

doi:10.15199/48.2022.12.36

Visualization of bronze material structure in virtual reality

Abstract. This experimental study aims to design and apply procedures for visualizing a real object in a virtual reality environment. 3D reconstruction of the object by photogrammetry is the basis for further procedures of working with the 3D model. Attention is focused primarily on working with the bronze material and structure of the object. The experiment aims to achieve a high level of image quality in virtual reality. The text describes the characteristic properties of the material and structure, which is the subject of separate image processing in a digital 3D model. Furthermore, procedures for further processing the 3D model and modification of its attributes for export and import between the individual software used in this experiment are designed and applied. The 2D and 3D graphics methods are used for the final visual appearance of the object in virtual reality and tools for creating the original material of the real object.

Streszczenie. To eksperymentalne badanie ma na celu zaprojektowanie i zastosowanie procedur wizualizacji rzeczywistego obiektu w środowisku wirtualnej rzeczywistości. Rekonstrukcja obiektu 3D metodą fotogrametrii jest podstawą do dalszych procedur pracy z modelem 3D. Uwaga skupiona jest przede wszystkim na pracy z brązem i strukturą przedmiotu. Eksperyment ma na celu osiągnięcie wysokiego poziomu jakości obrazu w wirtualnej rzeczywistości. Tekst opisuje charakterystyczne właściwości materiału i struktury, która jest przedmiotem odrębnej obróbki obrazu w cyfrowym modelu 3D. Ponadto opracowano i zastosowano procedury dalszego przetwarzania modelu 3D i modyfikacji jego atrybutów w celu eksportu i importu pomiędzy poszczególnymi programami używanymi w tym eksperymencie. Metody graficzne 2D i 3D służą do ostatecznego wyglądu wizualnego obiektu w wirtualnej rzeczywistości oraz narzędzia do tworzenia oryginalnego materiału obiektu rzeczywistego. (**Wizualizacja struktury materiału z brązu w wirtualnej rzeczywistości**)

Keywords: virtual reality, 3D model, image processing, bronze material, photogrammetry
Słowa kluczowe: wizualizacja, rzeczywistość wirtualna, model 3D.

Introduction

Virtual reality (VR) technology is a progressive trend Today. Virtual reality is already widely used Today. [1, 2, 3] The gaming industry significantly influences the development and rapid rise of this technology. [4, 5] Today, this technology (VR) is affordable to the general public. Virtual reality is now being used and widely used in commercial fields. [6, 7, 8] Examples are virtual galleries, advertising industry, marketing, utility graphics, retail, architecture, design, or industry 4.0. [8, 9,] The real estate market uses virtual reality to present real estate. Today, a virtual visit to company premises or buildings is a standard part of the promotional strategy of companies and public institutions. However, virtual reality also finds its place in the field of science. Currently, efforts to apply this technology (VR) can also be found in many scientific fields. In social sciences, studies of human behavior in various simulated situations and their reactions to them can be found. In archeology, it is possible to create an environment of historical realities. [5] With the help of virtual reality, one can easily immerse oneself in the historical VR environment. The virtual environment can also be used in medicine to stimulate and train medical operations. [10, 11] Virtual reality technology is also used in agriculture, environmental sciences, and the agricultural industry. [12]

The issues of computer vision, computer graphics, 3D modelling, and image processing processes are also closely related to creating virtual reality and creating a virtual environment. [13, 14] VR environment can be entirely created using 2D / 3D graphics and animation software (SW). The virtual environment created in this way can be very close to displaying natural objects and the actual environment in one's life. However, these do not capture real-life processes, situations, scenes, or objects. In VR capturing a real space or object is currently possible almost immediately. Many interior and exterior scanning devices are available for this purpose. [15, 16] Many of these devices have tools for displaying a VR scene already during the shooting process of the scene. However, these tools do not address the issue of reproducing a real object in a VR environment. In particular, it is accurate to capture in three-dimensional space and the quality of reproduction of the

structure and material of the object. Various devices and procedures are used today to capture an object to transform the object into a virtual environment. Laser handheld 3D scanners are one of the ways to convert an object into a 3D digital form. However, these devices are costly. [15] The solution for the realization of a 3D digital model of a real object is the method of photogrammetry (SFM - *Structure From Motion*). [17] This method is called low-cost because it can use any camera. However, the disadvantage is the higher time required for image capture and processing.

The method of terrestrial image photogrammetry and its possibilities of use for digital 3D reconstruction of a real object has already been expressly described. [18, 19] The experiment described in this paper uses the acquired knowledge and follows up on the experiment of transforming an actual 3D model into a VR environment. The object is a bronze statue of a beast, which in the previous experiment was the object for 3D modelling by multi-image ground photogrammetry. [17, 20] This item is made of bronze, and the surface of the material complements the structure of walnut shells. The surface of the bronze statue is variable in terms of optical and physical properties. The statue's surface changes mainly due to the impact of light on the bronze surface of the statue.

This article aims to describe the work with the material and structure of the object in more detail. The purpose is a faithful reproduction of the material and structure of the subject [21] in the VR environment. The text describes the work with individual 3D models and their transformation into the VR environment. Furthermore, attention is focused on working with image data of the material and structure of the object and procedures for implementation in VR.

The material and structure of the object

The object for 3D reconstruction and subsequent transformation into a VR environment was a bronze statue of a beast, the author of which is the academic sculptor Michal Gabriel. [20] The first model of the sculpture was made of clay and then from plaster cast using a plaster, the so-called lost mold. With this casting method, the clay statue is destroyed, and the plaster mold as well. The plaster model of the sculpture remains. This model is used

to create a high-quality detachable silicone-laminate mold. A light and easy-to-store silicone-laminate model is cast from this mold, entirely replacing the plaster model. The mold is removed from this casting by a casting process. Then the individual parts of the sculpture are cast into the wax. The wax is formed into a disposable clay mold and cast into bronze. The individual bronze parts are welded, and the surface of the finished bronze statue is finished. The sculpture is finally made up of several connected parts. This text describes the process of pictorial material of the final form of the statue and its bronze form with a structure created by walnuts.

As mentioned above, the sculpture was modeled in 3D using ground multi-image photogrammetry. For this purpose, 200 photographs of the statue were taken and used. The statue was converted into a basic 3D model of *point clouds* and a *polygonal network*. Then the primary form of the object material texture was created. This procedure is shown in Figure 1. [17]

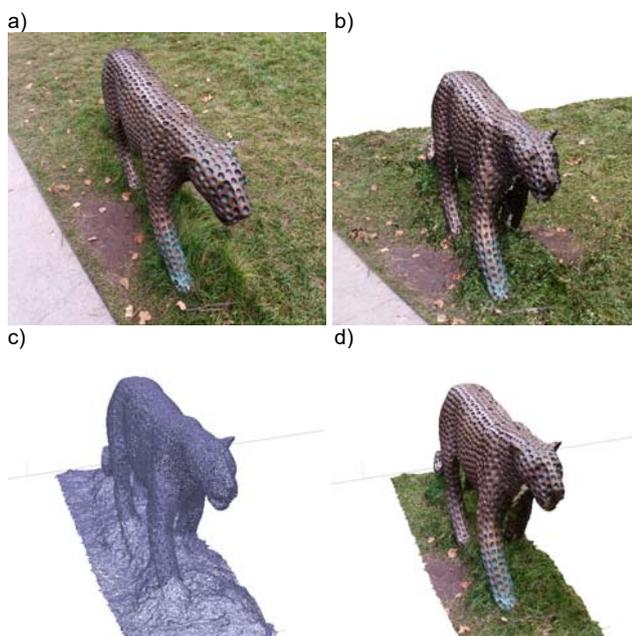


Fig. 1. a) Object photography for 3D modelling b) 3D model of the object in the form of a dense cloud c) Polygonal network 3D model Wireframe d) Basic texture of the 3D model

Figure 1 shows the basic reconstruction process of a real object into a 3D digital form. Figure 1a) shows an actual photograph of an object from a series of 200 photographs that were added for the modeling process. Figure 1b) basic 3D model of *Dense cloud*, from which the *polygonal network* was constructed and then the primary form of the texture of the object material, as shown in Figure 1c) and d). From these fundamental processes of image processing of the object into 3D form, other processes of the final output model can be created for the desired purpose of its use. The purpose of using the 3D model also defines other procedures that differ for individual outputs in further image processing of the reconstructed 3D model.

In this experiment, the goal is to reproduce a real object in a virtual reality environment. In particular, visualize the material and structure of the object in the VR environment in the required quality and the most accurate visualization in the virtual environment for users. The next chapter describes processing individual types of 3D models for the transfer and display of a real object in VR. Emphasis is placed mainly on the processing and visualization of the textural material of the bronze sculpture.

Creating a 3D model of an object and its texture

The resulting quality of the 3D model and its attributes affect, in particular, the procedures described in the previous chapter. That is the number of individual points in the *3D Dense cloud model*, from which a *polygonal network* is subsequently generated. For both of the mentioned 3D models, the elements can be supplemented or removed for a qualitatively better future visible result. Table 1 contains the essential attributes from which the future final visual model output of the reconstructed object and the representation of its material structure are derived.

Table 1. Basic attributes for creating a 3D model

BASIC POINT CLOUD	
Points	245,910
Point colors	3 bands/uint8
Key point limit	40,000
Key point limit per Mpx	1,000
Processing time	8 min. 23 sec.
DEPTH MAPS	
Count	200
Quality	Medium
Filtering mode	Disabled
DENSE CLOUD	
Points	9,852,929
Point colors	3 bands/uint8
Quality	Medium
Filtering mode	Disabled
Processing time	15 min. 41 sec.

Table 1 contains three steps based on using a series of 200 photos uploaded to the *Agisoft Metashape Professional* 3D modeling software. [22] A base *point cloud* was generated from a series of photographs. Each point in the cloud is a carrier of information about position, geometry, and color. A *3D model Dense cloud* is generated from this basic cloud, which already characterizes and specifies the object in the future 3D model.

The following Table 2 then lists the characteristics of the generated 3D models that need to be created for the required final output in virtual reality. The 3D model 1 *Wireframe* was subsequently duplicated and its attributes modified to create the 3D model 2 *Texture*, which generated and characterized the texture of the 3D model from the original images.

Table 2. Attributes of generated 3D models

3D MODEL 1 / WIREFRAME	
Faces	121,331
Vertices	61,113
Vertex colors	3 bands/uint8
Quality	Medium
Filtering mode	Disable
Max. neighbors	40
Source data	Dense cloud
Surface type	Arbitrary
Interpolation	Enable
3D MODEL 2 / TEXTURE	
Faces	100,000
Vertices	50,421
Texture	4,096 x 4,096 / 4 bands/ uint8
Quality	Medium
Mapping mode	Generic
Blanding mode	Mosaic
Texture size	4,096

Table 2 presents the attributes of the following two 3D models that need to be generated to apply the object and its structure to the VR environment. The *Wireframe model* consists of polygonal networks and is created as a fixed model by connecting and interconnecting points to form a *Dense cloud*. This 3D model must be duplicated. By modifying the attributes during the subsequent generation of the texture model, we obtain the desired result in the form of a texture model. The process of generating 3D models is summarized in the following graphic diagram, shown in Figure 2.

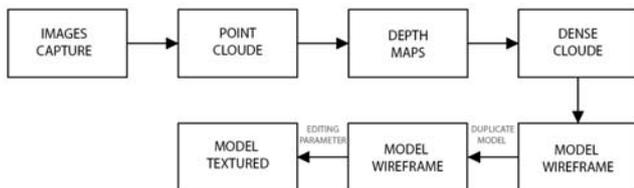


Fig.2. Process of creating 3D models to generate an object texture

The next step in transforming a real object into a virtual environment is the export of both created 3D models. In this step, the emphasis is mainly on exporting the created texture, which is the visual essence of the texture material transferred to the VR. Figure 3 shows the visual appearance of the exported 3D model types.

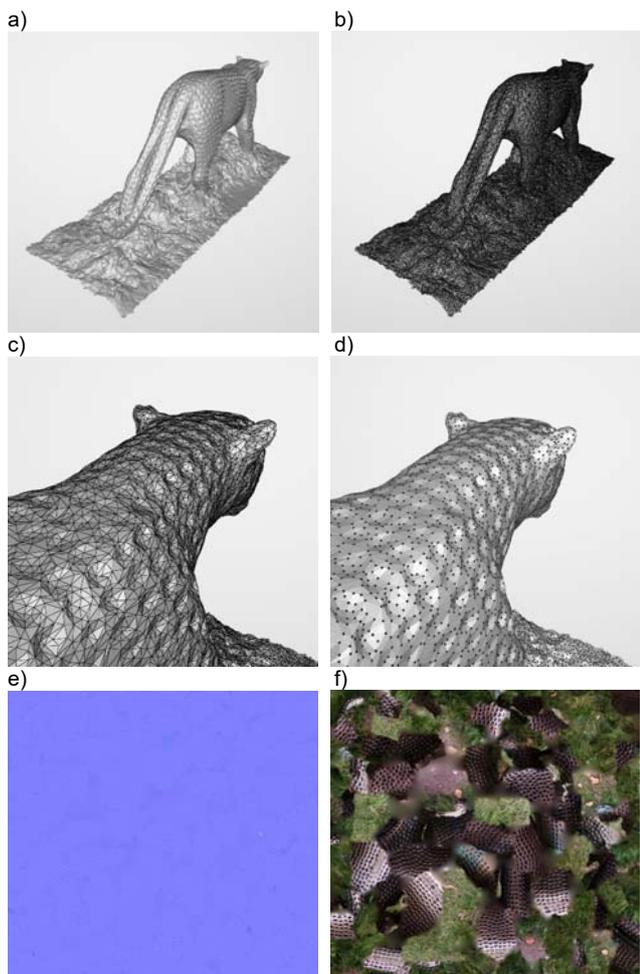


Fig.3. Export of 3D models for application to VR environment: a) solid 3D model generated on the basis of polygonal network and points b) 3D model Wireframe c) detail of 3D model Wireframe d) detail of 3D model in points e) component of exported texture for fixed 3D model f) exported texture component in color attributes for application to a solid 3D model

Although it is possible to export the texture model comprehensively, it is not suitable for application to the VR environment creation software used in this experiment. It was, therefore, necessary to create two independent 3D models. The *solid 3D model* reflects all the information in the individual points from which the model was generated. That model contains a *polygonal network*. The *textured 3D model* was exported in 2D form. This model is used to occlude the first 3D model. The textured form shown in Figures 3e) and f) thus visually complements the information contained in the 3D solid model. The properties of this model are shown in Figures 3a) -d). 3D models are ready for further procedures in the visualization of the reconstructed real object and its material structure in a virtual environment. This image processing process is the subject of the following chapter.

Application of 3D models in the VR environment

Unity software was used to visualize the bronze statue. [23] This SW makes it possible to create 3D environments and objects for subsequent virtualization. It is a freely available software with many tools and possibilities for commercial purposes.

This practical experiment aims to transform a real bronze object, including its material structure. Therefore, in the SW were models processed in the assets of *Model* and *Material* with the generated underlying 3D models. The object folder was defined as *Prefabs* for the use and visualization of a *3D solid model* (exported in .obj format) in individual visual forms. The generated 2D textures (in .jpg format) of the *3D texture model* were components in the SW as applied as a different material used for individual prefabricated parts. The difference in the application and processing of both generated 3D models visually is represented in Figure 4.

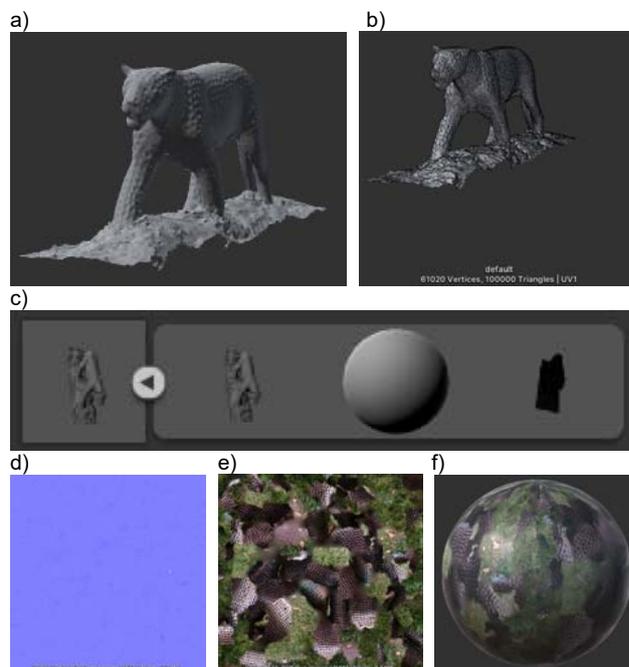


Fig.4. Process of processing 3D models in SW Unity: a) solid shadow 3D model b) Wireframe 3D model c) Content of 3D solid model components d) 2D component texture e) 2D component material f) assembly of components a) and e) in the form of material applied to 3D solid model

Figure 5 shows why it is necessary to primarily create two different 3D models for processing in the SW. The individual components of the created 3D model are

combined in the last step. Finally, a 3D model will be created to have a visual appearance of bronze material with a structure that has an authentic bronze statue. The image processing for the visual effect of the reconstructed object in VR and especially its material in *SW Unity* is shown in Figure 5.

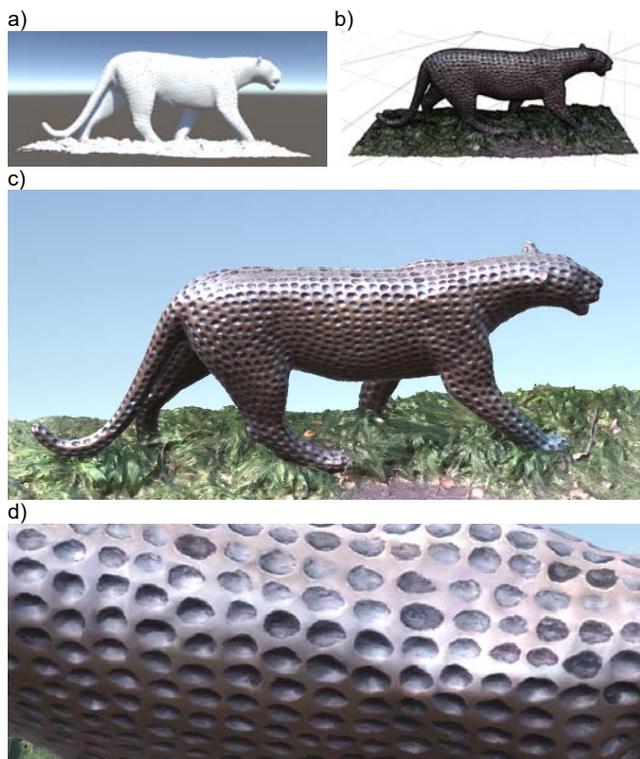


Fig.5. a) solid 3D model b) Wireframe 3D model with material texture c) representation of the 3D model with the texture in VR d) detail of material texture

Figures 5a) and b) show a solid model and a model with a material texture in a polygonal network. Figure 5c) shows the environment of the final visualization of the bronze sculpture material in VR. Figure 5d) shows a visual detail of the reconstructed fundamental material structure of the bronze statue in a virtual environment. The summary of the whole process of image processing and transformation of a real object into a VR environment is shown in Figure 6.

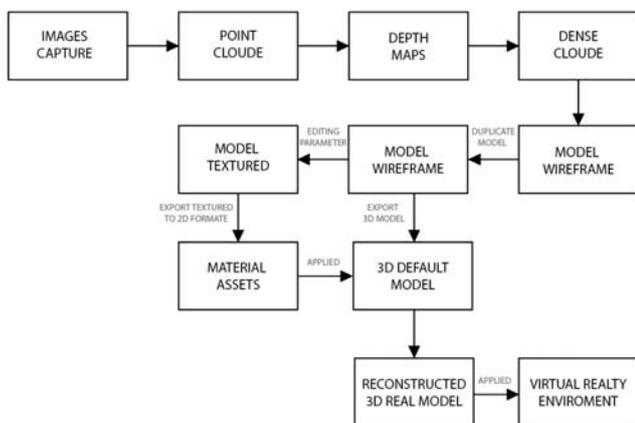


Fig.6. The process of image processing of the material structure of a 3D reconstructed bronze sculpture for application in a VR environment

The overall appearance of the material structure in VR can also be influenced by working with light in 3D modelling software. The only spotlight was used in this experiment. The process of working with light and other attributes can affect the shadow and gloss of the material according to the user's position nested in the virtual environment and connection with the background of the VR environment.

Conclusion

Virtual reality technology currently offers extensive possibilities across commercial and scientific fields. Today, VR technologies are fully used in education, training, and coaching. It is potentially may be used in material properties simulation in many fields. The gaming industry is of great importance for the availability and rapid development of VR. There have also been incredible speeds and the dynamic development of digital technologies, the image processing process, computer vision, and computer graphics. In particular, the quality of image information transmission is now at a very high level. High-quality scanning devices, software for image processing, and the possibility of transforming data into VR environments are available to the general public today. This data display technology thus offers many challenges in scientific disciplines, especially in the field of transformation of the natural environment or objects to transfer the image data captured from the real object, including its material structure, as faithfully as possible. That topic had the subject and goal of this experiment which attention was focused on the material of a bronze structured object. That aim was the image processing of the material to display in the VR environment as close as possible to the original sculpture, which became the subject of 3D reconstruction.

This experiment is a follow-up to the previous work dealing with the reconstruction of a bronze object into a 3D model using the method of photogrammetry (SFM - *Structure From Motion*). In the case of multi-image ground photogrammetry, which was used in the experiment, it is a low-cost method for the 3D reconstruction of the object. This experiment was based on the results of a 3D reconstruction of a bronze statue. The goals and the use of the 3D model of the reconstructed object, another way of processing the attributes of the image 3D models, then takes place. This experiment concerns the work with the bronze structure of the building and the aim of faithful reproduction in the VR environment. The bronze material with a walnut structure exhibits optical and physical properties, which presuppose a higher degree of complexity in processing image data of the material.

To apply and display the 3D model, including its original structure, it was necessary to create two 3D models. The first 3D model was created from the basic Wireframe model. It contains a polygonal network that connects the created point cloud into a solid 3D model. These were contained in the clouds points as information carriers about their location. Especially about the color and texture of the object. However, it was impossible to immediately apply the texture model to software designed to create a VR environment. The reason is the processing of the image component. Therefore, the image data of object material texture had to be processed separately. Therefore, the primary 3D model was duplicated, and then a custom 3D texture model was created from this model, as shown in Figure 6. This point proved crucial and critical in the whole image processing of the fundamental object structure in this experiment. Table 2 shows the different attribute values of the two models. These are mainly the attributes of Faces and Vertices, which define the properties of the polygonal network. As

can be seen from Table 2, the Wireframe 3D model contains 121,333 Faces and 61,113 Vertices. These attributes are defined at a lower value for a texture model generated from a duplicate 3D Wireframe model. The 3D texture model contains 100,000 faces and 61,113 vertices. Modifying the attributes was crucial for the generation and further steps of processing the image data of textures and their export to other graphics software to apply this created object model in the VR environment. Another essential element in processing the material structure image was the need to work with a 3D model exported in a 2D image. The structure was exported in two components, shown in Figures 4d) and e). It was necessary to create these different materials in SW Unity for the 3D application from two components. The material component thus created was applied to the primary 3D model. The final processing of material quality and structure for visualization in a VR environment is shown in Figures 5c) and d).

In conclusion, it can be concluded that the image processing of authentic materials and structures and their application to the VR environment offers a wide range of uses and applications across disciplines. The overall final appearance of structural materials and structure in the VR environment can be influenced by the work processing with light and shadows in connection with the observer embedded in the VR and thus create an authentic environment for the remote user. The use is offered, for example, in the virtual presentation of artwork. This is represented by the object selected for reconstruction. Using tools for applying physical phenomena in VR, we can work virtually with the material and its properties. It is possible to deform and reshape it in interaction with the user. That offers the possibility of use to simulate the deformation of materials under the laws of physics. Therefore, we can anticipate the rapid future development of VR technologies, their tools, and, in particular, their use across fields of human activity.

This research was based on the support of the International Grand Agency of Tomas Bata University in Zlin, IGA/CebiaTech/2022/004, and the Department of Security Engineering, Faculty of Applied Informatics, and of the author of the artwork, Prof. Michal Gabriel.

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REFERENCES

- [1] Samiei, S., Rasti, P., Daniel, H., Belin, E., Richard, P., Rousseau, D., Toward a Computer Vision Perspective on the Visual Impact of Vegetation in Symmetries of Urban Environments, *Symmetry*, 10 (2018), 666, doi:10.3390/sym10120666
- [2] Buyego, P., Katwesigye, E., Kebirungi, G., Nsubuga, M., Nakyejwe, S., Cruz, P., McCarthy, M.C., Hurt, D., Kambugu, A., Arinaitwe, J.W., Ssekabira, U., Jjingo, D., Feasibility of virtual reality based training for optimising COVID-19 case handling in Uganda, *BMC Medical Education*, 22. (2022) doi:10.1186/s12909-022-03294-x
- [3] Nėmec M., Fasuga, R., Trubač, J., Kratochvíl, J., Using virtual reality in education, *15th International Conference on Emerging eLearning Technologies and Applications (ICETA)*, (2017), pp. 1-6, doi: 10.1109/ICETA.2017.8102514
- [4] Reer, F., Wehden, L. O., Janzik, R., Tang, W.Y., Quandt, T., Virtual reality technology and game enjoyment: The contributions of natural mapping and need satisfaction, *Computers in Human Behavior*, 132 (2022), 107242, doi:10.1016/j.chb.2022.107242
- [5] Kargas, A., Loumos, G., Mamakou, I., Varoutas, D., Digital Routes in Greek History's Paths. *Heritage*, 5 (2022), 742–755.. doi:10.3390/heritage5020041
- [6] Wu, D.-Y., Lin, J.-H.T., Bowman, N.D., Watching VR advertising together: How 3D animated agents influence audience responses and enjoyment to VR advertising, *Computers in Human Behavior*, 133 (2022), 107255, doi:10.1016/j.chb.2022.107255
- [7] Gonçalves, A.R., Dorsch, L.L.P., Figueiredo, M., Digital Tourism: An Alternative View on Cultural Intangible Heritage and Sustainability in Tavira, Portugal, *Sustainability*, 14 (2022), 2912.. doi:10.3390/su14052912
- [8] Kristofferson, K., Daniels, M.E., Morales, A.C., Using virtual reality to increase charitable donations, *Marketing Letters*, 33 (2022), 75–87. doi:10.1007/s11002-021-09601-8
- [9] Hilken, T., Chylinski, M., Keeling, D.I., Heller, J., Ruyter, K., Mahr, D., 2022. How to strategically choose or combine augmented and virtual reality for improved online experiential retailing, *Psychology & Marketing*, 39 (2022), 495–507. doi:10.1002/mar.21600
- [10] Behmadi, S., Asadi, F., Ershad, S. R., Virtual reality-based medical education versus lecture-based method in teaching start triage lessons in emergency medical students: Virtual reality in medical education, *Journal of Advances in Medical Education & Professionalism*, 10 (2022), 48-53, doi: 10.30476/JAMP.2021.89269.1370
- [11] Allgaier, M., Chheang, V., Saalfeld, P., Apilla, V., Huber, T., Huettl, F., Neyazi, B., Sandalcioğlu, I.E., Hansen, C., Preim, B., Saalfeld, S., A comparison of input devices for precise interaction tasks in VR-based surgical planning and training, *Computers in Biology and Medicine*, 145 (2022), 105429.. doi:10.1016/j.compbiomed.2022.105429
- [12] Klaas, E., Roopaei, M., Immersive Analytics Application in Smart Agriculture and Animal Behavior, *IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC)*, (2021), pp. 0290-0296, doi: 10.1109/CCWC51732.2021.9375943
- [13] Poczekajlo P., Suszynski R., Ortogonalna realizacja potokowego filtru Laplace'a do przetwarzania obrazów medycznych 2D, *Przegląd Elektrotechniczny*, ISSN 0033-2097, 96 (2020) nr. 9, 80-84, doi: doi:10.15199/48.2020.09.17
- [14] Selivanova K. G. , Avrunin O. G., Tymkychovych M. Y., Manhora T. V., Bezverkhyy O. S., Omiotek T. V., Kalizhanova A., Kobzakova A., 3D visualization of human body internal structures surface during stereo-endoscopic operations using computer vision techniques, *Przegląd Elektrotechniczny*, ISSN 0033-2097, 97 (2021) nr. 9, 30-33, doi:10.15199/48.2021.09.06
- [15] Gefos ČR Leica BLK360, (2022), [online], <https://www.gefos-leica.cz/o-produktech/3d-laserove-skenovani/3d-laserove-skenery/blk360>
- [16] Insta 360 Pro, (2022), [online], <https://www.insta360.com/product/insta360-pro/>
- [17] Drofova I., Adamek A., Analysis of the structure material of the bronze object in 3D models point cloud, *Przegląd Elektrotechniczny*, ISSN 0033-2097, 98 (2022) nr. 3, 97-101, doi: 10.15199/48.2022.03.22
- [18] Middleton, W., Shu, Q., Ludwig, F., Representing living architecture through skeleton reconstruction from point clouds, *Scientific Reports*, 12. (2022) doi:10.1038/s41598-022-05194-y
- [19] Alfio, V.S., Costantino, D., Pepe, M., Restuccia Garofalo, A., A Geomatics Approach in Scan to FEM Process Applied to Cultural Heritage Structure: The Case Study of the "Colossus of Barletta", *Remote Sensing*, 14 (2022), 664. doi:10.3390/rs14030664
- [20] Gabriel M., Smečka (2010), <http://www.michal-gabriel.cz/smecka-pred-divadlem-v-trutnove/>
- [21] Pranjić, I., Deluka-Tibljaš, A., Pavement Texture–Friction Relationship Establishment via Image Analysis Methods. *Materials*, 15 (2022), 846. doi:10.3390/ma15030846
- [22] Agisoft, [online], (2022), <https://www.agisoft.com/features/professional-edition>
- [23] Unity, [online], (2022), <https://unity.com/>