



# Photogrammetry in a Virtual Environment

Jakub Kaščák<sup>1</sup>  , Marek Kočiško<sup>1</sup> , Rebeka Tauberová<sup>2</sup> , Stella Hrehová<sup>2</sup> ,  
and Justyna Trojanowska<sup>3</sup> 

<sup>1</sup> Faculty of Manufacturing Technologies with a Seat in Prešov, Department of Computer-Aided Manufacturing Technologies, Technical University of Košice, Štúrova 31/A, 080 01 Prešov, Slovak Republic

{jakub.kascak,marek.kocisko}@tuke.sk

<sup>2</sup> Faculty of Manufacturing Technologies with a Seat in Prešov, Department of Industrial Engineering and Informatics, Technical University of Košice, Bayerova 1, 080 01 Prešov, Slovak Republic

{rebeka.tauberova, stella.hrehova}@tuke.sk

<sup>3</sup> Faculty of Mechanical Engineering, Department of Production Engineering, Poznan University of Technology, Piotrowo Street 3, 61-138 Poznan, Poland

justyna.trojanowska@put.poznan.pl

**Abstract.** The use of photogrammetry is currently considered one of the most time-efficient ways of digitizing objects, the preparation of which does not require a high level of accuracy. It is generally known that the digitization of objects is demanding in terms of hardware and software, and it also requires a certain amount of skills and knowledge of this technology. Therefore, the use of photogrammetry in virtual environments makes the entire process significantly more efficient because it facilitates the process of digitizing physical objects from a digital model. This is achieved by the creation of an object, such as a classroom, that was used in this case by taking the photographs required during the scanning process to capture all the characteristics of the object. These images are combined to create a 3D model of the object that can be used in various software. A large number of special software can process point clouds and greatly simplify the reconstruction of objects. In this case, Rhinoceros software and its other extensions are used. Their combination enables the reconstruction of this data on an arbitrary scale using a VR headset.

**Keywords:** Virtual Reality · Reverse Engineering · CAD Modeling · Virtual Room · Education · Photogrammetry

## 1 Introduction

Virtual environment or interactive education in a virtual environment was a relatively significant trend due to the events of the past years. Since some parts of educational processes follow this trend and enrich it with new possibilities, even nowadays we quite often encounter the so-called virtual rooms. The presented article responds to this trend

and presents the possibilities of digitizing objects, or digitalization of large-scale objects like a whole classroom or laboratory, and the creation of a virtual twin in which several users can participate in the educational process or other types of courses. In the first phase, elements of reverse engineering were implemented in the virtual reality (VR) environment to streamline the process necessary for the digitization of objects, in this case, the entire room. The purpose of this initiative was to create the so-called virtual laboratory, i.e. a virtual space that can serve as a tool used for distance education. For this purpose, a series of software and hardware solutions were used, which are part of the equipment of the faculty and are currently becoming relatively available and widespread in the commercial area as well.

### 1.1 Photogrammetry and Its Current State

Photogrammetry is a process of taking precise images of an object or scene from many different angles. Photogrammetry is widely used in a variety of industries, such as automotive manufacturing and product development. The data can be collected from both real objects and from models or prototypes manufactured using rapid prototyping technologies [1]. The data can then be used to create a 3D model of the object that can be analyzed and optimized for various purposes. Image-based modelling has emerged as a popular technique for generating 3D digital representations of objects or scenes. It typically involves collecting images of the object or scene from different viewpoints and then using computer algorithms to merge the multiple images to form a complete 3D model [2]. An example of this process can be seen in Fig. 1.



Fig. 1. Demonstration of digitization of interiors and objects [2]

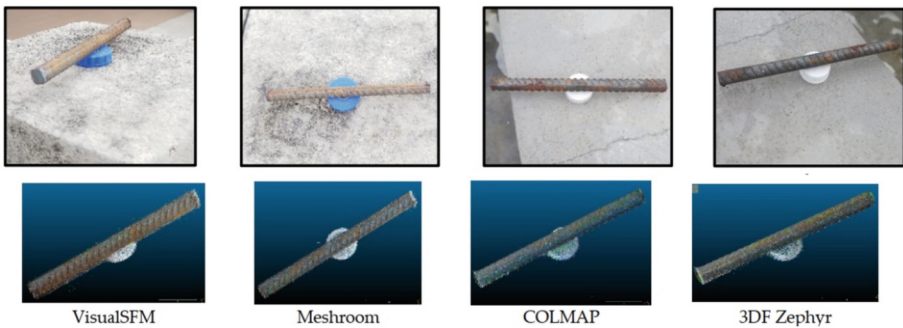
Using this method, it is possible to create a highly accurate representation of the object or scene. However, it is also a computationally intensive process and requires a large amount of processing power to perform image merging accurately [3]. Currently, the use of Unmanned aerial vehicles (UAVs) in the field of reverse engineering is a fairly big trend. Especially when it comes to the digitization of exteriors and historical monuments. The use of devices such as lidar, or various types of videogrammetry and photogrammetry

is currently on the rise. On the following Table 1 we can see selected types of available software, which are used for the aforementioned video or photogrammetry purposes.

**Table 1.** General information on photogrammetry tools and techniques [3].

S No	Name	Developer	Mode of Operation	Free/Paid
1.	Python Photogrammetry Toolbox	Pierre Moulon, Alessandro Bezz/ Code provided by steve-vincent (GitHub)	Aerial, Close-Range	Free
2.	3DF Zephyr	3DFlow	Aerial, Close-Range	Free/Paid (Paid for more than 50 images)
3.	WebODM	OpenDroneMap	Aerial	Paid
4.	Agisoft Metashape	Agisoft LLC.	Aerial, Close-Range	Paid
5.	RealityCapture	Capturing Reality/ Epic Games	Aerial, Close-Range	Paid
6.	ReCap Pro	Autodesk	Aerial, Close-Range	Paid (provides free educational license)
7.	PhotoModeler	Eos Systems Inc.	Aerial, Close-Range	Paid
8.	SOCET GXP	BAE Systems	Aerial, Satellite	Paid

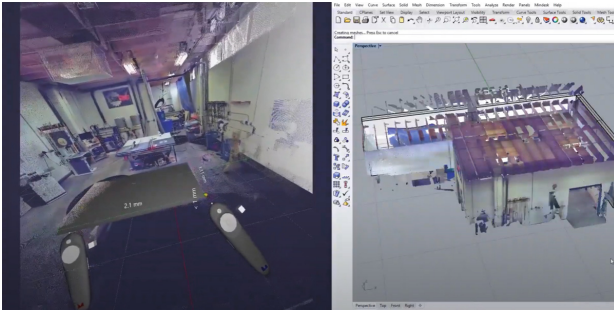
As mentioned in the publication “Evaluation of Photogrammetry Tools following Progress Detection of Rebar towards Sustainable Construction Processes” by A.H. Qureshi, 2022, not all available photogrammetry software achieves the expected results. For this purpose, several types of available software were selected from Table 1, and a series of measurements and data processing was subsequently performed. For this purpose, a model was used, which can be seen in Fig. 3. The image also shows the result in the form of a processed point cloud, which is usable in the next process [3].



**Fig. 2.** The level of data processing from photogrammetry with different software [3]

Based on the results of the aforementioned analyzes and the rate of data processing, the 3DF Zephyr software was chosen for this article. In the area of data processing, intuitive software control, and the ability to supplement details with additional photos, it demonstrated superior and user-friendly properties [5].

The next step in this process is to digitize the input data in another series of software. For this purpose, based on the previous experiences mentioned in the publications “Virtual reality and its possible integration into the process of distance learning focused on technically oriented subjects” E. Franas, 2021, we can build on the already existing solution implemented using Rhinoceros and Mindesk software.



**Fig. 3.** The user interface of the Mindesk (Rhinoceros) software in a virtual environment [4]

As the presented publication states, the use of such a software solution allows us several solutions. The first is importing the required data formats [5]. Working with a cloud of points, creating planes, and surfaces, or working with a mesh is characteristic of this kind of software. In the second phase, it is necessary to state that this process takes place thanks to the Mindesk plugin simultaneously in CAD, and also a VR environment. By simply changing the input devices respectively keyboard and mouse for a VR Headset, the user can participate in a specific solution on a real scale and with full VR support. The third phase is the possibility to interactively intervene in this process through standard input devices and thus increase the degree of achieved accuracy of the reconstructed models, as well as the degree of interactivity in the VR environment [6]. The software enables the use of the so-called multiuser platform that allows the participation of several users in solving one problem [7]. This solution enables interventions in the reconstruction process of other “invited” users, which are displayed in real-time on the output device of all participating users.

## 2 Methodology

Considering the information presented in the previous chapter, which is related to the choice of an effective software solution and the justification of the choice, we can describe the methodology of the solution procedure in the following points:

- Creation of photo- documentation of individual parts of the VR classroom.
- Importing the obtained photos into the photometric software and creating a series of files containing information about the so-called point clouds.
- Importing the acquired data into Rhinoceros software and subsequent reconstruction of objects in the VR environment of one of his plugins called Mindesk.

- Reconstruction of partial scans of the classroom and their subsequent connection into one unit.
- Use of the Mindesk software interface, which allows connecting more users to the virtual environment.
- Creation of a virtual clone of the laboratory, also suitable for a virtual form of education.

As can be seen from the previous information, it is expected that such a solution will ultimately enable more than just the reconstruction of objects within the VR environment [9]. Due to the already mentioned interactivity of the environment with several users, in the case of reconstruction of objects, manipulation of virtual models, and full interactivity of the virtual environment, there is an opportunity to create and use a fully interactive VR room [10]. The use of such an environment in combination with available VR equipment can have a relatively large impact on further increasing the level of distance education.

## 2.1 Data Collection

The quality, level of processing, and accuracy achieved during data collection are practically the most important part of the entire process in this regard. Making a sufficient amount of photo documentation that captures as many details and views as possible is a key factor in this case [11].

In the first phase, the classroom as a whole was photographed using a 360° camera of the Fly 360 type, (Fig. 4b). The images from this process were subsequently supplemented with photo documentation created by the Canon EOS 2000D device, (Fig. 4c). For the digitization of objects in the virtual environment, the HTC Vive Pro 2 device was used in the final phase, which can be seen in Fig. 4a.



**Fig. 4.** Devices used (a- HTC Vive Pro2, b- Fly 360 camera, c- Canon EOS 2000D) [12]

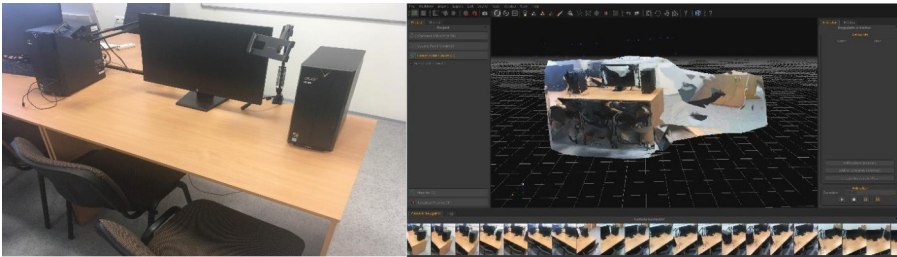
The collection of data for the digitization of the model was quite simple. It consisted in placing the 360° camera in a suitable place to create a panoramic image that can capture the largest possible area of the digitized space. [13] Subsequently, these panoramic images were supplemented with detailed images created by a DSLR camera. All this collected data is imported into the Zephyr software.

As already mentioned, digitization using photogrammetry is undemanding in terms of the skill requirements of the implementer [14]. Compared to other equipment for digitization, which often requires e.g. treatment of glossy surfaces, use of position marks or other manual skills, using the camera is a relatively simple matter [15]. The negative side of this process is the relatively low geometric accuracy of digitized objects, as we can see in Fig. 2. However, this was trivial in the case of digitizing the room and not the functional components.

## 2.2 The Process of Creating a Virtual Room

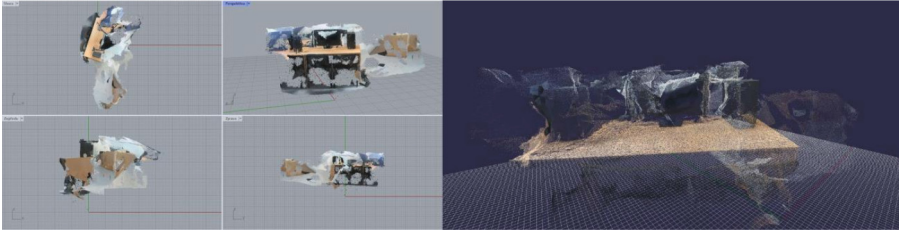
After the successful creation of a cloud of points in the specialized software, this data was processed in the programs Rhinoceros and its Mindesk plugin. The Rhinoceros software and its plugins fulfil 3 basic conditions that are necessary for the successful creation of a functional version of the digital model.

First of all, as we can see in Fig. 5, Rhinoceros software allows importing and working with point clouds. This type of data is essential for the reconstruction of digitized objects. In Fig. 5 we can see the addition of data to the panoramic image, respectively photos that the comprehensive shot could not capture. This data is later added to the process and thus allows for capturing digitized objects with a higher degree of detail.



**Fig. 5.** Preview of the first part of the digitized classroom

The second important part is its plugin called Mindesk. This enables the import of this data into a virtual environment and the modification of CAD functions to suit the specific type of reconstructed parts. Using the HTC VIVE device and its full compatibility with the used software, it is possible for the user to fully immerse himself in the virtual space and work on the reconstruction on a 1:1 scale. The view of the user in VR and the palette and the reconstruction of simpler parts can be seen in Fig. 6.



**Fig. 6.** Point cloud import into the CAD and VR part of the software

### 3 Results

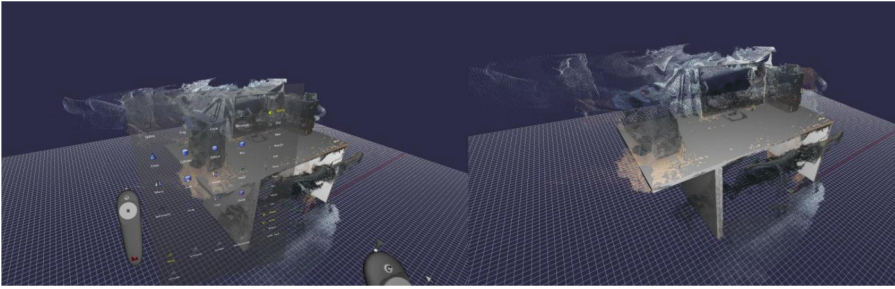
As c seen in Fig. 7, the drivers allow both a preview of the interface of the Grasshopper plugin functions, the use of the basic palette of CAD tools, and self-created functions that facilitate work in solving specific problems.

All these mentioned functions and the use of a VR headset require a certain amount of manual skills. Even after they were achieved, there were shortcomings and inaccuracies during modeling in CAD environment, which correlate with the already mentioned geometric deviations caused by digitization through photogrammetry.



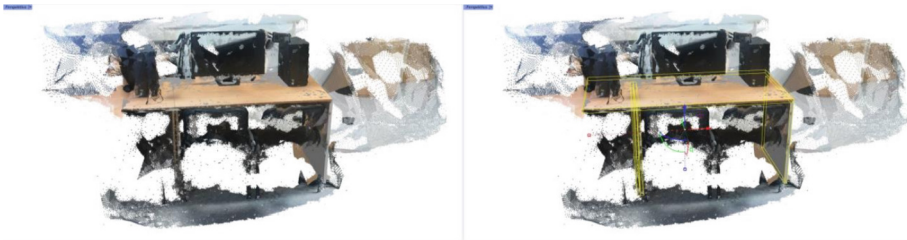
**Fig. 7.** Demonstration of editing the optimized tool palette

In Fig. 8, we can observe the work performed by the user in the VR environment in real-time and edit the CAD functions used by him to make the reconstruction process as efficient as possible. As we can see Fig. 8 also captures a preview of the tool palette that is available to the user in a virtual environment. This palette contains the basic CAD functions of Rhinoceros software. Its advantage is the possibility of modification, addition, or removal of functions due to the nature of the work performed by the user. Another advantage is full access to the Grasshopper plugin, also supported in the VR environment. This subsequently enables the creation of new functions, their combination, or the use of other generative algorithms. They enable a significant streamlining of work, especially in an environment with repetitive tasks.



**Fig. 8.** Demonstration of work in a virtual environment

It must be emphasized that working with a VR device and in a VR environment is difficult, less accurate compared to other input devices, and requires a certain form of skills that the user must acquire during this process. After literally getting used to using an alternative type of equipment, the reconstruction process becomes intuitive and the work efficiency is relatively high. Despite the possibilities of using different types of scales for digital models, this process cannot be considered sufficiently accurate, even in the case of data obtained by technologies other than photogrammetry. In Fig. 9 we can see the gradual reconstruction of the object as it is displayed in the CAD interface of the software. A rendered model including textures is used for better orientation. All data in the VR and CAD environment are updated in real-time for all connected users.



**Fig. 9.** Display of the rendered model and reconstruction progress in the CAD environment

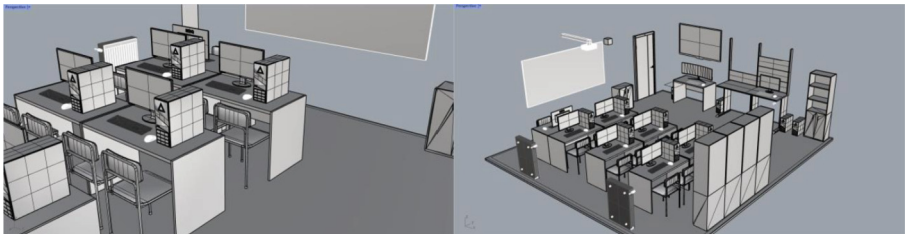
As already mentioned, renovations and getting used to the new control method take quite a lot of time in the initial stages [17]. More than once it is necessary to supplement the VR activity with individual steps in the CAD interface. After getting used to the new way of controlling, the first advantages of its use appear. The possibility of being “directly in the process” is invaluable, and the already-mentioned support by the plugin for generating 3D algorithms significantly simplify the process itself. Figure 9 shows us a partial reconstruction of the digitized object.

Regarding digitization as such, it is necessary to point out that all achievements of modern CAD modelling apply and work in the VR environment. Using constraints, capturing points, and working with surfaces are part of the functions that are fully available in this environment [18].

## 4 Conclusion

The overview article informatively describes the current state of software solutions and the possibilities of implementing elements of reverse engineering in a virtual environment. An illustrative example describes the procedure and possibilities for solving the problem of digitizing the laboratory room and points out other possibilities of such a digitized room as part of the educational process. Figure 10 represents the resulting model of a digitized room, which is the result of the reconstruction of digital objects in a virtual environment.

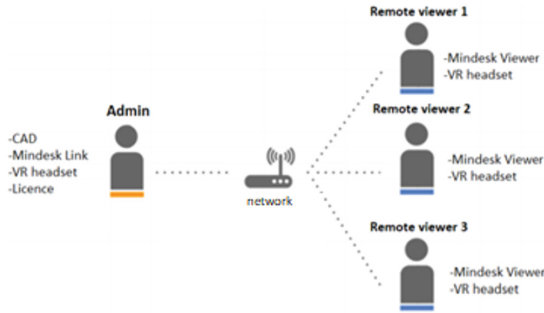
The article describes the process of digitizing models using photogrammetry and subsequent data processing in its entirety. It thus informs about the possibilities of working with this kind of hardware and software equipment, its advantages and disadvantages, and the subsequent possibilities of using this procedure also in the distance form of education.



**Fig. 10.** The resulting model after complete reconstruction

Considering the number of actions that accompanied the demonstration and were implemented in the VR, in the end, it is possible to draw several strong arguments that in the future can significantly influence the use of these technologies to improve specific parts of education. The first of them is the possibility of reconstruction of digitized objects in VR. It can have e.g. a great advantage with the Building Information Modeling (BIM) method. Placing the design implementer directly in the designed laboratory, robotic workplace, etc. can significantly affect the entire design. The second is the fact that, after the situations of previous years, the distance form of education has become an inseparable part in many aspects. Also, it is necessary to pay increased attention to this area and try to improve the quality of this form of education.

The third and not the last advantage is the use of the platform for connecting more users, schematically the principle of operation of this connection can be seen in Fig. 11. The creation of such a digital space within education and the use of available VR devices can contribute to a significant streamlining of the entire educational process. It is known from the preparation process that all objects placed in VR are fully interactive with all users. In the case of e.g., training in the field of machining processes thus provides an opportunity for detailed display and interaction with digital copies of machining centres without endangering the health or disrupting production processes.



**Fig. 11.** Schematic display of interaction between multiple users [16]

**Acknowledgements.** This work was supported by the projects VEGA 1/0268/22, KEGA 004TUKE-4/2022 granted by the Ministry of Education, Science, Research and Sport of the Slovak Republic.

## References

1. Li, Q., Huang, H., Yu, W., Jiang, S.: Optimized views photogrammetry: precision analysis and a large-scale case study in Qingdao. *IEEE J. Select. Top. Appl. Earth Observations Remote Sens.* **16**, 1144–1159 (2023)
2. Top 8 Best Photogrammetry Software. <https://manufactur3dmag.com/top-8-best-photogrammetry-software-free-paid/>. Accessed 28 Feb 2021
3. Qureshi, A.H., et al.: Evaluation of photogrammetry tools following progress detection of rebar towards sustainable construction processes. *Sustainability* **15**(1), 21 (2023)
4. Franas, E., Kočiško, M., Kaščák, J., Hlavatá, S., Vodilka, A.: Virtual reality and its possible integration into the process of distance learning focused on technically oriented subjects. In: *IOP Conference Series: Materials Science and Engineering*, vol. 1199, no. 1, p. 012028. IOP Publishing (2021)
5. Jasińska, A., Pyka, K., Pastucha, E., Midtiby, H.S.: A simple way to reduce 3D model deformation in smartphone photogrammetry. *Sensors* **23**(2), 728 (2023)
6. Buń, P., Trojanowska, J., Rewers, P.: VR and AR in lean manufacturing classes. In: Trojanowska, J., Ciszak, O., Machado, J.M., Pavlenko, I. (eds.) *MANUFACTURING 2019. LNME*, pp. 342–351. Springer, Cham (2019). [https://doi.org/10.1007/978-3-030-18715-6\\_29](https://doi.org/10.1007/978-3-030-18715-6_29)
7. Costa, R., Neves, J., Novais, P., Machado, J., Lima, L., Alberto, C.: Intelligent mixed reality for the creation of ambient assisted living. In: Neves, J., Santos, M.F., Machado, J.M. (eds.) *EPIA 2007. LNCS (LNAI)*, vol. 4874, pp. 323–331. Springer, Heidelberg (2007). [https://doi.org/10.1007/978-3-540-77002-2\\_27](https://doi.org/10.1007/978-3-540-77002-2_27)
8. Knapčíková, L., Husár, J., Behúňová, A., Hrehová, S.: Augmented reality as a tool of increasing of competitiveness of enterprise. In: Perakovic, D., Knapcikova, L. (eds.) *FABULOUS 2021. LNICSSITE*, vol. 382, pp. 337–349. Springer, Cham (2021). [https://doi.org/10.1007/978-3-030-78459-1\\_25](https://doi.org/10.1007/978-3-030-78459-1_25)
9. Esteves, M., Miranda, F., Machado, J., Abelha, A.: Mobile collaborative augmented reality and business intelligence: a system to support elderly people’s self-care. In: Rocha, Á., Adeli, H., Reis, L.P., Costanzo, S. (eds.) *WorldCIST’18 2018. AISC*, vol. 747, pp. 195–204. Springer, Cham (2018). [https://doi.org/10.1007/978-3-319-77700-9\\_20](https://doi.org/10.1007/978-3-319-77700-9_20)

10. Kaufmann, H.: Collaborative augmented reality in education. *Inst. Softw. Technol. Interact. Syst.* Vienna University of Technology, 2–4 (2003)
11. Lazár, I., Husár, J.: Validation of the serviceability of the manufacturing system using simulation. *J. Effi. Responsib. Educ. Sci.* **5**(4), 252–261 (2012)
12. Mota, J.M., Ruiz-Rube, I., Doderó, J.M., Molina, D.: Learning augmented reality in the classroom. In: *ICERI2017 Proceedings*, pp. 8579–8582 (2017)
13. Yusuf, Y.A.M., Ismail, I., Hamzah, W.M.A.F.W., Amin, M.A.M., M. Arsad, M.A.: A literature review on mobile augmented reality in education. In: Alareeni, B., Hamdan, A. (eds.) *Innovation of Businesses, and Digitalization during Covid-19 Pandemic. ICBT 2021. Lecture Notes in Networks and Systems*, vol. 488, pp. 875–888. Springer, Cham (2023). [https://doi.org/10.1007/978-3-031-08090-6\\_56](https://doi.org/10.1007/978-3-031-08090-6_56)
14. Schramm, L.T., Hariharan, A., Götz, T., Fegert, J., Schmidt, A.P.: Facilitating mixed reality public participation for modern construction projects: guiding project planners with a configurator. In: Wölfel, M., Bernhardt, J., Thiel, S. (eds.) *ArtsIT, Interactivity and Game Creation. ArtsIT 2021. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, vol. 422, pp. 275–291. Springer, Cham (2021). [https://doi.org/10.1007/978-3-030-95531-1\\_19](https://doi.org/10.1007/978-3-030-95531-1_19)
15. Ivanov, V., Pavlenko, I., Trojanowska, J., Zuban, Y., Samokhvalov, D., Bun, P.: Using the augmented reality for training engineering students. In: *4th International Conference of the Virtual and Augmented Reality in Education, VARE 2018*, pp. 57–64 (2018)
16. Husár, J., Knapčíková, L., Hrehová, S.: Augmented reality as a tool of increasing the efficiency of RFID technology. In: Perakovic, D., Knapcikova, L. (eds.) *FABULOUS 2021. LNICSSITE*, vol. 382, pp. 401–414. Springer, Cham (2021). [https://doi.org/10.1007/978-3-030-78459-1\\_30](https://doi.org/10.1007/978-3-030-78459-1_30)
17. Trojanowska, J., Kolinski, A., Galusik, D., Varela, M.L.R., Machado, J.: A methodology of improvement of manufacturing productivity through increasing operational efficiency of the production process. In: Hamrol, A., Ciszak, O., Legutko, S., Jurczyk, M. (eds.) *Advances in Manufacturing. LNME*, pp. 23–32. Springer, Cham (2018). [https://doi.org/10.1007/978-3-319-68619-6\\_3](https://doi.org/10.1007/978-3-319-68619-6_3)
18. Bower, M., Howe, C., McCredie, N., Robinson, A., Grover, D.: Augmented reality in education—cases, places and potentials. *Educ. Media Int.* **51**(1), 1–15 (2014)