

The basis for the creation of project documentation for the historic building of Kunerad Castle was a cleared pointcloud from terrestrial scanning and textures from terrestrial and aerial photogrammetry. It was possible to create 2D plans and a real image of the building in 3D by reverse engineering. Drawing documentation was generated, which can further serve as a basis for architects, employees of the monument office and other professions. The project and documentation created in this way eliminates many errors because the model is made to the smallest detail, and the coordination of all professions is easier. Collisions between individual professions can be detected much more easily, which brings considerable financial savings during construction. Figure 7 shows a volumetric 3D model of the castle and figure 8 shows a floor plan of the castle.

Likewise, the investor, for whom the drawing documentation may be incomprehensible, has an excellent idea of the project, of the architectural plan as well as of the design process.

If the BIM model was updated during construction and corresponds to the real image of the building, then during the use of the building it is an invaluable source of information for proper maintenance and saving of funds.

Figure 7. Volumetric 3D model of the castle

Figure 8. Floor plan of the castle

VI. Conlusion

In this article, we have described our approach to creating 3D virtual model and drawing documentation for the historic building of Kunerad Castle. The total time required for implementation was 1000 hours. The working team consisted of four members. We used following inovative technologies:

- terrestrial laser scanning - the output was cleaned and filtered pointcloud,
- terrestrial and aerial photogrammetry - to document missing details and visualization of the building appearance,
- combining all three above technologies - to achieve detailed pointcloud,
- import into the visualization software - where using the SCAN to BIM method, the object was generated as full-volume 3D model and drawing documentation has also been created.

The combination of all these technologies contributes to the preservation of cultural heritage for future generations.

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