Augmented reality in the dynamic world of virtual tourism

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Abstract. The issue of virtual tourism penetrates the consciousness of many current explorers and visitors to interesting sites and local attractions. Is it really necessary to physically travel to the chosen location, sacrifice time, money and increase your carbon footprint? The article deals with the issue of creating an application using augmented reality for the presentation of 3D models of cultural monuments. The application is designed for mobile devices, on which museum visitors can view digital copies of selected objects of interest. They can also take a virtual tour of the museum through their mobile devices from the comfort of their home. The introductory part of the article describes surveying of shape and visual properties in situ using photogrammetry and laser scanning. The sequent chapters are an analysis of the creation of 3D models in real scale with photorealistic textures and their presentation in a mixed reality environment. In our case, we will specifically focus on the augmented reality application and its development in the Unity multiplatform game engine. The article aims to describe the development of a mobile marker-based AR application briefly, to demonstrate the possibilities of augmented reality and to indicate the potential benefits resulting from the integration of X-reality into our lives. Specifically, we will focus on the application of AR to cartographic works and the enrichment of the content of classical 2D map works and plans with virtually designed 3D models on their surface.

1. Introduction

The aim of the research is to apply progressive geodetic technologies and combine the measurement results with innovative digital technologies in order not only to document existing historical monuments, but also to bring a new dimension to their presentation to the public through mobile applications, augmented and virtual reality. The usage and continuous development of measurement methods such as 3D laser scanning, spherical photogrammetry, structure from motion (SfM) photogrammetry and aerial photogrammetry brings a strong change in the acquisition, processing and interpretation of metric information as Barille is pointing out with his research activities [1]. Augmented reality is becoming one of the few options for 3D output that is relatively inexpensive but also provides very clear and interesting results as demonstrated by Canciani in his research paper on a topic of virtual reconstruction of Aurelian Wall [2]. Specifically, this research case is focused on modifying the plan of the museum premises using a visual/marker-based AR application.

Individual objects of interest are coded using unique symbols and linked to 3D models of focused historical objects. Objects are generated on the museum's plan automatically during the museum's tour in the environment of augmented reality – the real world enhanced of virtual objects. The connection
of possibilities and knowledge of various technological and research branches is an essential condition for the creation of new, but at the same time functional and meaningful products and services. Innovative ideas based on market needs will find their application in the coming days. Barrado-Timon also attempts to point to the benefits of incorporating the AR technology into the visualization and presentation of cultural heritage. He sees the benefits of AR not only by learning, marketing or promotions, but also by gamification and by attracting new target groups of visitors and tourists of cultural sites by improving visitors experience with AR systems [3].

2. Creation of 3D models
The aim of the implementation of measurement work for the creation of a 3D model with subsequent visualization was in this case to capture historical monuments located in the area of the National Open-Air Museum - Wallachian Open-Air Museum, located in Rožňov, Czech Republic. This open-air museum consists of three main areas: The Wooden Town, the Wallachian Village and the Mill Valley, which has become the subject of interest in this research. The Wallachian Open-Air Museum is the largest and oldest open-air museum in Czech Republic. The Mill Valley area is unique, as the only of its kind in Czechia, representing the industrial buildings of rural lifestyle from the past centuries. It is an area of significant importance to the cultural heritage of the Silesian and the Moravian region.

Water utilization structures and other buildings located in this area have been relocated from several municipalities and are in very good condition. The objects of the mill and sawmill were chosen for the surveying - moved from the village of Velké Karlovice, the bell tower, the oil press and several stone sculptures also. To date, a small percentage of similar technical monuments have been preserved, which reflects the need not only for protection and support from the state, but also documentation and visualization for the general public and future generations.

Contactless methods were chosen for geometric capture of the position of selected objects, namely terrestrial laser scanning (TLS), SfM and, last but not least, aerial photogrammetry.

Due to the complex structure of the objects, the main part of the project is a point cloud, captured by the terrestrial laser scanning system Faro Focus 3D X330, consisting of 25 stations connected by reference spheres (complete connection and capture of the interior of the mill). Their application eases subsequent processing, in this case using semi-automated referencing in the environment of the Faro Scene product software. The detailed capture of the mill’s water wheel required the use of a compact Leica BLK 360 laser scanner. Steep terrain, cramped conditions and weight did not allow the use of the more robust Faro Focus3D X330 scanning system in this part. The application of two scanning systems did not impair the quality of the data obtained during the final processing.

Complementary methods, to the above-mentioned, were terrestrial and aerial photogrammetry, which ensured the capture of those parts where laser scanning did not reach (in our case a saddle roof of objects), but this disadvantage of the TLS method could be solved in the future using a higher tripod.

The shooting of the details of the object was performed using two Canon EOS 7D cameras (Canon EF-S 18-135mm lens) by taking 450 UHD images. The method was chosen due to the rapid variation of the position of the camera centre, which allows you to capture a lot of detail in a relatively short time. Despite these advantages, it is often considered a low-cost method, but it is a significant and effective tool in combination with TLS.

The method of aerial photogrammetry was used to capture the saddle roofs of objects, where other methods did not allow the acquisition of photographs or geometric shape and details [1]. Aerial shooting was performed using a Mavic Pro UAV. The achieved resolution of 1.4cm/pix on the area of 90m x 50m was stimulated by the low flight altitude - 40 m ATO. 100 images in UHD resolution were secured during the flight, which became the basis for the creation of DTM in the environment of the Reality Capture software.

By combining the method of laser scanning and photogrammetry, we obtained a comprehensive final model of the physical model, which was preceded by the use of a wide range of software.
Unification of heterogeneous measured data into a single homogeneous system is a key part of project realisation. (see Figure 1) [4].

![Figure 1. Combination of surveying methods used for obtaining 3D models](image)

The processed data from individual devices went through various degrees of generalization, conditioned by methodological procedures. The most important part of the project was the connection of heterogeneous data into a single system, which ensured the use of Reality Capture software. The strong point of this software is the work with a combination of data from laser scanning and photogrammetric data into a single integrated polygon network known as mesh model, on the principle of cloud to cloud connection [5].

During the processing, the models were corrected using reference points, which allowed to incorporate models from individual measurement methods into one homogeneous project and thus make a polygon model - mesh model. The geometric accuracy of the model was ensured by laser scanning, however on the other hand, the colouring and texturing were strengthened by terrestrial and aerial photogrammetry [6].

According to the size, the individual buildings and terrain models were exported separately and optimized in the ZBrush software (reduction of the triangles of the polygon network and smoothing of contours). The resulting models in such a format is a suitable resource for creating virtual experiences in augmented reality, which we will begin to encounter on a daily basis in the near future [2].

3. **Augmented reality in the world**

There are several software tools for developers on the market used for development of a mobile application with integrated support for augmented reality. Some of them come from small-scale developers, are based on university projects or are continuously being developed by renowned software companies that are established in the segment for long time. Godot, Unity and Unreal Engine are among the best known and most used. They are primarily developed for the gaming sector, but during their existence and software evolution they have found application in many other segments.

Unity software was chosen for the development of the application, which has well-integrated support for the use of plug-ins for the augmented reality in mobile devices. The ARCore plug-in, created by Google, works with tablets and smartphones running operating system Android 7.0 or higher. Apple Inc. similarly allows its devices to work with augmented reality applications through the
ARKit plug-in (running with operating system iOS 11 and higher). According to the statistical internet portal Statista.com, there were 3.6 billion active smartphones on the world market in 2020, of which almost 1 billion supported cooperation with AR applications (Figure 2).

A significant advantage of Unity is the ability to connect to the EasyAR Sense software tool. By the reason of the camera of the mobile device and the Time-of-flight (ToF) sensor, EasyAR can create a simple three-dimensional 3D map of the surfaces of the surrounding real-world objects.

Unity currently supports (May 2021) exports for 19 different platforms, including mobile, desktop and augmented reality web solutions.

We already had previous development experience with Unity, which simplified not only the decision to choose the main development tool, but also the entire process of creating an application.

![AR Compatibility of Smartphones](image-url)

**Figure 2.** Ratio of AR compatible devices in the world smartphone market, 2020 (source: statista.com)

4. **Simplified principle of application operation**

Casella summarized the theoretical key concepts and principles of AR systems in his research paper [7]. After the application is launched, the rear camera of the mobile device is activated. Systematically moving the device in the environment, user captures a part of the surroundings. The data recorded by the visual sensor of the camera system in combination with the data of the ToF sensor are processed by a computational algorithm. In this way, the application obtains information about the spatial distribution and shape of the surrounding objects, creates a three-dimensional map of surfaces, which is then covered with a virtual mesh (Figure 3). The application then creates planar zones on the surface of which it is possible to display generated models of augmented reality. The fundamental elements of any AR system are tracking, real-time rendering and visualisation technologies Barille stated in his research about integration of geomatics methodologies with AR systems in cultural heritage [8]. In our AR system the tracking of AR tags and planar zones is important in particular.
The developed application works on the principle of designing 3D models of augmented reality to a predefined position in space. We signal the place where we want to display the object with a unique code mark. When the application using the camera locates the given mark in space, the position and the orientation in space is calculated, the normal vector to the planar zone is determined and the corresponding 3D model is displayed above the mark, which is stored in the device's memory.

5. Application optimization

The operation of the application was tested on mobile devices using the Android 11 operating system. From the devices available on the market supporting augmented reality, we chose the Sony Xperia 1 smartphone and the Samsung Galaxy Tab S7+ tablet for testing. Both devices have a fast processor and a powerful graphics chip capable of displaying even more demanding 3D graphics models.

The Samsung Galaxy Tab S7+ generated augmented reality objects above the map faster. We accredit this to a more powerful processor and a newer graphics chip, thanks to which the device processes information registered by the camera system faster. The application recognized and identified individual AR tags in space the fastest when tested directly with a PC. Although the notebook's built-in camera only achieves the HD resolution (720p), its computing power helps the application to run faster, compared to mobile devices.

| Device name          | Type   | Operating system | Primary Camera                  | Processor       | GPU          | RAM  |
|----------------------|--------|------------------|---------------------------------|-----------------|--------------|------|
| Sony Xperia 1        | Smartphone | Android 11       | 12Mpix, F 1.6, 26mm (wide), 1/2.6" sensor | Snapdragon 855 Octa-core 2.8GHz | Adreno 640 | 6 GB |
| Samsung Galaxy Tab S7+ | Tablet     | Android 11       | 13Mpix, F 2.0, 26mm (wide), 1/3.4" sensor | Snapdragon 865 Octa-core 3.1GHz | Adreno 650 | 8 GB |

Table 1. Testing mobile devices, key hardware and software specifications

The original full-resolution 3D models processed in Reality Capture software have ranged from 9 to 30 million triangular polygons. After export, the size of one model exceeded 1 GB of data on disk. To reduce the volume of model data and applications, we decided to generalize the models. By smoothing the edges, we simplified the geometry of each object and reduced the number of polygons to around 500,000. The size of the models used in the application after export to the .obj format ranges
between 35-45 MB depending mostly on the shape of the model. All objects are covered with photorealistic textures in 8K resolution. If you need more significant data savings, it is possible to apply an even higher level of generalization to 3D models. However, below the limit of 50,000 polygons, a significant loss of details of their shape and texture was observed on photogrammetric models. Low-polygon models are suitable for applications with high count of 3D models stored in the application database [9].

The desire for 3D model generalization is also based on their application. VR application developed for computer manage to run smoothly high quality 3D models with millions of polygons. Portable devices relying on the processing power of mobile chips require implementantation of simplified 3D models so ensure the device manage to display and run the scene for augmented or mixed reality.

6. Objects localization in space
The mobile application works on the principle of recognizing the AR tag in space, identifying its shape and assigning a specific model for a given object from the database. For unambiguous and reliable identification of the AR mark, it is important to visually distinguish it from the environment. Markers are usually generated in a square shape, which helps the application determine its spatial orientation and tilt angle. They should contain contrasting colours (e.g. black and white) with clearly identifiable geometric shapes. It is advisable to generate unique QR codes for this purpose (Figure 4A).

Alphabetical tags are easy to read and recognize by a human brain, but the variety of marks is limited to count of symbols in alphabet. QR codes provide much larger set of unique combinations of figures, ranging from hundreds to thousands, depending on the size and density of used square grid.

In the case of a map, the possibility of using a map key is offered for this purpose (Figure 4D). For example, we can display a 3D model of a restaurant in augmented reality above all the map symbols for refreshments on the map. Else, we can use a contrast marker with the letter of the alphabet, which is easily located on the map and in its legend (Figures 4B, 4C). Objects on the map can also be located using map segments – the image section directly from part of the map or plan (Figure 4F).

When identifying map segments, selection of area with a high colour contrast ratio and unique shape is essential. In poor lighting conditions, the identification of map segments is considerably complicated. Therefore, we recommend using AR tags in the form of QR codes, if the purpose of the map allows their location on the cartographic work.
Figure 4. Visual-based AR markers examples. (A) QR Code, (B), (C) Alphabetical based tags, (D) Symbol based tag, (E) High-contrast chroma marker, (F) Visual marker based on map-segment recognition

Individual AR tags can be incorporated directly into the plan of the museum premises. After the code is read by the mobile application, a virtual 3D object is displayed on the surface of site map on an exact georeferenced position (Figure 5). Individual symbols can be placed next to the directional arrows in the area to improve spatial orientation of guests and to visualize the selected destination target. For virtual tourists, the museum can send an AR application via email directly to its remote visitors after purchasing e-ticket. After printing the map or separated AR tags, by visualization of museum tour plan on a digital display (e. g. TV) they become a virtual tourist. The museum complex will be viewed from the comfort of home with the help of augmented reality with the help of AR tags or the AR enhanced museum plan. Mobile devices provide the accessibility to the content from anywhere [10].

Figure 5. Georeferenced 3D models view on the map using marker-based augmented reality application on an area plan, Mill Valley, Wallachian Open-Air Museum, Rožnov, Czechia

7. Conclusion
Incorporating augmented reality brings many challenges but also benefits. This project also points to the statement. It was necessary to establish cooperation between the branches of structure surveying, information technology and the Heritage Institute in order to document and visually present selected objects of the open-air museum. Considering the size of the augmented reality mobile device market, AR represents an easy way to get the final product to the end customers - physical or virtual museum visitors. With the AR developed application the users can print the AR enhanced museum plan and start a virtual tour of the museum right at their home. The AR tags can be exported separately like “pexeso cards” as well. The users can position the AR tags around their current environment and create the virtual museum exhibition e. g. directly in their living room. The AR application is bringing the museum tour experience right to the users. Custom-built visual-based AR application runs on
Unity engine. Using EasyAR and ARCore plug-ins, Android mobile devices are becoming useful tools for implementing augmented reality. Although the AR applications find their utilization only for small tasks currently. But thanks to AR the small tasks can be shifted into a whole new dimension.

Acknowledgments
This work was supported by the Project for Specific University Research (SGS) No. SP2020/87 "Archiving of historical objects in Virtual Reality" from the Faculty of Mining and Geology of VSB – Technical University of Ostrava & Ministry of Education, Youth and Sports of the Czech Republic.

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