Creation of Digital Twins using Spatial Artificial Intelligence - A Pilot Study

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Abstract: This study explores the integration of spatial artificial intelligence (SAI) in the creation a digital twin of a university campus - namely the Zalaegerszeg University Centre of the University of Pannonia - for immersive virtual reality tours. Spatial AI techniques such as photogrammetry and LiDAR scanning were used to create detailed virtual replicas of campus buildings, landscapes, and infrastructure. These virtual environments also represent a shift towards Digital and Cognitive Corporate Reality (DCR), where AI-driven digital spaces enhance human cognitive and operational processes. With the help of these tours in virtual reality, users can explore the campus remotely, experiencing enhanced accessibility, interactivity, and engagement. Using the 4-factor version of the Presence Questionnaire 3.0 and the System Usability Scale, the virtual environment was evaluated by assessing the opinions of 18 university students. Our results show the transformative role of spatial AI and virtual reality technology in redefining how environments are experienced and accessed. This can open new ways for spatial cognition research and other, immersive experiences. Furthermore, our study contributes to the field of DCR by showing how AI-driven spatial models can influence learning, decision making, and digital interaction in educational institutions.

Keywords: digital twin; digitization; human-computer interaction; spatial AI; virtual reality

1 Introduction

Digital twins, virtual counterparts mirroring real-world entities or systems, have emerged as a transformative concept with large implications across multiple industries [1, 2, 3]. These digital replicas are capable of simulating, predicting, and optimizing the behavior of their physical counterparts [4, 5, 6, 7]. They have also revolutionized traditional approaches to design, monitoring, and maintenance. However, the effectiveness of digital twins often depends on the accuracy and adaptability of the underlying models, which in turn rely heavily on the quality and relevance of input data.

In recent years, the fusion of spatial artificial intelligence (SAI) with digital twin technology has opened up new ways for creating more sophisticated and dynamic virtual representations of physical assets and environments. Unlike conventional digital twins that primarily rely on static data and predefined models, SAI-enabled digital twins have the power of spatial data and advanced AI algorithms to generate real-time, context-aware simulations.

The integration of SAI offers several advantages over traditional digital twin methodologies. Firstly, it enables the incorporation of diverse spatial data sources, including satellite imagery, LiDAR scans, GPS data, and geographic information systems to create comprehensive and geospatially accurate representations [8]. Secondly, AI algorithms such as deep learning and reinforcement learning enhance digital twins to learn from historical data, adapt to changing environmental conditions, and optimize performance in real-time. Finally, the spatial context provided by SAI enhances the situational awareness of digital twins, enabling them to capture complex interactions and dependencies within physical systems.

According to the literature, there is a high potential of using machine learning and deep learning techniques for interpreting 3D point clouds without the need for explicit spatial 3D models or rule sets, streamlining the creation and maintenance of base data for geospatial digital twins (like virtual 3D city models, indoor models, or building information models) [9].

Understanding the capability levels of digital twins, ranging from standalone to autonomous, can guide the development and implementation of these virtual representations for real-world assets. The use of a modern house as a case study illustrates how sensors and data can be leveraged to create digital twins, offering a practical blueprint for monitoring and optimizing physical assets in various industries [10]. Visualizing digital twins in virtual reality (VR) enables users to interact with and manipulate the virtual environment (VE). This, in turn, enhances decision making processes and facilitates better asset management. By unlocking the full potential of digital twins through comprehension of their capabilities, organizations can improve predictive maintenance, optimize operations, and enhance overall efficiency in asset management.

The rise of using autonomous vehicles has also created a number of challenges [11]. Achieving high accuracy level in safety performance in is essential for the reliable operation of autonomous vehicles in real-world scenarios [12]. Through the use of convolution neural networks and spatial-temporal graph convolution networks, an autonomous cars digital twins prediction model with high accuracy in road network prediction can be developed [13]. By leveraging AI-enabled digital twins, advancements in autonomous driving technology can be made, contributing to the overall progress of smart city infrastructure [14].

This research also aligns with the principles of Digital and Cognitive Corporate Reality (DCR) as discussed in the study by Ko et al. [15] and Kovari [16]. DCR represents a paradigm where digital and cognitive elements interact dynamically [17, 18]. By doing so, corporate operations, education, and spatial cognition can be affected. Our study shows how digital twin technology combined with AI and immersive VR can contribute to the concept of DCR by enhancing digital interactivity and cognitive adaptability.

This paper is an initial step in a larger research project, where our current goal is to test the level of realism of the 3D walk through we have produced. Accordingly, the following research questions have been defined.

- RQ1: What is the user experience of using a head-mounted display for the 3D walk through?
- RQ2: How does a sense of reality develop using a head-mounted display for the 3D walk through?

This study has the following structure. Firstly, the materials and methods are presented in Section 2. In there, the scanning and re-modeling of buildings as well as the data analysis are detailed. Afterward, the results of the two questionnaires are shown in Section 3, while they are discussed in Section 4. Lastly, conclusions are drawn.

2 Materials and Methods

This section is split into five subsections. In Subsection 2.1 the digitization process is detailed. Subsections 2.2 and 2.3 present the two versions of the VE. The data collection process is shown in Subsection 2.4, while the data analysis is presented in Subsection 2.5.

2.1 The Digitization Process

The 3D indoor/outdoor building scanning and re-modeling was created with a 1 mm laser scanner and high dynamic range (HDR) panoramic images, in between summer and autumn 2023. The scanning process included not only exterior areas (building facades, vegetation, roofs) but also interiors of university buildings. The mapped parts are covered by a 3D tour of 2000 square metres each, accessible online, with interactive information points on the borders to open the following parts. Several different techniques and tools were combined for the digitization process, including a Leica laser camera, a photometric solution and a spherical panorama technique. In addition, tripods (1.7 m and 3.5 m) were used for the exterior shots to facilitate the mapping of the façade, roof and vegetation.

Thus, 80% of the university campus was scanned. In the end, two digital twins were created: a point-cloud one and a 360° photo version. Overall, it can be said that the outcome has thousands of points of interest (POIs), interactive information points, a VR headset viewing option, and an automated tour on mobile devices and computers. This digitization process aligns with the cognitive transformation of corporate and educational environments under DCR. By integrating AI-driven spatial modeling and VR visualization, not only digital accessibility is enhanced, but future methodologies for human-machine interaction is also shaped in corporate and academic settings.

2.2 The Point-Cloud Version

The first version of the VE was the point-cloud version. 263 713 338 points were digitized of the Zalaegerszeg University Centre of the University of Pannonia. Afterward, the virtual campus was exported into an XYZ file which can be opened with point-cloud handling software, such as CloudCompare. The whole digitized campus can is observable in Figure 1.

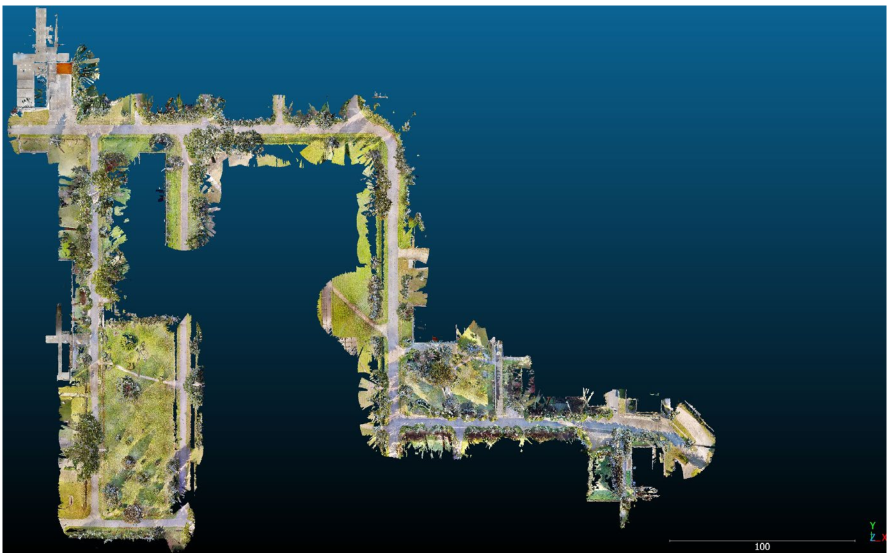

Figure 1
Upper view of the campus

The digitized point-cloud campus has a high detail as can be seen in Figure 2. A high resolution is ideal when generating 3D models or reconstructions from point-clouds as they result in more accurate and faithful representations. This could be done with the previously mentioned point-cloud software. It is also possible to take a VR tour in the point-cloud, although this was not used due to the required high computing power.

Figure 2
A zoomed-in upper view of the campus

Naturally, the digitized point-cloud version can be looked around in the software from different angles as well. This is illustrated in Figure 3.

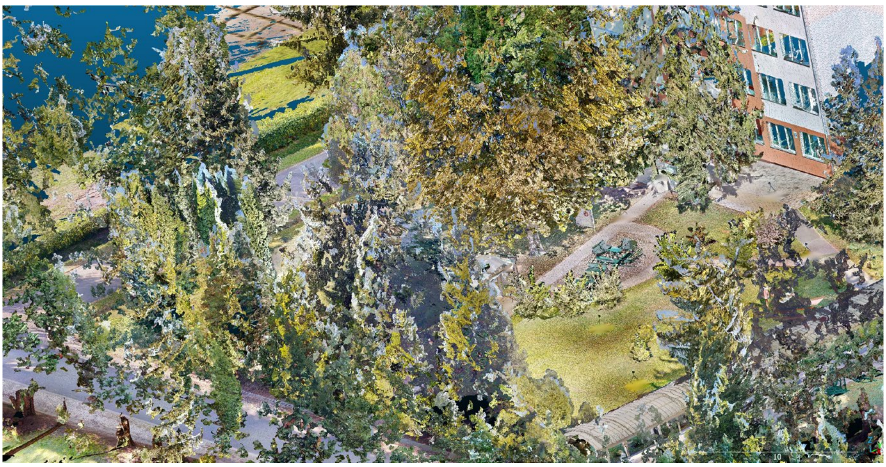

Figure 3
Another angle of the campus

2.3 The 360° Photo Version

After the creation of the point-cloud digital twin, another version was created that required less computing power. This version uses Matterport and it is freely available online [19]. It can be used with a desktop display and a head-mounted display as well. Figure 4 shows a screenshot of the desktop display version.

Figure 4
The 360° photo version of the campus

As can be seen in Figure 4, this version even includes information about certain landmarks in Hungarian. One landmark is clicked on in Figure 4 and it shows information about the building called Infocentrum. Another landmark can be seen on the left, but it was not clicked on.

To access the VR version, the user has to click on the head-mounted display icon in the lower right corner of the screen. Afterward, the user can walk around in the VE using the sensors of the VR setup.

2.4 Collecting Data on Presence and Usability

Participants included students at the University of Pannonia in Hungary. Overall, 18 students participated in the virtual tours (M_{age} = 23.22, SD_{age} = 4.45). Of the 18 participants, 11 were male and 7 female. The students participated on their own volition and gave informed consent before the data collection commenced. Participants had to use an HP Reverb G2 head-mounted display for the virtual campus tour [20]. There was no time limit, they could stop anytime. After completing or stopping the tour, they had to complete two questionnaires.

The first one was the 3.0 version of Presence Questionnaire (PQ) which is a questionnaire that was developed for assessing the users' presence in VEs [21]. According to the authors of the study referenced above, the 4-factor method provides the best results, therefore, we used it as well. Participants could answer the questions on a 7-point Likert-scale. With this questionnaire, we could examine the involvement, sensory fidelity, adaptation/immersion and interface quality of the VE. Involvement measures the extent to which users feel engaged and mentally absorbed in the virtual environment. Naturally, higher involvement scores indicate a greater sense of participation and attention focus within the virtual space. Questions about sensory fidelity assess the realism and quality of sensory inputs in the VE. For example, these can be about visual, auditory, and tactile feedback. In this case, higher scores suggest that users found the virtual world visually and aurally convincing, which enhances immersion. Adaptation/immersion is about how quickly and effectively users adapt to the VE. A high adaptation score means that users feel naturally integrated into the virtual space without excessive effort. Questions about interface quality investigate the ease of interaction with the VR system. This investigation can include controls, latency, and responsiveness. Higher scores indicate that users found the interface intuitive and free from distracting technological limitations.

The next questionnaire was based on the System Usability Scale (SUS) which allowed us to examine how usable the VE was [22]. In the case of SUS, a 5-point Likert-scale was used.

2.5 Data Analysis

After data collection, the data was imported into the statistical program package R for further analysis. Before assessing the results, the reliability of the two questionnaires was examined using Cronbach's α. A function for this could be found in the *psych* package in R. This α value can be interpreted as follows:

- $\alpha \geq 0.9$: excellent,
- $\alpha \geq 0.8$: good,
- $\alpha \geq 0.7$: acceptable,
- $\alpha \geq 0.6$: questionable,
- $\alpha \geq 0.5$: poor,
- $\alpha < 0.5$: unacceptable.

Although both are validated questionnaires, it would be interesting to see how reliable our results were. Regarding PQ, $\alpha = 0.93$, meaning that the results have a very good level of reliability. Meanwhile, regarding SUS, $\alpha = 0.65$, indicating that the results are at a moderately reliable level. Afterward, the answers on the questionnaires were evaluated.

To calculate the aforementioned four factors regarding the presence of the users, the rules of the PQ define that the results of the following questions had to be added together:

- Involvement: 1, 2, 3, 4, 6, 7, 8, 10, 14, 17, 18, 29

- Sensory fidelity: 5, 11, 12, 13, 15, 16
- Adaptation/immersion: 9, 20, 21, 24, 25, 30, 31, 32
- Interface quality: 19, 22, 23

To calculate the usability of the VE, the following method was done using the results received on the SUS:

- In the case of the odd numbered questions, one had to be subtracted from the score
- In the case of the even numbered questions, their value had to be subtracted from five
- These values had to be added together
- Lastly, the final value had to be multiplied by 2.5

After the Shapiro-Wilk normality test [23] showed that the datasets did not follow a Gaussian distribution in all cases, we have used the Wilcoxon rank-sum test with continuity correction to compare the results of males and females [24]. The Wilcoxon rank-sum test returns two values: W and p. The former is a statistical value calculated based on the sum of ranks. It represents the rank sum of one of the samples (typically the smaller sample). The p-value indicates the probability that the observed W statistic or a more extreme value could occur under the null hypothesis. Since we selected a significance level of 0.05 for our study, we can state that if $p < 0.05$, a significant difference is observable between the two samples.

3 Results

As there were two questionnaires used, this section is split into two subsections. The results regarding PQ are detailed in Subsection 3.1, while the results regarding SUS are shown in Subsection 3.2.

3.1 Results on the Presence Questionnaire

In general, it can be stated that the VE received positive results regarding user presence. The minimum of means was 3.33, while their maximum value was 6.50. Similarly, the minimum of standard deviations was 0.78, while the maximum was 2.16. The results regarding each question can be seen in Figure 5.

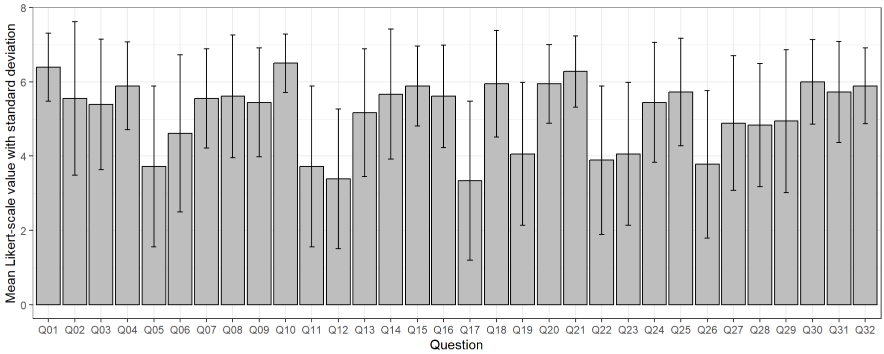

Figure 5

Results on the PQ

Males and females also had similar opinions regarding presence. The means of males were between 3.00-6.54, while that of females were 3.28-6.57. Their standard deviations were between 0.82-2.20 and 0.78-2.73, respectively. No significant differences were found between the answers of males and females, $W = 378.5$, $p = 0.073$.

However, one important observation is that participants reported a strong sense of immersion since they provided higher scores to questions related to spatial awareness, interactivity, and realism. The highest-rated questions suggest that participants perceived the VE as a realistic and engaging environment. This supports the fact that AI-driven spatial modeling and VR technologies can effectively enhance cognitive presence.

Still, afterward, the aforementioned four factors regarding presence were calculated. The results can be seen in Figure 6.

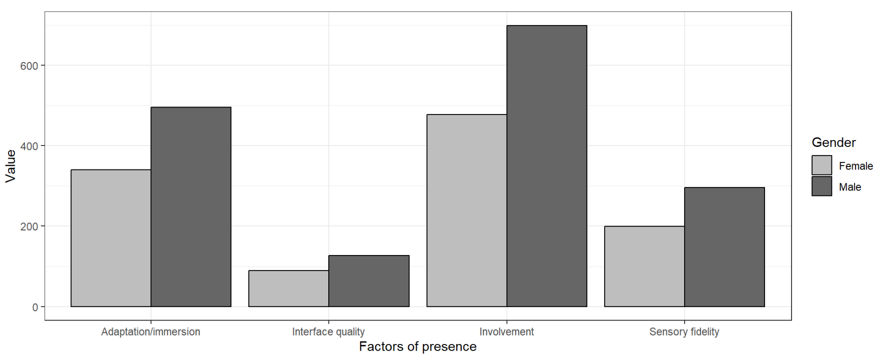

Figure 6

Levels of presence regarding the four factors

As can be observed in Figure 6, males felt a larger level of presence during the virtual tour regarding each factor. Regarding involvement, males felt significantly more involved with the VE, $W = 6466$, $p = 0.031$.

In the case of sensory fidelity, no significant differences were found between males and females, $W = 1524.5$, $p = 0.376$. Regarding adaptation, males felt significantly more adapted to the VE, $W = 2963$, $p = 0.032$. No significant differences were found between the opinions of males and females in the case of interface quality, $W = 390$, $p = 0.440$.

3.2 Results on the System Usability Scale

Next, the results received on the SUS were examined. Regarding means, their minimum value was 1.55, while their maximum value was 4.44. Regarding standard deviations, their minimum value was 0.61, while their maximum value was 1.30. The results regarding each question can be observed in Figure 7.

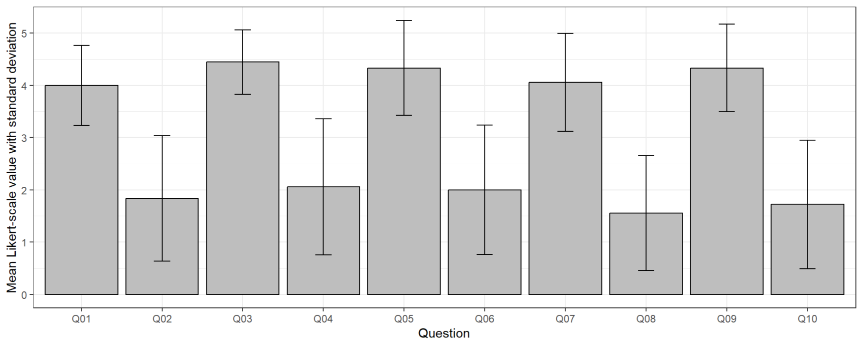

Figure 7
Results on the SUS

Regarding the usability of the VE, both males and females felt similarly. The means of males were between 1.72-4.45, while they were between 1.28-4.42 in the case of females. Their standard deviations were between 0.55-1.36 and 0.75-1.46, respectively. No significant differences were found between the two groups, $W = 53.5$, $p = 0.819$.

Lastly, the usability values were calculated for the VE. If the results of all participants is examined, this value is 80. This means that overall, the developed VE can be considered acceptable. When calculated by gender, the results show that females though that the virtual tour was more usable (83.57) than males (77.72). Still, both values can be considered acceptable.

4 Discussion

In this study, we used spatial AI techniques to digitize the Zalaegerszeg University Centre of the University of Pannonia and provide immersive VR tours. During the study, two versions of the mentioned campus were created: a point-cloud version and a version comprised of 360° photos.

Digitizing the Zalaegerszeg University Centre of the University of Pannonia involved the application of various spatial AI techniques, including photogrammetry and LiDAR scanning. These methods allowed us to create accurate and detailed virtual replicas of buildings, landscapes, and infrastructure. Despite encountering challenges such as data acquisition and processing complexities, our approach demonstrates the feasibility of using spatial AI for large-scale campus digitization projects.

By placing our results within the context of DCR, we can see how the digitization of physical environments using AI and VR extends beyond educational applications. Our study suggests that similar approaches could be used in corporate settings. This can enable virtual workplaces, enhance remote collaboration, and optimize digital work-flows. The cognitive aspect of DCR is evident in how users interact with these digital spaces. It makes it possible to adapt to VEs and use digital tools for spatial decision making. Additionally, our results contribute to the field of Cognitive InfoCommunications as well by allowing us to understand how AI-enhanced VEs can affect user presence and engagement in corporate and educational contexts [25, 26].

Offering tours in digitized environments provides numerous advantages over traditional methods. By immersing users in a VE, accessibility can be enhanced for students, and researchers alike regardless of their geographical location. Furthermore, users can navigate the Zalaegerszeg University Centre of the University of Pannonia at their own pace and explore areas of interest in-depth. Feedback from the users who participated in the VR tours was positive. Participants reported a high-level of presence in the VE, while believing that it was easy to use.

The use of VR technology for exploration has significant educational and research implications. In educational settings, VR can serve as a valuable tool for orientation programs, campus tours, and virtual classrooms. By simulating real-world environments, VR can enhance spatial cognition and helps with experiential learning opportunities. Moreover, VR can support research studies in fields such as urban planning, architecture, and human-computer interaction by providing a platform for data visualization, simulation, and experimentation.

Despite the promising results of our pilot study, the following limitations should be acknowledged. Technical constraints such as hardware requirements and software compatibility may limit the accessibility of VR tours for some users.

The other limitation is that only 18 people participated in the virtual tours. Future research efforts should focus on addressing these limitations and exploring other technologies, such as augmented reality (AR) and mixed reality (MR) for campus exploration and interaction.

Conclusions

In conclusion, our study demonstrates the potential of spatial AI and VR technology in digitizing university campuses and providing immersive campus tours. By offering such virtual experiences, VR can revolutionize how we explore and engage with certain environments. As technology continues to evolve, the integration of spatial AI and VR can transform experiences and advance research in spatial cognition and human-computer interaction. The results also show that users experience a strong sense of presence, immersion and adaptability within these types of VEs. These can strengthen the idea that digital twins and VR technology can bridge the gap between physical and digital worlds.

Overall, our results provide a foundation for the adoption of SAI-based VR environments across multiple fields of research. As digital transformation evolves, SAI, digital twins and VR will play and important role in shaping the future of research in digital and cognitive corporate realities.

Acknowledgement

This work has been implemented by the TKP2021-NVA-10 project with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the 2021 Thematic Excellence Programme funding scheme.

The research presented in this paper was supported by the Hungarian Research Network (HUN-REN) and was carried out within the HUN-REN Cognitive Mapping of Decision Support Systems research group.

The authors would also like to thank Patrik Péter Kiss (http://vrgo.hu/) for his help in the digitization process.

References

[1] P. Baranyi, A. Csapo, T. Budai, and G. Wersényi, "Introducing the concept of internet of digital reality–part I," *Acta Polytechnica Hungarica*, Vol. 18, No. 7, pp. 225-240, 2021

[2] G. Wersényi, Á. Csapó, T. Budai, and P. Baranyi, "Internet of digital reality: Infrastructural background–part II," *Acta Polytechnica Hungarica*, Vol. 18, No. 8, pp. 91-104, 2021

[3] I. Horváth, Á. B. Csapó, B. Berki, A. Sudár, and P. Baranyi, "Definition, background and research perspectives behind 'cognitive aspects of virtual reality'(cvr)," *Infocommunications Journal*, Special Issue: Internet of Digital & Cognitive realities, pp. 9-14, 2023

[4] N. Szántó, Á. Csapó, and I. Horváth, "Information basis of digital twins: A quantifiable metric for spatio-temporal expressivity," *Acta Polytechnica Hungarica*, Vol. 20, No. 6, pp. 151-171, 2023

[5] T. Kaarlela, S. Pieskä, and T. Pitkäaho, "Digital twin and virtual reality for safety training," in *2020 11th IEEE international conference on cognitive infocommunications (CogInfoCom)*, pp. 000115-000120, IEEE, 2020

[6] C. Liu, P. Jiang, and W. Jiang, "Web-based digital twin modeling and remote control of cyber-physical production systems," *Robotics and computer-integrated manufacturing*, Vol. 64, p. 101956, 2020

[7] V. Havard, B. Jeanne, M. Lacomblez, and D. Baudry, "Digital twin and virtual reality: a co-simulation environment for design and assessment of industrial workstations," Production & Manufacturing Research, Vol. 7, No. 1, pp. 472-489, 2019

[8] M. Cserép, A. Demján, F. Mayer, B. Tábori, and P. Hudoba, "Effective railroad fragmentation and infrastructure recognition based on dense lidar point clouds," *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 2, pp. 103-109, 2022

[9] J. Döllner, "Geospatial artificial intelligence: potentials of machine learning for 3d point clouds and geospatial digital twins," *PFG–Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, Vol. 88, No. 1, pp. 15-24, 2020

[10] E. M. Elfarri, A. Rasheed, and O. San, "Artificial intelligence-driven digital twin of a modern house demonstrated in virtual reality," *IEEE Access*, 2023

[11] V. Patrik, "Conditions for the introduction of autonomous vehicles," *Macrotheme Review: A Multidisciplinary Journal Of Global Macro Trends*, Vol. 10, No. 1, pp. 77-85, 2021

[12] Á. Somogyi, T. Tettamanti, P. Varga, Z. Szalay, D. Baranyai, and T. Lovas, "Digital map generation workflow demonstrated on zalazone automotive proving ground elements," in *NOMS 2023-2023 IEEE/IFIP Network Operations and Management Symposium*, pp. 1-6, IEEE, 2023

[13] D. Chen and Z. Lv, "Artificial intelligence enabled digital twins for training autonomous cars," *Internet of Things and Cyber-Physical Systems*, Vol. 2, pp. 31-41, 2022

[14] T. Lovas, T. Ormándi, Á. J. Somogyi, D. Baranyai, V. Tihanyi, and T. Tettamanti, "Opencrg models from different data sources to support vehicle simulations," *IEEE Access*, Vol. 10, pp. 42690-42698, 2022

[15] A. Ko, I. Szabó, Á. Csapó, T. Kovács, L. Lorincz, and P. Baranyi, "Digital & cognitive corporate reality," *Infocommunications Journal*, Special Issue on Internet of Digital and Cognitive Realities, pp. 2-10, 2023

[16] A. Kovari, "Model of the Internet of Digital Education and its links to VR," *Infocommunications Journal*, Joint Special Issue on Cognitive Infocommunications and Cognitive Aspects of Virtual Reality, pp. 76-83, 2024

[17] G. Wersényi, "Musings on the Metaverse and on how the Internet of Digital Reality Encompasses Future Developments of the Internet," *Infocommunications Journal*, Special Issue: Internet of Digital & Cognitive realities, pp. 21-28, 2023

[18] G. Sallai, "Evolution of Digitization toward the Internet of Digital & Cognitive Realities and Smart Ecosystems," *Infocommunications Journal*, Special Issue: Internet of Digital & Cognitive realities, pp. 2-8, 2023

[19] "Explore Pannon Egyetem Zalaegerszegi Központ in 3D." https://my.matterport.com/show/?m=45j6qV29Yjt&ts=1, Accessed: 13-May-2024 [Online]

[20] "HP Reverb G2." https://www.hp.com/gb-en/vr/reverb-g2-vr-headset.html, Accessed: 13-May-2024 [Online]

[21] B. G. Witmer, C. J. Jerome, and M. J. Singer, "The factor structure of the presence questionnaire," *Presence: Teleoperators & Virtual Environments*, Vol. 14, No. 3, pp. 298-312, 2005

[22] A. Bangor, P. T. Kortum, and J. T. Miller, "An empirical evaluation of the system usability scale," *International Journal of Human–Computer Interaction*, Vol. 24, No. 6, pp. 574-594, 2008

[23] S. S. Shapiro and M. B. Wilk, "An analysis of variance test for normality (complete samples)," *Biometrika*, Vol. 52, No. 3-4, pp. 591-611, 1965

[24] . Wilcoxon, S. Katti, and R. A. Wilcox, "Critical values and probability levels for the wilcoxon rank sum test and the wilcoxon signed rank test," *Selected tables in mathematical statistics*, Vol. 1, pp. 171-259, 1970

[25] P. Baranyi and Á. Csapó, "Definition and synergies of cognitive infocommunications," *Acta Polytechnica Hungarica*, Vol. 9, No. 1, pp. 67-83, 2012

[26] P. Baranyi, B. Berki, and Á. B. Csapó, "Concepts of cognitive infocommunications," *Infocommunications Journal*, Joint Special Issue on Cognitive Infocommunications and Cognitive Aspects of Virtual Reality, pp. 37-48, 2024