Project of the Digital Monuments Funds: Digitization of the Cultural Heritage of Slovakia

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During the years 2013-2016 a great number of buildings (medieval castles, churches, and other monuments) in Slovakia were digitized. STUDIO 727 was the main provider of these digitization works. The subjects of our investigation were the most significant Slovakian historical objects. Within the digitization project, we created 3D models of several of the most important Slovakian monuments, such as Bojnice castle, a gothic church in Spišský Štvrtok, and Devin castle, where there are also artifacts from the Roman period, La Tène era, and Middle Ages. The aim of the project was to identify current technological possibilities for the creation of virtual presentations of real spaces. During the creation of the 3D models we used a combination of photogrammetry and 3D space scanning by laser scanner LIDAR (Leica brand). Final modification of laser outputs was made using Cyclone software. Post processing was done with software: RealityCapture, Autodesk Maya, and MeshLab software. 2D documentation was made using Autodesk AutoCAD. The purpose of documentation was to capture the appearance of historical buildings and their technologies to preserve cultural heritage for the next generation, as well as to contribute to publicity about cultural heritage and to aid in future renovation of these particular monuments. The beginning of this project was the process of creating 3D virtual models and 2D documentation.

Key words:

Architectural heritage, Digitization, Slovakia, 3D models.

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1. INTRODUCTION

From 2012 to 2015, STUDIO 727 participated in projects dealing with the digitization of cultural heritage by digitizing museum artifacts and national monuments of Slovakia. The project of the Digital Monuments Funds (DMF) was implemented within the Operational Programme "Informatisation of Society" (OPIS), the goal of which was the digitization of selected cultural monuments and historical objects in order to reconstruct them in detail and preserve them for future generations. The task to document the most beautiful museum exhibits and architecture in Slovakia

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within a short period of time, while simultaneously delivering top quality, was extremely challenging both for our company and its partners.¹ Our work was organized into two projects. The first consisted of digitizing a vast number of museum artifacts from different museums in Slovakia, and the second comprised the digitization of various selected objects of architectural heritage.

2. THE STATE OF THE ART

We would like to highlight some important international projects, which have already been realized in the field of digitization of cultural heritage.

2.1 Smithsonian X 3D

Established in 1846, the Smithsonian Institution is the world's largest museum, an education and research complex consisting of 19 museums and galleries, the National Zoological Park and nine research facilities² administered by the Government of the United States. The total number of objects, works of art and specimens at the Smithsonian is estimated at 156 million.

The Smithsonian developed The Digitization Program Office as the hub for the Smithsonian's inquiry into 3D. They support their institutions in their quest to increase the quantity and quality of Smithsonian digital assets. The Smithsonian digitization challenge and opportunity can be measured by the total number of collection items: at 137 million objects, works of art and specimens, capturing the entire collection. The Digitization Program Office is promoting rapid capture photography workflows for two-dimensional collections and exploring innovations to speed up the capture of our three-dimensional collections, preferably in 3D. All of these digital items of the collections will be available not only to specialists but also to the general public.

2.2 3D COFORM

Another example is an international project named 3D COFORM "Tools and Expertise for 3D Collection Formation." "This project aims to demonstrate the use of 3D technologies for documenting and semantically enriching 3D content based on shape analysis in the cultural heritage domain."³

2.3 CultLab3D

Fraunhofer IGD developed the pipeline CultLab3D, robotic system for 3D scanning and digitization of three-dimensional objects. They use software CultSoft 3D to control and configure the two stations (CultArc3D and Cult Arm3D) which scan museum artifacts. This system was used during the program 3D COFORM.⁴

¹GEODETICCA, IQServices, Ornth sro.

²<http://newsdesk.si.edu/about>

³<https://www.iese.fraunhofer.de/en.html>

⁴<https://www.iese.fraunhofer.de/en.html>

2.4 UCL's Petrie Museum of Egyptian Archaeology

University College London (UCL), in collaboration with UCL's Department of Civil, Environmental and Geomatic Engineering and business partner Arius 3D, has been developing a groundbreaking program for creating 3D images of objects in the Petrie collection, which holds one of the top collection of ancient Egyptian artifacts in the world. Visitors can view an interactive online 3D object library of the artifacts.⁵

2.5 3D ICONS

Another successful project in the field of digitization of cultural heritage is 3D-ICONS, a pilot project realized between 2012 and 2015 that was funded by the European Commission's ICT Policy Support Programme [Guidi et al. 2015]. Bringing together partners from across Europe with the relevant expertise to digitize architectural and archaeological monuments in 3D, it was designed to establish a complete inventory of 3D replicas of archaeological monuments and historic buildings by establishing processing, utilization, and production guidelines that cover all technical, legal, and organizational aspects. Further, the project aimed to create 3D models and a range of other materials (images, texts, and videos) of a series of internationally important monuments and buildings and to contribute content to Europeana using the CARARE aggregation service.⁶

3D-ICONS is one of a suite of projects, funded by the European Commission, to develop Europeana and its contents. It aims to complement the collections that have been made accessible to Europeana through CARARE, Europeana Local, ATHENA and other projects. It plays an important role by involving organizations with recognized expertise in 3D data acquisition and modeling in establishing a full production pipeline. This will cover all aspects of a 3D digitization project from planning and obtaining permissions, selection of methods and tools, data acquisition, post-processing, publication of content online, and metadata capture to making the content available to Europeana.⁷

2.6 Other previous works

Several important works have already been done in the field of digitization of the cultural heritage. We would like to mention the paper "The Digital Michelangelo Project: 3D Scanning of Large Statues," which describes an experiment to digitize the shape and color of large fragile objects, the statues of Michelangelo, under non-laboratory conditions [Levoy et al. 2000].

In 2004, a team of specialists digitized the wooden statue of the Maddalena by Donatello, situated in Florence. In their paper they described the dimensional accuracy and a methodology for its quality control. They compared photogrammetric and optical scanning data in a unique reference system and achieved a deviation below 0.5 mm as a result [Guidi et al. 2004].

⁵ <http://petriecat.museums.ucl.ac.uk>

⁶ <http://www.3dicons.ie>

⁷ <http://www.3dicons.ie/about>

Another paper, focused on the description of a photogrammetry-based survey technology for the acquisition of point clouds and 3D models only from digital image processing, was "Survey and 3D reconstruction of the St. Orso capitals in Aosta, through three-focal photogrammetry" [Salonia 2009, 35]. This technology allowed the acquisition of high-quality range data of the capitals with all the details.

A significant book, "Close-Range Photogrammetry and 3D Imaging," [Luhmann 2013] provides fundamental mathematics covering subjects such as image orientation, digital image processing, and 3D reconstruction methods, as well as a discussion of imaging technology, including targeting and illumination, and its implementation in hardware and software. It concludes with an overview of photogrammetric solutions for typical applications in architecture, archaeology, engineering, manufacturing, medical science, and other fields.

3. FIRST PROJECT – DIGITAL MUSEUM

The first project was the digitization of 72,000 museum 3D artifacts from different museums in Slovakia (33 museums, in around 70 locations), such as the Slovak National Museum, the Archaeological Museum in Bratislava, the Slovak National Gallery in Bratislava, the Museum of the Slovak National Uprising in Banská Bystrica, and the Slovak Technical Museum in Košice.

We digitized objects of different sizes made from various materials, for instance, the traditional female costumes from different regions of Slovakia (Figure 1); priests' robes from the Western Slovakian Museum in Trnava; wooden smoking pipes from the nineteenth century; the statues of saints from several historical collections; and diverse historical musical instruments and paintings.

Figure 1. 3D model of the traditional female costume from Ábelová in Slovakia, 1920. (Model made by STUDIO 727).

The result of the digitization of most objects was image panoramas. Virtual 3D models have been developed from selected objects.

Each object required individual consideration based on its size, shape, and texture, resulting in different procedures, technologies, and post-processing approaches. For the digitization of paintings, we took into account the correct illumination in order to capture all details. In the scanning of decorated Easter eggs, we had to be very cautious not to damage the fragile exhibits. In the case of particularly glossy materials and glass, it was necessary to apply special procedures with regard to the problematic creation of the 3D models. An example of an object requiring these procedures was the golden ceremony sled made from wood and painted gold (Fig. 2).

Among the largest objects were a historical carriage from the nineteenth century, a tank from World War II, airplanes in the military museum in Piešťany, and others. Small objects were a big challenge as well, including coins and archaeological finds such as Iron Age pottery dated to the 600s BC. The traditional folk culture is represented by objects such as a hatchet, a studded belt, shepherd's pouches, carved cups and painted ceramics (Fig. 3).

Figure 2. 3D model of a golden ceremonial sled from wood, 18th cent. (Model made by STUDIO 727).

Figure 3. 3D model of a mobile fire engine from 1812. (Model made by STUDIO 727).

3.1 Technologies

In some museums, we established external offices and photography studios (Fig. 4). The total count of objects intended for digitalization was high, and the most important objects required individual approaches. For regular objects that were primarily designated for cataloging, we used a standardized approach. This was based on average time available for one object and designed around the best available technology so that we could streamline our workflow and achieve the best possible results.

We decided to use robotic systems, such as Milo, Bolt, and Modula equipped with two types of cameras, a full frame Nikon and a medium format PhaseOne. That enabled us to take a total of 144 photos for each object from different positions, mostly consisting of 4 elevations with 36 photos for each elevation. To these 144 photos, we added top view and calibration photos. If necessary, we added more photos to attain special detail, such as the logo of the manufacturer, texture of the clothes, or the interiors of pieces of furniture.

This concept was designed for mobile objects that can be scanned in a given way and with a given number of shots. For immobile, complex, and specific subjects, individual methods were used, including multiple images and manual shooting. Some objects, such as guns, were disassembled prior to being photographed. For objects like cups and vases, we were sure to capture the bottom.

During the photography of about 3500 coins, we chose the method "Reflectance Transformation Imaging" (RTI)⁸ with 32 lights situated around a construction in three rows (Fig. 5).

This standardized approach maintains the level of detail relative to the size of the object. That means the smaller the object, the higher the level of detail relative to the unit of size. The camera choice for small objects between 0-70cm was the Nikon D800E (36 megapixels), as there is a greater choice of lenses, particularly Macro lenses. For the objects over 70 cm in size, we chose a medium format PhaseOne camera with IQ180 digital back (80 megapixels). In addition to these setups, we used necessary accessories, such as additional lighting, in order to capture the appropriate amount of data.

For larger objects, we used photogrammetry to reconstruct 3D objects and applied textures from the original photos.

In the case of small objects, we used photo stacking, which involved taking ten photos at each position with different depths of field and combining them for perfect focus. Each object was therefore photographed several thousand times in order to result in 144 pictures. Because macrophotography has a very shallow depth of field, it is not possible to get a sharp picture of the whole object.

Figure 4. Robotic system MILO in the working stage. Photo: STUDIO 727.

⁸ Reflectance Transformation Imaging (RTI), also known as "Polynomial texture mapping" is a technique of digital imaging and interactively displaying objects under varying lighting conditions to reveal surface phenomena (<http://vcg.isti.cnr.it/rti/index.php>)

STUDIO 727 used eleven MRMC rigs – five Orbital Rigs, two Bolt CineBots, Milo, Talos and Modula. Mark Roberts Motion Control⁹ is a designer and manufacturer of robotic motion control solutions. As the entire range of MRMC robotics is programmable, it was a case of using the different robots for the different tasks of capturing the images. All the robots ran from the same software user interface while the operations between the robots remained the same. The captured images were streamlined to flow into the 727's capture database, where innovative tools greatly simplified any post-processing required.

The Orbital is a photography rig capable of taking a very high volume of photos quickly. Given that each of the artifacts needed 144 individual photos in order to create a 3D image, the Orbital provided a perfect automated solution. STUDIO 727 programmed in the moves, and with a single click, the rig could capture all 144 photos for a single artifact.

The Bolt (Fig. 6) was used to photograph a high volume of different museum products. The Bolt also runs on a track, which makes it much more versatile when capturing larger items or other awkward heritage items.

The Milo is MRMCs flagship robot (Fig. 7). Larger than the Bolt, it was used in bigger spaces in the museums and set up similarly for repeatable, precise moves. It seldom had to be moved and therefore could be set up to run continuously as needed for a huge volume of artifacts.

The Talos is designed to fit into much smaller spaces. It can pass through a normal sized door. It was perfect for more awkward or cramped locations and could be moved from room to room as needed.

The Modula, as the name suggests, can be broken down into smaller sections, allowing both easier shooting capabilities and ease of movement from one location to another.

Rodeon is a programmable robotic head focused on capturing large pixel count images, 360×180 panoramas and gigapixel panoramas. We adapted the Rodeon mount, equipped it with Nikon D810 camera and took advantage of its primary feature, i.e., taking high quality and precisely positioned photos. That means low ISO, high aperture, high depth of field while using wide and medium field-of-view lenses. With a custom mount and programming, we set Rodeon to capture photos with enough overlap of all of its surroundings or only specific fields of view. This contributed to accelerating our work process, as such data would require using tripods and would be hard to maintain the desired overlap. Our Rodeon-based solution covered large areas within a short period and was reliable while changing position and crossing harsh terrain.

⁹<https://www.mrmoco.com/>

Figure 5. A device developed by NUSTEP for coin digitization. Method Reflectance Transformation Imaging. Photo: STUDIO 727.

Figure 6. Taking pictures with high-speed Cinebot BOLT from the company Mark Roberts Motion Control. Photo: STUDIO 727.

Figure 7. Robotic system MILO from the company Mark Roberts Motion Control. Photo: STUDIO 727.

4. PROJECT – VIRTUAL MONUMENTS

The second project consisted of the digitization of architectural heritage. It comprised national monuments, castles, churches, monasteries, castle ruins, and historic town centers. We scanned 1,400 buildings, and 1,000 3D models have been subsequently created.

4.1 Objects

The selected objects rank among the most important Slovak monuments, and many of them are inscribed on the UNESCO World Heritage List, including, for example, the Spiš Castle and its environment, and the urban conservation area of the cities Bardejov and Banská Štiavnica. We digitized many castle ruins, including the Devin Castle, the Spiš Castle, the Trenčín Castle, and the Uhrovec Castle. We also digitized important churches of Slovakia, including the Basilica of the Virgin Mary of Seven Grievances in Šaštín, St. Martin's Cathedral in Bratislava, Church of the Virgin Mary's Assumption in Banská Štiavnica (Fig. 8), St. Elisabeth Cathedral in Košice (Figs. 9 and 10), the Gothic chapel in Spišský Štvrtok (Fig. 14), the basilica and the monastery in Šaštín-Stráže (Fig. 15), and many others.

Figure 8. Church of the Virgin Mary's Assumption in Banská Štiavnica. Photo: STUDIO 727.

Figure 9. St. Elisabeth Cathedral in Košice. 3D model. (Model made by STUDIO 727).

Figure 10. St. Elisabeth Cathedral in Košice. Working desktop of software CapturingReality. (STUDIO 727).

4.2 Technologies

4.2.1 Terrestrial Laser Scanning (TLS)

As the first step of the digitization in our project, we began with the collection of data directly on site. The initial capturing of each object was done using the LIDAR method, by Leica ScanStation P20 Laser scanner technology. This technology can record 1 million space points per second with a precision of 3 mm. The greatest distance to measure was 150 meters. In the beginning of the project, we realized that in order to produce full 3D models, the process of terrestrial LIDAR scanning itself was not sufficient. Roofs and small details on the upper parts of the architecture were not totally captured; in the interiors of the buildings, the upper parts were missing as well.

4.2.2 Photogrammetry

For data collection, we used a number of methods, including photography using Rodeon. The aerial photographs were taken from a helicopter, and at a later date, we started to deploy drones.

Figure 11. Robotic system Rodeon used in capturing architecture. Photo: STUDIO 727.

The drone presents a cheap solution for data collection while increasing safety. The use of helicopters, cranes, or scaffolding is costly. The drone was able to capture parts of buildings such as roofs, chimneys, and eaves that were otherwise inaccessible with former methods. Further, its ability to take bird's eye view photos proved to be crucial when it came to the creation of models. We used the AIBOT X9 V2 type drone in combination with a Nikon D810 camera.

Rodeon in combination with a Nikon D810 contributed to accelerating our work process. It covered a large area and guaranteed a significant number of high-quality photographs within a short period. The large volume of data was achieved thanks to the deep depth of field and low ISO. The robotic Rodeon system practically replaces the tripod and accelerates data collection by robotic capturing and changing of position (Fig. 11).

4.2.3 Post-processing

The second stage of the digitization was data processing, which had to be carried out within a reduced timeframe. We realized that the use of TLS scanning alone or photogrammetry alone was not sufficient, and that it was necessary to combine these two methods. We started to collaborate with the Slovak company Capturing Reality, which is developing the RealityCapture software that is capable of combining LIDAR data and photogrammetric data. This software can process astonishing amounts of laser-scans and images in a very reasonable time. Algorithms in RealityCapture automatically split the problem into smaller parts, which then can fit the available hardware in an optimal way (Fig. 12) [Dedík-Nemčovič 2016, 15].

Figure 12. Church of the Virgin Mary's Assumption in Banská Štiavnica., different phases of the 3D model. (Model made by STUDIO 727).

In the table below there are three different sized digitized monuments related to data volume and processing time. The time includes alignment, meshing, and coloring of final models.

The final products of the digitization were: 3D models, videos, panoramas, virtual tours, 2D technical documentation, and virtual reality.

Table 1. Data volume and processing time for three differently sized monuments in the project

Monument	Scan positions	Images	Processing time
Church Virgin Mary Assumption in Banská Štiavnica	70	80,000	1 month
Basilica and the monastery in Šaštín-Stráže	481	170,000	2 months
Historical town Banská Štiavnica	400	400,000	5 months

3D models were used during recreation of the 2D technical documentation of the buildings. By using the RealityCapture software, we generated orthoprojections that were georeferenced while textures had the information of the original colors of the buildings. In Autodesk AutoCAD, we drew 2D technical documentation, like situations, elevations, and sections. For some of the monuments, we have also created 3D technical documentation using the Autodesk Maya software (Fig. 13a, b, c).

Figure 13, a, b, c. Church of Virgin Mary's Assumption in Banská Štiavnica, 3D model. (Model made by STUDIO 727 in software CapturingReality).

5. CONCLUSION

For the first project, "Digital museum," the difficulty was that we had to adapt to various complicated conditions. Thus, it was important to choose the right techniques based on the object conditions to achieve the desired data. For the photogrammetric campaigns, reflective surfaces, such as metallic and glass objects, posed the greatest challenge to photograph.

Within our work on the second project "Virtual monuments," we tried to optimize our technique to create accurate, high-quality models. It was important to devise an efficient way of collecting, archiving, and post-processing of obtained data. For the photogrammetric campaigns, the important considerations were acquiring sufficient overlap between the images and connecting the interior and exterior photos by using open doors.

Laser scanning is precise and highly accurate, the scanning is independent of light conditions, and collection is very fast. We can scan a lack texture, and we can also measure distant objects at a distance of up to 120 m (at 18% reflectivity).

Figure 14. Gothic chapel in Spišský Štvrtok in Slovakia, 3D model – LIDAR data and photogrammetry. (Model made by STUDIO 727 in software CapturingReality).

Disadvantages are that it is unable to capture color without additional photos, occluded features are difficult to scan, it is not suitable for close and narrow spaces, and the equipment is relatively expensive.

Photogrammetry produces true color 3D models that can be achieved without any special scanning method without targets and the equipment is relatively simple and affordable. It is possible to shoot from unstable positions, e.g., with a hand-held camera or telescopic rod, and hard to reach areas and rugged terrain are easy to shoot. However, the results depend on fair lighting conditions, and modeling of objects which lack geometric or textural structure is problematic. Changes in or around the subject during the process of taking pictures can significantly complicate the model processing.

When we summarize and compare the advantages of photogrammetry and terrestrial laser scanning, we can conclude that the best solution is the combination of both methods and that the use of the CapturingReality software proved very helpful. During this project, we helped to develop this software, which is among the best that has been developed so far in this field.

When we review the processes of data collection and processing, we can see that significant progress has been made in optimizing the processes and improving the quality of the final products during

the three-year project period. The input and output data that we archived are characterized by a level of quality that is sufficient for use in the course of the next 20 years in the fields of science, education, and tourism development.

We prepared data for The Slovakiana Culture Portal¹⁰, which was launched in November 2015. Everyone can see and download videos, photos, panoramas, and information about the monuments. The portal forms a part of a network of European culture portals led by the Europeana portal.¹¹ The content of the portal will be continuously updated in line with the progress of cultural heritage digitization.

Figure 15. 3D model of the basilica and the monastery in Šaštín-Stráže (SK). (Model made by STUDIO 727).

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¹⁰ <https://www.slovakiana.sk/virtualna-exkurzia/pamiatky>

¹¹ <http://www.europeana.eu/portal/en>

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