Integrating point clouds to support heritage protection and VR/AR applications

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Abstract

Current paper discusses the surveying of a ~30 m high tower in a Hungarian castle; since it is a protected monument, its documentation is of national interest. Besides the surveying and data processing, the paper provides details on the procedure of sharing the collected data in virtual/augmented reality environment.

Due to the tower's complex geometry (uneven wall surfaces, irregular shapes) and size, multiple surveying techniques have been applied. The gate, the near environment of the building and rooms have been mapped by terrestrial laser scanning, while structured light scanners have been used for small objects to capture the fine details. Aerial images have been taken by UAV to acquire information on the tall parts of the building. The paper gives an overview on the applied data acquisition procedures.

Data from different sources have been merged and handled in a unified system that enables the integrated analysis of all surveyed objects. The result product can be further used to derive data for architectural purposes, e.g. views, sections or numerical values. The high density point cloud supports virtual/augmented reality applications; both experts and tourists can take a virtual walk in the tower, the practical solutions and future options are also presented in the paper.

Our investigations proved how the state-of-the-art spatial surveying technologies can support heritage protection, and, by merging multiple types of data, how the results can be used in virtual/augmented reality applications.

Keywords: terrestrial laser scanning, structured light scanning, unmanned aerial vehicle, augmented reality, virtual reality, architectural modelling, head mounted display

1 Introduction

The Humansoft Ltd. was founded in 1989, which has been operating as a member of 4iG Plc. since 2014. With its high level services and high quality solutions it is a prominent player of the Hungarian IT market. Income from sales was 60 million USD (2015), number of employees is 300.

The Mensor3D Ltd. was founded by Humansoft Ltd. in 2014. Our main profiles are technical testing and analysis in architecture and mechanical engineering based on 3D scanning.

Hungary is incredibly rich in cultural heritage. Their preservation, digital documentation and spectacular preservation is of common interest. The Mensor3D employs the most advanced 3D technologies for the purpose of 3D digital preservation of the monuments in the country and artifacts of national importance. We strive for that our products were utilized for museum, tourist and educational purposes. We know that the researchers, educators, students, tourists and those roaming in the virtual space would like to get and see a different set of the opportunities offered by these technologies.

Several companies and scientific projects can be found worldwide with similar goals, mainly cultural heritage preservation, architectural survey and documentation, mechanical engineering and visualization. CyArk is one of the most remarkable non-profit organization, which is dedicated to digital heritage protection. Mensor3D Ltd. is the successor of project SziMe3DAR which was selected by the CyArk 500 challenge to digitally document the Medieval Palace of Visegrad in Hungary.

2 Historical background

2.1 The Solomon tower

Solomon-tower is one of the most important Arpad-era relic in Hungary. It was the main fortress of Visegrad Castle. The five-storey, 32 meter high hexagonal tower was built in the 13th century (Figure 1). Its southern side collapsed during the Turkish battles in the 16th century. It was rebuilt several times between 1870 and 1960. The building is currently facing a number of technical problems; renovation of the building cannot be postponed anymore. Planning procedure requires an accurate and comprehensive survey documentation. Surveyed data also support scientific research: in addition to the exact geometry of the building structures, texture is recorded and it is presentable as a colored point cloud.

2.2 The fountain

The biggest fountain of Visegrad was built by I. Louis in the inner courtyard of the residential building of the Visegrad palace. The octagonal, originally two-storey, tower-like fountain's ground was based on the archway on the eastern side of the courtyard (Figure 2). The fountain's upper, rectangular structure was standing on its balcony-like second floor. Except the parts made of red marble, the fountain was painted in colors (Buzás, 2010).

2.3 The stove

The stoves of the Visegrad palace are exceptionally important in the development of the stoves of the medieval Hungarian kingdom (Figure 2). The archaeological artifacts of the last years enabled the detailed documentation of the stoves from the particular era. The current statically appropriate stove model reconstruction provided valuable information about the real historically correct layout (Kocsis, 2016).

3 Surveying the Solomon tower

Several technologies were combined during the data acquisition procedure. The goal of the survey was to create a dataset that enables deriving architectural 2D products (views, layouts, sections) and detailed 3D model for virtual reality presentations as well. The survey had two stages: first the fountain and the stove (both from the Anjou era), then the building and its environment were captured. There was one year gap between the two survey stages. We used the data acquisition equipment as follows:

- Z+F Imager 5010C and Leica HDS7000 terrestrial laser scanners (TLS)
- Nodal Ninja + Canon EOS 600D
- Leica TCR803 Total station
- Leica Viva GS14 GNSS receiver
- Artec EVA and Breuckmann structured light scanners (SLS)
- DJI Phantom unmanned aerial vehicle equipped with GoPro Hero3 (UAV)
- Bosch laser distance measurer

The tower has five floors, 350 m^2 each, the directly connected environment is 400 m^2. Since the tower is 32 m high, and below the top of the tower an external ramp/corridor and its rail structure blocked the line-of-sight, its upper area cannot be captured by TLS (Figure 1).

Figure 1 - The 32 m high Solomon tower with the external ramp at the top

Therefore UAV was used to complement the TLS datasets and to survey the environment in a distance from the tower. TLS was used indoor to capture large spaces, the rooms and stairways, while SLS was applied to survey the fine details. The main geometry of the fountain inside the tower was captured by TLS, but SLS was used for the inner parts of its columns and for the basin (Figure 2). Note that for architectural analysis mm-level point density and accuracy was required. ArtecEVA was widely used to survey the details but for small objects with fine details the Breuckmann SLS was applied, e.g. the extremely decorated stove covered by shiny tiles was only captured by Breuckmann (Figure 2).

Figure 2 - The Anjou stove (left) and fountain (right) of the Solomon tower

During the TLS measurements tie points were used to join the point clouds acquired from different scan stations, but a part of them was also used as control points to transform the point cloud into geodetic reference system (Lovas, Berényi, & Barsi, 2012). Registering the point cloud into high level coordinate system also enables to merge the dataset with the results of other surveys carried out earlier or later. Moreover, these control points support to connect the TLS data with that of the UAV. The control point coordinates were obtained by conventional surveying methods, such as total station and GNSS measurements.

The tower floors inside are connected with narrow spiral staircases, therefore point cloud registration was supported by measuring the tie points with total station. In especially small areas and narrow spaces tapes and laser distance measurer were used to capture the geometry, which was joined to the 3D model during the post-processing.

Since the tower's layout is very fragmented, instead of creating scan stations very close to each other, some small rooms were captured without using tie points; these point clouds were merged with cloud-to-cloud registration.

The entire tower was surveyed with two scanners, from 96 scan stations in two days. The UAV flight took 2 hours, the total station survey required 4 hours, manual distance measurements lasted for 6 hours, while SLS measurements with two instruments needed a whole day; 8 people worked on-site in the project.

39 panoramic images were captured during laser scanning from areas having high priority considering presentation purposes, intensity measurements were used otherwise. Since several different kinds of instruments producing big data were used, the applied point density values had to be selected carefully on-site to optimize data storage, handling, management, and processing.

4 Surveying the fountain and the stove

The goal was to support the reconstruction procedure of the particular artifacts. By modelling the fragments and small parts of the object, it can be virtually reconstructed by the experts.

In case of the fountain the SLS and TLS technologies were used combined; the artifact was captured from 15 scan stations. In the further stages of the project, when the fountain's environment was surveyed, these point clouds have also been reused, saving 3-4 hours on-site. Since no permanent tie points were deployed, cloud-to-cloud matching was used to register the point clouds captured in different times.

The fountain's area of base is 25 m^2, its height is 5.5 m. The main body's geometry was captured by TLS, while Artec EVA SLS scanner was used for acquiring data from the fine details (Figure 3). The inner parts of the fountain can only be surveyed from inside, here also the Artec scanner was used due to size limits. Some separated parts, fragments of the fountain were surveyed by SLS on their current storage location; these datasets were merged with that of the fountain during the post-processing procedure supported by art historian experts.

The primary issue in surveying the details is the surface of the particular area. Too porous surface results in limited reflectance. Too smooth and shiny surfaces have similar effects that could be eliminated by using thin layer of marker dust that doesn't change the object's geometry, easy to remove and improves the reflectance capability.

Figure 3 – TLS survey of the fountain

The stove is covered by glazed ceramic tiles. Breuckmann 3D structured light scanner was used to capture its geometry. The result is a TIN surface model complemented with texture by using images taken during the scans. Each stove element was surveyed separately, the integrated model was created by the instructions of the art historian expert (Figure 4).

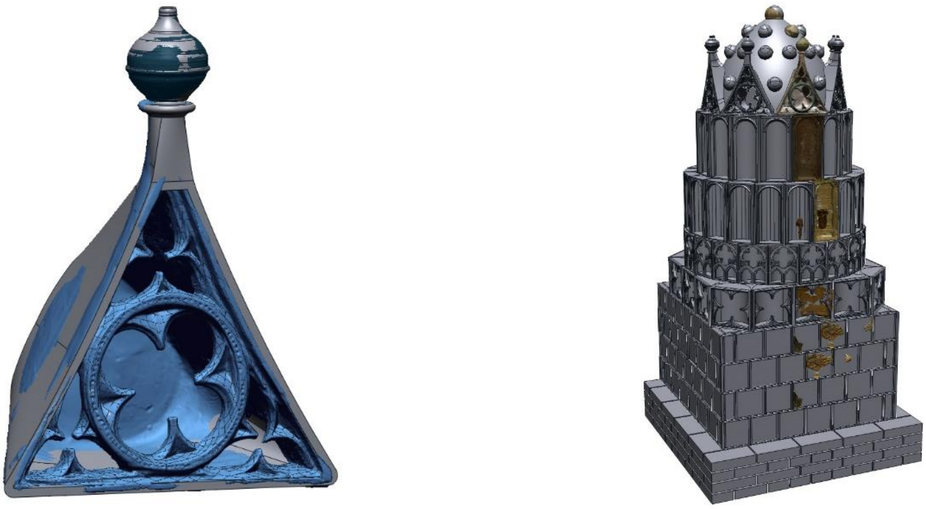

Figure 4 - Separated stove elements and the integrated model

These elements differ in size, shape and level of decoration; there are sizeable but simple tiles and small but finely detailed parts. These have been separated and surveyed using different scanner optics. If the object size allowed, it was put on a rotating stand and was scanned from a fixed scanner position. The accurate survey of the objects required 20 to 100 scan positions. The scanners own software was used to register the scans by manually marking the tie points. The integrated surface model was corrected, e.g. by filling holes on the mesh. The separately modelled elements were merged using reconstruction plans and instructions resulting an integrated stove model. This model has been put in a virtual environment that enables its presentation. Additional products have also been created: augmented reality card, 3D print, poster, video footage that are also part of the museum's presentation (SziMe3D, 2016).

5 UAV measurements

During complex surveys UAV measurements cannot replace but complement terrestrial laser scanning by measuring inaccessible areas. Compared to laser scanning, one major advantage of UAV is the small size of equipment and the less on-site measurement time. However, as a shortcoming, UAV cannot be used indoor. Although the accuracy and resolution provided by the UAV is sufficient for multiple purposes, these parameters are depending on light and weather conditions. The laser scanner as an active remote sensing technology is capable of surveying in dark environment, and is not sensitive to shadows. (Hadzijanisz, 2014)

To estimate the required flying time and number of images, the flight was planned in a google maps based software. Take off location is to be selected with good GPS visibility and without objects disturbing the take-off and landing; the tower top (2 take-offs) and the open area next to the tower (1 take-off) were reasonable options (Figure 5).

Camera settings have to be adjusted before take-off, no changes are enabled during the flight. To ensure overlap between the images, 0.5 fps capture rate was set considering the flying speed (6 m/s). The UAV captured 968 images with 12 Mpixel resolution in jpeg format.

Figure 5 – Aerial image positions (left) and derived point cloud (right)

Image correction was carried out in two steps, first is the exposure correction. The GoPro camera doesn't save raw files, only compressed jpeg images, but with exposure corrections the details of the too dark or too bright images can be revealed (Figure 6). The second step is adjusting color temperature that was done by each RGB channels.

Figure 6 – Original and exposure corrected aerial images

Images taken during take-off and landing, and those with too much overlap or with motion blur have been removed; 914 images remained for further processing. The UAV's OSD (on screen display) cannot record navigation data, therefore the GNSS coordinates of the ground control points were used for registering the image in geodetic reference system.

Generating and filtering the point cloud from 914 pieces of 12Mpixel images is time-consuming that requires high computation capacity; the result is a colored, geo-referenced point cloud that consists of 47 million points (Figure 5).

6 CAD - modeling

To support heritage protection the thorough documentation have to be created based on the previously discussed acquired data. The architectural documentation contains 8 floor plans (6 main and 2 intermediate floor plans), 3 ceiling plans, 2 sections, 1 top view and 6 façade views. Multiple section planes were defined to derive the floor plans and sections to ensure the representation of all the required objects on the drawings (Figure 7). The resolution of the data acquisition enabled 1:50 scale representation of the details.

To achieve additional thematic information, the orthogonal point cloud image was used as a layer under the vector drawing that provided valuable information on the texture of the surfaces. Based on these data the different building periods could be separated and indicated with different hatch patterns.

Figure 7 – Cross-section layers with point cloud background

The 3D model of the building was also created based on the surveying. The building is part of the museum, a realistic, high resolution 3D model can be part of the exhibition. Such model can be the base of BIM (building information modeling) that would support the building operation. To achieve this goal the point cloud was cut to separate parts before modeling. The building environment (courtyard, gate) was not modeled, therefore was cropped from the dataset. The outer shell of the building, the staircase and the floors have been also separated. The high point density enabled to create a mesh from the tower walls without gaps which is perfect for visualization purposes (Figure 8). Being a historical site, no objects from CAD-repository (e.g. window, wall) can be used in the modeling procedure.

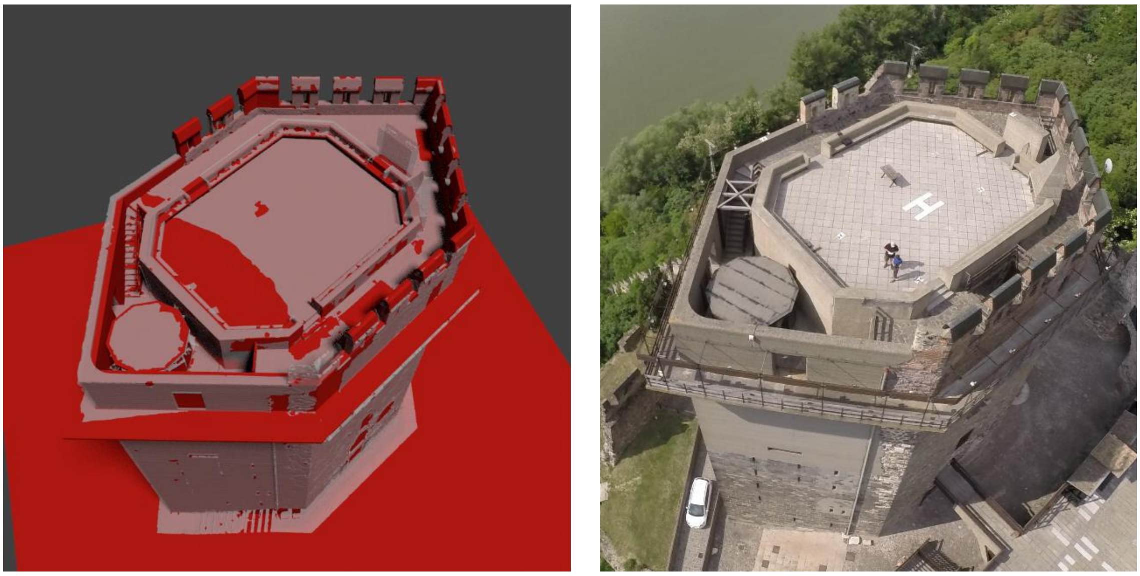

Figure 8 - 3D mesh and model representation (left) of the Solomon tower (right)

7 Using the surveyed data to augmented reality

The primary objective was to digitally document Solomon tower's historical site and its artifacts in 3D with high fidelity and precision. The applied technologies capable of providing multimedia (i.e. AR – augmented reality, VR – virtual reality) experience for the general public, tourists (Figure 9).

Aerial photogrammetry, terrestrial laser scanning and structured light scanning devices have been used successfully to capture real-world sites and objects. These methods provide reliable results, but considered expensive. The output of current scanners are not yet ready for direct analysis or real time interaction on generic platforms. Usually some minor data continuity issues have to be addressed, basic editing is necessary. There are robust tools to correct these deficiencies. Specialized, independent virtual working environments provide solutions from the initial steps (processing raw captures) to delivering the final results – Augmented Reality (Bödő, 2015).

Our objective is to share and introduce these scanned datasets and models (reconstructions) with non-researchers, to create an interactive presentation based on research and design data. We intend to introduce current display and motion capture technologies (HMDs – Oculus Rift; stereo sensors – Leap Motion) and explore how to apply these devices in open or confined spaces.

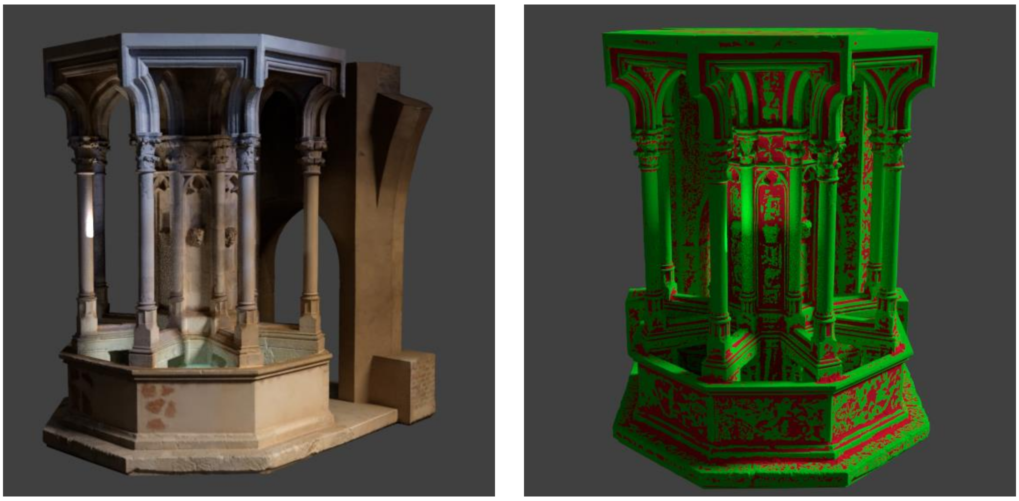

Figure 9 – Anjou era ornamental fountain rendering (left) High-(green) and low (red) resolution mesh composition

The scanned spatial data can be converted into a high resolution mesh or complex digital model of the objects which can be further processed. Creating high resolution meshes require high computation power and capacity, thus optimization is required. Optimized meshes with high resolution textures are visually undistinguishable from high resolution scan data. The model can be just a virtual reconstruction of the present state but can also be used to reconstruct former structures. It is measurable, and can depict the object in different stages of construction or decay. By coupling other imaging technologies, i.e. photogrammetry, the original visual surface of the object can be recreated in impressive details with the help of recorded textures. (Magnor, Grau, Sorkine-Hornung, & Theobalt, 2015)

For research purposes high accuracy scanners have to be used to achieve the maximum precision, to find subtle but potentially important information. With basic pre-processing tools, high polygon count surface models can be created based on scan data. These high polygon count models then can be used to create (fluid) simulation ready parametric models. They also serve as a foundation for reconstructions or even to make low polygon count models for real time AR experience (Figure 10). On the basis of the lower resolution models an entertainment and educational AR application can be developed. With overlaying images on the visible reality, for example populating a historical place with virtual figures, with sound effects and/or narration, the augmented reality application can offer not just the sense of presence but also give a touch of time travel back to imaginary but historically correct scenes. This approach also creates new opportunities for impaired people who may have difficulties in visiting remote historic places.

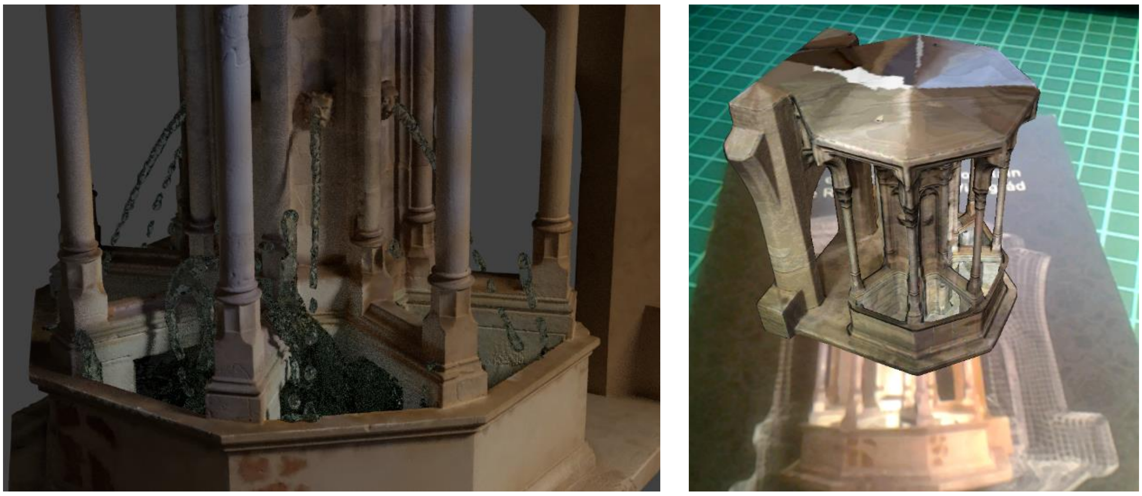

Figure 10 – Simulated water splashing in the fountain (left), AR experience (right)

To fully experience the surroundings in 3D and in right scale, special hardware has to be utilized. There are many ready to use and in development technologies to display virtual content. The HMD (Head Mounted Display) technology can seamlessly involve visitors in visual scenarios. The tracking and display technology should work together. The limbs are kept free to be able to walk and browse the exhibition and initiate interaction with virtual and real-world objects in the same way. Real time image processing has to be utilized to virtually track human motion, and interpret it to help interaction with virtual surroundings.

8 Conclusions

3D scanning is a powerful tool to measure objects with exceptional precision, from tiny ones to entire buildings. In our project we proved that the applied spatial surveying technologies (i.e. TLS, SLS, UAV) can effectively complement each other and therefore capable of providing a complete, state-of-the-art solution for engineering or archeological documentation tasks. Our investigations proved how the accurate, dense point clouds can support creating virtual models that can be used in VR/AR environment.

The applied technologies and the derived products can remarkably support heritage protection through the documentation of selected areas and artifacts. Cutting edge visualization techniques enable the realistic and interactive presentation of the current and past objects.

9 Acknowledgement

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