3D Reconstruction of a Virtual Building Environment

Ihor Tytarenko[1], Ivan Pavlenko[2,3](✉), and Stella Hrehova[3]

[1] Beketov National University of Urban Economy in Kharkiv, 17, Marshal Bazhanov Street, O.M, Kharkiv 61002, Ukraine

[2] Sumy State University, 2, Rymskogo-Korsakova Street, Sumy 40007, Ukraine
i.pavlenko@cm.sumdu.edu.ua

[3] Technical University of Košice, 1, Bayerova Street, Prešov 080 01, Slovak Republic

Abstract. After years of the russian's military invasion of Ukraine, preserving the architectural heritage has become more critical. Moreover, the world's increased interest in the historical heritage of Eastern Europe countries prompts the scientific community to restore the building environment with an up-to-date computer quickly means for 3D modeling. Therefore, the research aims at the virtual reproduction of historical heritage objects with the extensive use of existing computational software. The research methodology includes collecting information from historical, archaeological, cartographic, and other sources. It was compared with archaeological and historical maps. Further superimposing of schemes with the related features on a working map was also realized. A detailed study of the object's current state for the case study of virtual 3D reconstruction was carried out based on the Google Maps services and Geographic Information System (GIS) mapping. Moreover, a relief for the studied territory was analyzed using available topography and geodetic data. As a result of the research methodology implementation, the relief model allowed the reproduction of the structure of architectural objects. This allowed creating the initial 3D model, designing its layout, and realizing the final texturing and rendering. The developed virtual model makes it possible to reproduce essential architectural, cultural, and historical heritage objects.

Keywords: Sustainable Land Management · Infrastructural Development · Smart Cities · 3D Reconstruction · Building Rendering · Sustainable Development

1 Introduction

The modern history of Eastern Europe has a very significant and rapid development of historical heritage research. The active national identification of Ukrainian people contributed to the greater activation of the scientific community in the fields of local history, archeology, and the improvement of historical authenticity [1].

European scientists use advanced computer technologies, especially 3D modeling, to achieve more effective results in scientific research [2]. However, Ukraine is just beginning to actively develop in using Building Information Model (BIM) technologies

V. Tonkonogyi et al. (Eds.): InterPartner 2023, LNME, pp. 105–114, 2024.
https://doi.org/10.1007/978-3-031-42778-7_10

based on scientific archaeological research with an implementation in actual projects [3].

Creating a modeling methodology to provide specialists with relevant knowledge to help research and popularize historical objects remains relevant. The result of the modeling will be a 3D model that can be used for future BIMs.

Therefore, the research aims to reproduce a historical heritage object using modern 3D technologies. The following objectives have been formulated to achieve this goal. Firstly, information collection should be realized to study historical, archaeological, cartographic, and other scientific sources. Secondly, analyzing archival, archeological, and historical maps will allow further plotting schemes on a working archaeological map, considering the main features.

Also, using Google Maps services and Geographic Information System (GIS) mapping [4] will allow a detailed study of the object's current state. Finally, research on territory relief using topography and geodetic data can be realized by laser scanning technology [5] and photogrammetry [6]. Overall, the result of analytical experiments is modeling, followed by creating a 3D model. It should make it possible to recreate Pontic Olbia as an object of Ukraine's cultural and historical heritage.

2 Literature Review

Due to a high level of up-to-date software means developments, many research works in creating 3D virtual building environments have rapidly increased recently. Particularly, Yue and Limao [7] mainly presented an integrated approach based on BIM and Artificial Intelligence (AI) for smart construction management. Doula et al. [8] studied the effect of the detailing level on city landmarks recognition in a virtual environment. Also, Chernyshev et al. [9] implemented digital administration of the project-based smart construction concept. As a result of introducing a life cycle management system for building objects using BIM was proposed.

Bevilacqua et al. [10] applied digital software to implement digital twins and virtual reality (VR) in the 3D reconstruction of architectural heritage objects. As a result, digital prototypes of interior spaces for the First Italian Parliament, the Charterhouse of Pisa in Calci, and the Cathedral of Carpi (Italy) were developed by applying modern VR software. Also, Lang et al. [11] reconstructed an extinct settlement using VR software for the Advent City (Norway) case based on a series of survived historical photographs.

Another successful experience in 3D virtual reconstruction using VR technologies was demonstrated by Shanthini et al. [12] in the case of recreating the ancient Poompuhar (India). Also, Croce et a. [13] developed a virtual model for reconstructing the Globe Theatre (United Kingdom).

The following research proposed entirely different approaches to the 3D reconstruction of virtual environments. Particularly, Ou [14] implemented digital reconstruction of a building environment. For this purpose, automated decision-making algorithms [15, 16], deep learning [17], and information management systems [18] can be applied. Moreover, Zhou et al. [19] researched key technology for the virtual restoration of ancient buildings. For this purpose, Convolutional Neural Networks [20] were applied. The obtained results allow for improving the quality of 3D virtual reconstruction of architectural and cultural heritage as a fundamental problem for sustainable development.

3 Research Methodology

The following methods have been used during the research (Fig. 1): observation (research and analysis of the territory for the studied object), analytics (data collection, use and analysis of archival, library, and cartographic sources), and 3D modeling (reproducing the research object in a virtual space using appropriate software).

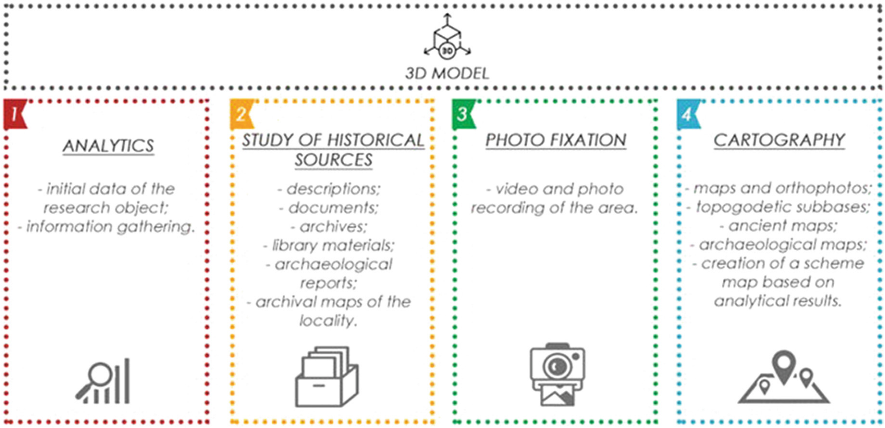

Fig. 1. Research methodology.

The first analytical stage includes collecting initial data on the research object and other necessary information. The second stage deals with the research of historical sources. It mainly provides analysis of descriptions, documents, archives, library materials, archaeological reports, s well as archival maps of the area.

The third stage is video and photo recording of the area. The following stage concerns cartography. It consists of research on modern maps and orthophotos, topogeodetic subbase, and ancient maps of different periods. It also includes the study of archaeological patterns of the area and the analysis and comparison of maps by combining them with different software. Creating a spatial map based on the research on geographic differences in heights (horizons) in the appropriate software is also an integral part of the fourth stage. It also includes creating a 3D model of several relief feature variants. All these activities are needed to reproduce the lost parts of the relief due to water corrosion of the plateau, analysis of the placement of known, studied by archaeologists, and recorded on the diagrams, quarters, and individual objects of the studied object. As a result, maps of the street grid location and city structure will be built based on the analytical results.

The final stage allows creating a 3D model of the object under study with all its elements. It is realized using the proposed stages (Fig. 2).

The following software can be used while modeling and further processing: SketchUp, Blender, and Autodesk 3ds Max – for modeling; Photoshop – to form a mapping scheme for building the structure of the city; 3DF Zephyr, RealityCapture, Agisoft Metashape, and Meshroom – to create photogrammetry; Quixel Megascan – for

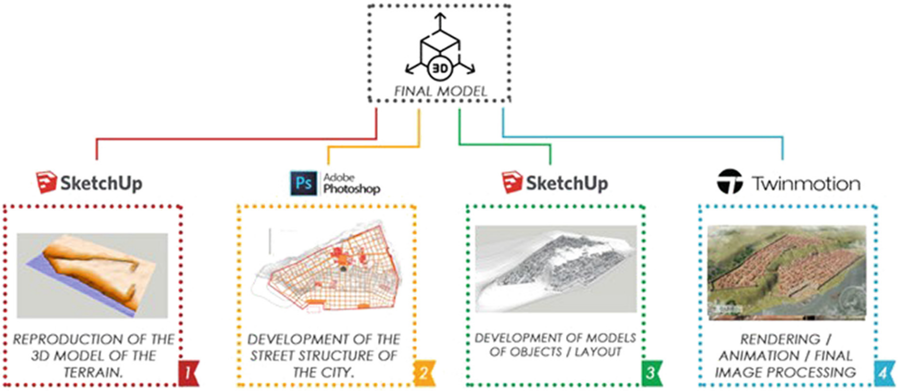

Fig. 2. Stages of 3D modeling.

using an available library of textures, models of photo scans; Twinmotion, Lumion – for rendering images and animations with library support Quixel.

4 Results and Discussion

The following computational means have been used to reproduce the 3D virtual model of the terrain. Firstly, the relief reproduction has been realized using the topogeodetic subbase data. Also, SketchUp has allowed for reproducing horizons and their heights to form a 3D model. After, the relief was reproduced using GIS data, Google Maps, and subsequent import to SketchUp.

As a result, the created relief model is presented in Fig. 3.

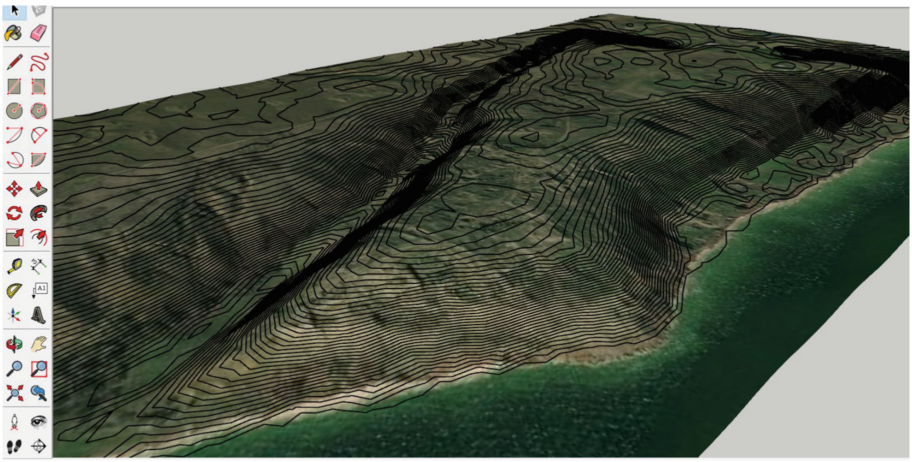

Fig. 3. The terrain model.

The development of the street structure of the city is as follows. Firstly, a mapping scheme has been formed using Photoshop software. On it, directions of the existing streets and exact locations of districts and other objects have been analyzed based on the archaeological data.

After, the mapping diagram of the researched object was superimposed on the created relief, forming the street and road network of the city. Thus, the placement of quarters in the structure of the 3D model has been revealed. Overall, the studied areas have been placed relative to the designed grid of streets.

The developed street structure of the city is shown in Fig. 4.

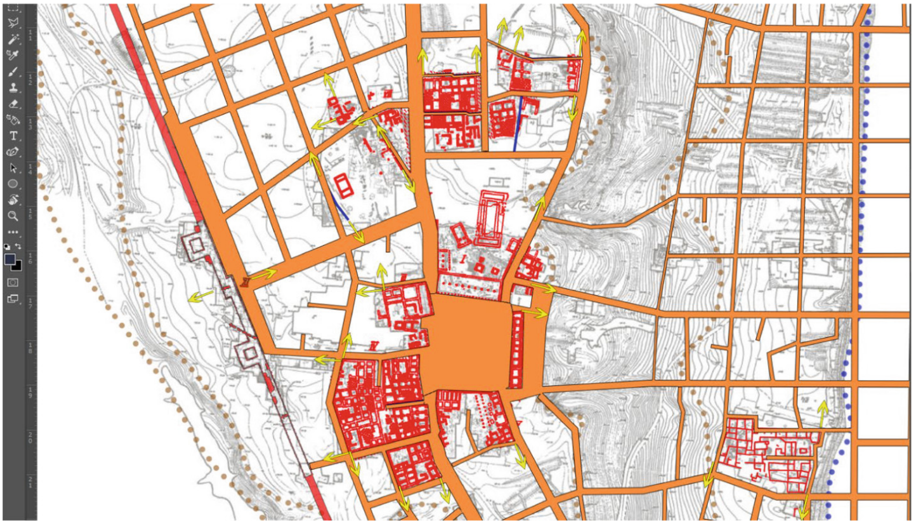

Fig. 4. Reproduction of the city structure.

The development of object models has been carried out as follows. Firstly, models of buildings and structures, defensive walls, and individual objects of the historic environment have been developed using the SketchUp software. After, a search for additional models has been realized. They should have an authentic look at the relevant era. The corresponding object library has also been created.

As a result, an initial 3D model has been built (Fig. 5).

The next stage deals with the 3D model layout. For this purpose, 3D objects have been placed according to the archaeological schemes and the created mapping scheme. As a result, a complete model of the city has been formed (Fig. 6).

The last stage includes rendering, animation, and final image processing. Firstly, a realistic virtual environment has been created using the Twinmotion software and Quixel Megascan library of materials. These computational means allow for further image and video rendering, considering constructional materials and historical environment features.

The rendering results have been processed and adjusted with Photoshop to create the final virtual model (Fig. 7).

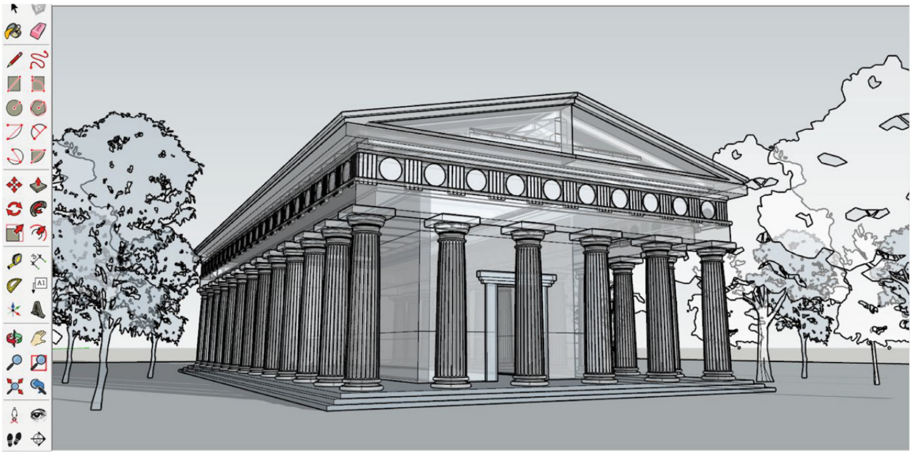

Fig. 5. The initial 3D model.

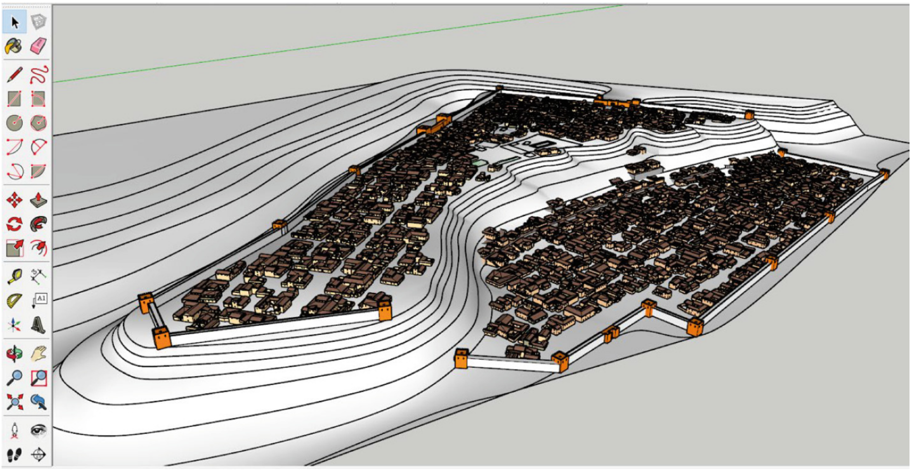

Fig. 6. Design layout of the model.

The developed 3D virtual model contains parts of the upper and lower city with quarters and streets, defense walls, river port, residential quarters, teminos, and central agora.

The obtained results are valuable for science, culture, and society. Particularly, the methodology of modeling the object under study can be applied to further work with the object at different stages. E.g., it can be supplemented by using BIM and CAD technologies for a promising reproduction or reconstruction of historical and architectural objects. Moreover, in today's realities, Ukraine is experiencing a growth of national identity. This encourages knowledge of own history, reconstruction, and research of partially lost objects of heritage. The proposed approach allows for enabling these processes.

Fig. 7. The final texturing and rendering.

The accuracy of the relief creation data can be improved using technologies of extended [21] and mixed reality [22], photogrammetry [23], or laser scanning [24] of a locality by the stereotopographic method as the most accurate but resource-consuming method of modeling and obtaining an information model. These tasks require applying the following software, e.g., Agisoft Metashape, Digitals, AutoCAD, and teleoperation by an unmanned aerial vehicle (UAV) [25, 26].

The proposed approach improves the results obtained by the previous study [3]. Also, architectural objects created based on archaeological research and foundation schemes can be imported into Revit [27] and extended using BIM technology and embedded vision equipment [28] to develop a comprehensive information model [29].

In the nearest future, it is also planned to investigate the following historical objects: the Konotop fortress of the period of 1659, the ancient Vorgol settlement in the Sumy region, the settlement Zelenyi Hai near Sumy, and other objects of architectural and historical heritage, as well as create their 3D virtual models of these objects using the developed methodology.

5 Conclusions

As a result of the research, a methodology of 3D virtual reconstruction for the building environment was proposed based on the comprehensive analysis of historical, archaeological, cartographic, and scientific sources.

A detailed study of the object's current state using the example of Pontic Olbia was carried out using Google Maps and GIS mapping services. Also, the study of the relief for the territory was carried out using topography and geodetic data. Laser scanning and photogrammetry technologies can also be applied to increase the accuracy of the obtained results.

Overall, the results of an analytical experiment are virtual modeling followed by creating a 3D model. It should make it possible to reconstruct the object of cultural and historical heritage.

As a result of implementing the proposed methodology, a 3D model of the architectural environment was created using this approach and close interaction with archaeological, historical, and cartographic materials. This model contains parts of the upper and lower city with quarters and streets, defense walls (Northern and Western Gates), river port, residential quarters of all available archaeological sites, Western and Eastern Temenos (Temples of Apollo Yatros, Apollo Dolphin, and Zeus), and Central Agora (Eastern Trade Row, Eastern and Western Stands, Dicasterium, and Gymnasium).

The model can be used in further experiments and its adjustment. Due to geodetic, topographical, and archaeological data, the areas of the model investigated by archaeologists can be considered as a historically grounded version of the 3D virtual reconstruction.

Acknowledgment. The research was partially realized within the Ulam NAWA Programme project BPN/ULM/2022/1/00042, ordered by the Polish National Agency for Academic Exchange. Also, it was partially supported by the Slovak Research and Development Agency under contract No. APVV-15-0602, and by the projects KEGA 022TUKE-4-2023, VEGA 1/0704/22 granted by the Ministry of Education, Science, Research and Sport of the Slovak Republic. Moreover, the authors appreciate the support of the International Association for Technological Development and Innovations.

References

1. Martynenko, N.M.: History of Ukrainian Culture. KNMU, Kharkiv (2015)
2. Xu, C.F., Zhou, X.C.: Three-dimensional animation technology in showing the application of the art of design. MATEC Web of Conferences **44**, 02044 (2016). https://doi.org/10.1051/matecconf/20164402044
3. Tytarenko, I., Dreval, I.: 3D modeling of a virtual built environment using digital tools: Kilburun fortress case study. Applied Sciences (Switzerland) **13**(3), 1577 (2023). https://doi.org/10.3390/app13031577
4. Fiorini, G., Friso, I., Balletti, C.: A geomatic approach to the preservation and 3D communication of urban cultural heritage for the history of the city: The journey of Napoleon in Venice. Remote Sensing **14**(14), 3242 (2022). https://doi.org/10.3390/rs14143242
5. Tan, Y., Chen, L., Wang, Q., Li, S., Deng, T., Tang, D.: Geometric quality assessment of prefabricated steel box girder components using 3D laser scanning and building information model. Remote Sensing **15**(3), 556 (2023). https://doi.org/10.3390/rs15030556
6. Meyer, T., Brunn, A., Stilla, U.: Geometric BIM verification of indoor construction sites by photogrammetric point clouds and evidence theory. ISPRS J. Photogramm. Remote. Sens. **195**, 432–445 (2023). https://doi.org/10.1016/j.isprsjprs.2022.12.014
7. Pan, Y., Zhang, L.: Integrating BIM and AI for smart construction management: current status and future directions. Archives of Computational Methods in Engineering **30**(2), 1081–1110 (2023). https://doi.org/10.1007/s11831-022-09830-8
8. Doula, A., Kaufmann, P., Guinea, A.S., Muhlhauser, M.: Effects of the level of detail on the recognition of city landmarks in virtual environments. In: Proceedings of the 2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, VRW 2022, pp. 860–861. IEEE, Piscataway (2022). https://doi.org/10.1109/VRW55335.2022.00281
9. Chernyshev, D., Ryzhakova, G., Honcharenko, T., Petrenko, H., Chupryna, I., Reznik, N.: Digital administration of the project based on the concept of smart construction. In: Alareeni,

B., Hamdan, A. (eds.) Explore Business, Technology Opportunities and Challenges After the Covid-19 Pandemic. ICBT 2022. Lecture Notes in Networks and Systems, vol. 495, pp. 1316–1331. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-08954-1_114
10. Bevilacqua, M.G., Russo, M., Giordano, A., Spallone, R.: 3D reconstruction, digital twinning, and virtual reality: Architectural heritage applications. In: Proceedings of the 2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, VRW 2022, pp. 92–96. IEEE, Piscataway (2022). https://doi.org/10.1109/VRW55335.2022.00031
11. Lang, M., Kluge, P., Kruse, F., Rosenkranz, V.: Advent City: The reconstruction of an extinct settlement in virtual reality. Polarforschung **90**(2), 49–61 (2022). https://doi.org/10.5194/polf-90-49-2022
12. Shanthini, E., Sangeetha, V., Vaishnavi, V., Aisvariya, V., Lingadharshini, G., Sakthi Surya, M.L.: Recreating Poompuhar ancient history using virtual reality. In: Rajakumar, G., Du, KL., Vuppalapati, C., Beligiannis, G.N. (eds.) Intelligent Communication Technologies and Virtual Mobile Networks. Lecture Notes on Data Engineering and Communications Technologies, vol. 131, pp. 135–144. Springer, Singapore (2023). https://doi.org/10.1007/978-981-19-1844-5_12
13. Croce, P., Leccese, F., Mordagà, M., Salvadori, G.: Towards reconstructing the Shakespeare's first Globe Theatre: A virtual model for research and development. Frontiers of Architectural Research **11**(6), 1104–1120 (2022). https://doi.org/10.1016/j.foar.2022.05.004
14. Ou, W.: Interactive garden landscape digital reconstruction system based on Particle Swarm Algorithm. In: Sugumaran, V., Sreedevi, A.G., Xu , Z. (eds.) Application of Intelligent Systems in Multi-modal Information Analytics. ICMMIA 2022. Lecture Notes on Data Engineering and Communications Technologies, vol. 138. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-05484-6_55
15. Javanbakht, T.: Optimization of graphene oxide's characteristics with TOPSIS using an automated decision-making process. J. Eng. Sci. **10**(1), E1–E7 (2023). https://doi.org/10.21272/jes.2023.10(1).e1
16. Javanbakht, T.: A novel automated decision-making process for analysis of ions and organic materials in drinking water. J. Eng. Sci. **10**(1), H1–H7 (2023). https://doi.org/10.21272/jes.2023.10(1).h1
17. Kuric, I., Kandera, M., Klarák, J., Ivanov, V., Więcek D.: Visual product inspection based on deep learning methods. In: Tonkonogyi, V., et al. (ed.) Advanced Manufacturing Processes. InterPartner-2019. Lecture Notes in Mechanical Engineering, pp. 148–156. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-40724-7_15
18. Haidabrus, B., Grabis, J., Protsenko, S.: Agile Project Management Based on Data Analysis for Information Management Systems. In: Ivanov, V., Trojanowska, J., Pavlenko, I., Zajac, J., Peraković, D. (eds.) Advances in Design, Simulation and Manu-facturing IV. DSMIE 2021. Lecture Notes in Mechanical Engineering, pp. 174–182. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-77719-7_18
19. Zhou, X., Liu, Y., Lian, X., Guo, H., Lee, S.: Research on key technology of virtual restoration of ancient buildings based on convolutional neural network. In: Proceedings of SPIE - The International Society for Optical Engineering 12348, 123480Q. SPIE, Bellingham (2022). https://doi.org/10.1117/12.2641425
20. Zidek, K., Lazorik, P., Pitel, J., Pavlenko, I., Hosovsky, A.: Automated training of convolutional networks by virtual 3D models for parts recognition in assembly process. In: Trojanowska, J., Ciszak, O., Machado, J., Pavlenko, I. (eds.) Advances in Manufacturing II, vol. 1 - Solutions for Industry 4.0. Lecture Notes in Mechanical Engineering, pp. 287–297. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-18715-6_24
21. Buń, P., Husár, J., Kaščak, J.: Hand Tracking in Extended Reality Educational Applications. In: Trojanowska, J., Kujawińska, A., Machado, J., Pavlenko, I. (eds.) Advances in Manufacturing

III. MANUFACTURING 2022. Lecture Notes in Mechanical Engineering, pp. 317–325. Springer, Cham (2022). https://doi.org/10.1007/978-3-030-99310-8_25
22. Buń, P., Gapsa, J., Husár, J., Kaščak, J.: Mixed reality training in electrical equipment operating procedures. In: Trojanowska, J., Kujawińska, A., Machado, J., Pavlenko, I. (eds.) Advances in Manufacturing III. MANUFACTURING 2022. Lecture Notes in Mechanical Engineering, pp. 306–316. Springer, Cham (2022). https://doi.org/10.1007/978-3-030-99310-8_24
23. Stellacci, S., Condorelli, F.: Remote survey of traditional dwellings using advanced photogrammetry integrated with archival data: the case of Lisbon. In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, vol. 43(B2–2022), pp. 893–899. ISPRS, Hannover (2022). https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-893-2022
24. Cai, H., Wang, Y., Lin, Y., Li, S., Wang, M., Teng, F.: Systematic comparison of objects classification methods based on ALS and optical remote sensing images in urban areas. Electronics (Switzerland) **11**(19), 3041 (2022). https://doi.org/10.3390/electronics11193041
25. Stedman, H., Kocer, B.B., Kovac, M., Pawar, V.M.: VRTAB-map: A configurable immersive teleoperation framework with online 3D reconstruction. In: Proceedings of the 2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct, ISMAR-Adjunct 2022, pp. 104–110. IEEE, Piscataway (2022). https://doi.org/10.1109/ISMAR-Adjunct57072.2022.00029
26. Pérez-Portugal, A., Atencio, E., Muñoz-La Rivera, F., Herrera, R.F.: Calibration of UAV flight parameters to inspect the deterioration of heritage façades using orthogonal arrays. Sustainability (Switzerland) **15**(1), 232 (2023). https://doi.org/10.3390/su15010232
27. Barros, B.A.F.S., Sotelino, E.D.: Constructability and sustainability studies in conceptual projects: a BIM-based approach. J. Constr. Eng. Manag. **149**(4), 04023012–04023021 (2023). https://doi.org/10.1061/JCEMD4.COENG-12767
28. Židek, K., Maxim, V., Piteľ, J., Hošovský, A.: Embedded vision equipment of industrial robot for inline detection of product errors by clustering-classification algorithms. Int. J. Adv. Rob. Syst. **13**(5), 1 (2016). https://doi.org/10.1177/1729881416664901
29. Luis Lugo, J., Gallegos Reyes, J.C., Weidner, J., Raheem, A., Cheu, RL: Evaluation of 3D reconstruction methods from terrestrial LiDAR point cloud data to create digital twins of civil infrastructure projects. In: The International Conference on Transportation and Development 2022: Application of Emerging Technologies - Selected Papers from the Proceedings of the International Conference on Transportation and Development 2022, vol. 1, pp. 81–92. ASCE, Reston (2022). https://doi.org/10.1061/9780784484319.008