Unlocking Cultural Heritage: The Gamified Digitisation Project of SMA-UniGe

Lara La Tessa[1(✉)], Mauro Coccoli[2], Stefano Schiaparelli[3], and Daniele Zolezzi[4]

[1] DIEC - University of Genoa, Via F. Vivaldi, 5, 16126 Genoa, GE, Italy
lara.latessa@edu.unige.it
[2] DIBRIS - University of Genoa, Via alla Opera Pia, 13, 16145 Genoa, GE, Italy
[3] DISTAV - University of Genoa, Corso Europa, 26, 16132 Genoa, GE, Italy
[4] DLCM - University of Genoa, Piazza di Santa Sabina, 2, 16124 Genoa, GE, Italy

Abstract. The University of Genoa, Italy, addresses the challenge of inaccessible cultural heritage stored in university archives worldwide by implementing a comprehensive digitisation initiative. This project focuses on collecting, storing, and digitising a wide array of items, including books, manuscripts, archival materials, and documents related to museum artifacts. To ensure accessibility for both humans and machines, the initiative involves providing alternate descriptions, metadata, and speech-to-text transcriptions for images and videos, as well as word-for-word transcripts for ancient texts where OCR is ineffective. We present the design of a transcription system for the University Museum System (SMA-UniGe) at the University of Genoa, which includes user interface elements and engagement techniques. By leveraging gamification theory, the system transforms the typically monotonous task of transcription into an engaging experience, encouraging participation from digital volunteers. This initiative aligns with the University's third mission of public engagement, aiming to disseminate knowledge beyond the academic environment and contribute to social, cultural, and economic development.

Keywords: Cultural Heritage · Gamification · User Experience

1 Introduction

After conducting a thorough census of the cultural assets at the University of Genoa (UniGe) in July 2021, it was decided that these valuable cultural resources should be made fully accessible. Consequently, the University Museum System (SMA, "Sistema Museale di Ateneo", in italian) was established, offering a unified online platform where the digitised and archived cultural heritage can be accessed by everyone as an interactive exhibition. This system encompasses multiple museums, botanical gardens, biobanks, archives, and a variety of collections.

E. Brooks et al. (Eds.): DLI 2024, LNICST 604, pp. 69–76, 2025.
https://doi.org/10.1007/978-3-031-85663-1_5

38. Spors, V., Laato, S., Buruk, O., Hamari, J.: Longing to be the mountain: a scoping review about nature-centric, health-minded technologies. In: Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, pp. 1–16 (2023)
39. Ulrich, R.S., Simons, R.F., Losito, B.D., Fiorito, E., Miles, M.A., Zelson, M.: Stress recovery during exposure to natural and urban environments. J. Environ. Psychol. **11**(3), 201–230 (1991)
40. Wang, X., Shi, Y., Zhang, B., Chiang, Y.: The influence of forest resting environments on stress using virtual reality. Int. J. Environ. Res. Public Health **16**(18), 3263 (2019)
41. Wang, X., Lo, K.: Just transition: a conceptual review. Energy Res. Social Sci. **82**, 102291 (2021)
42. Watson, D., Clark, L.A., Tellegen, A.: Development and validation of brief measures of positive and negative affect: the panas scales. J. Pers. Soc. Psychol. **54**(6), 1063 (1988)
43. Webber, S., Kelly, R.M., Wadley, G., Smith, W.: Engaging with nature through technology: a scoping review of hci research. In: Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, pp. 1–18 (2023)
44. Wilson, E.O.: Biophilia. Harvard university press, New York (1984)
45. Winter, P.L., Selin, S., Cerveny, L., Bricker, K.: Outdoor recreation, nature-based tourism, and sustainability. Sustainability **12**(1), 81 (2019)
46. Wolsko, C., Lindberg, K., Reese, R.: Nature-based physical recreation leads to psychological well-being: evidence from five studies. Ecopsychology **11**(4), 222–235 (2019)

18. Kaplan, R., Kaplan, S.: The Experience of Nature: A Psychological Perspective. Cambridge University Press, Cambridge (1989)
19. Kaplan, S.: The restorative benefits of nature: toward an integrative framework. J. Environ. Psychol. **15**(3), 169–182 (1995)
20. Kardong-Edgren, S.S., Farra, S.L., Alinier, G., Young, H.M.: A call to unify definitions of virtual reality. Clin. Simul. Nurs. **31**, 28–34 (2019)
21. Kellert, S.R., Wilson, E.O.: The biophilia hypothesis (1993)
22. Kikuchi, R.: Adverse impacts of wind power generation on collision behaviour of birds and anti-predator behaviour of squirrels. J. Nat. Conserv. **16**(1), 44–55 (2008)
23. Klain, S.C., Satterfield, T., Sinner, J., Ellis, J.I., Chan, K.M.: Bird killer, industrial intruder or clean energy? perceiving risks to ecosystem services due to an offshore wind farm. Ecol. Econ. **143**, 111–129 (2018)
24. Li, H., et al.: Access to nature via virtual reality: a mini-review. Front. Psychol. **12**, 725288 (2021)
25. Mäkelä, V., et al.: Virtual field studies: conducting studies on public displays in virtual reality. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–15 (2020)
26. Martin, L., White, M.P., Hunt, A., Richardson, M., Pahl, S., Burt, J.: Nature contact, nature connectedness and associations with health, wellbeing and pro-environmental behaviours. J. Environ. Psychol. **68**, 101389 (2020)
27. Mattila, O., Korhonen, A., Pöyry, E., Hauru, K., Holopainen, J., Parvinen, P.: Restoration in a virtual reality forest environment. Comput. Hum. Behav. **107**, 106295 (2020)
28. McCrickard, D.S., Jones, M., Stelter, T.L.: HCI Outdoors: Theory, Design, Methods and Applications. Springer, Heidelberg (2020)
29. Milgram, P., Kishino, F.: A taxonomy of mixed reality visual displays. IEICE Trans. Inf. Syst. **77**(12), 1321–1329 (1994)
30. Nysten-Haarala, S., Joona, T., Hovila, I.: Wind energy projects and reindeer herders' rights in finnish lapland: a legal framework. Elementa: Science of the Anthropocene **9** (2021)
31. Restout, J., et al.: Fully immersive virtual reality using 360° videos to manage well-being in older adults: a scoping review. J. Am. Med. Dir. Assoc. **24**(4), 564–572 (2023). https://doi.org/10.1016/j.jamda.2022.12.026
32. Richardson, M., Butler, C.W.: Nature connectedness and biophilic design. Build. Res. Inf. **50**(1–2), 36–42 (2022)
33. Salatino, A., et al.: Virtual reality rehabilitation for unilateral spatial neglect: a systematic review of immersive, semi-immersive and non-immersive techniques. Neurosci. Biobehav. Rev. **152**, 105248 (2023).https://doi.org/10.1016/j.neubiorev.2023.105248. https://www.sciencedirect.com/science/article/pii/S0149763423002178
34. Santos, B., Romão, T., Dias, A.E., Centieiro, P.: eVision: a mobile game to improve environmental awareness. In: Reidsma, D., Katayose, H., Nijholt, A. (eds.) ACE 2013. LNCS, vol. 8253, pp. 380–391. Springer, Cham (2013). https://doi.org/10.1007/978-3-319-03161-3_28
35. Sheffield, D., Butler, C.W., Richardson, M.: Improving nature connectedness in adults: a meta-analysis, review and agenda. Sustainability **14**(19), 12494 (2022)
36. Skarin, A., Sandström, P., Alam, M.: Out of sight of wind turbines-reindeer response to wind farms in operation. Ecol. Evol. **8**(19), 9906–9919 (2018)
37. Spangenberger, P., Freytag, S.C., Geiger, S.M.: Embodying nature in immersive virtual reality: are multisensory stimuli vital to affect nature connectedness and pro-environmental behaviour? Comput. Educ. **212**, 104964 (2024)

References

1. Ahn, S.J., Bostick, J., Ogle, E., Nowak, K.L., McGillicuddy, K.T., Bailenson, J.N.: Experiencing nature: embodying animals in immersive virtual environments increases inclusion of nature in self and involvement with nature. J. Comput.-Mediat. Commun. **21**(6), 399–419 (2016)
2. Burdea, G.C., Coiffet, P.: Virtual Reality Technology. John Wiley & Sons, Hoboken (2024)
3. Calogiuri, G., et al.: The impact of visualization techniques of immersive virtual scenarios in promoting nature connectedness: a blind randomized controlled trial with mixed-methods approach. J. Environ. Psychol. **90**, 102102 (2023)
4. Capaldi, C.A., Dopko, R.L., Zelenski, J.M.: The relationship between nature connectedness and happiness: a meta-analysis. Front. Psychol. **5**, 92737 (2014)
5. Chirico, A., et al.: Designing virtual environments for attitudes and behavioral change in plastic consumption: a comparison between concrete and numerical information. Virt. Real. **25**, 107–121 (2021)
6. Church, C., Crawford, A.: Minerals and the metals for the energy transition: exploring the conflict implications for mineral-rich, fragile states. In: Hafner, M., Tagliapietra, S. (eds.) The Geopolitics of the Global Energy Transition. LNE, vol. 73, pp. 279–304. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-39066-2_12
7. Cipresso, P., Giglioli, I.A.C., Raya, M.A., Riva, G.: The past, present, and future of virtual and augmented reality research: a network and cluster analysis of the literature. Front. Psychol. **9**, 2086 (2018)
8. Cosio, L.D., Buruk, O., Fernández Galeote, D., Bosman, I.D.V., Hamari, J.: Virtual and augmented reality for environmental sustainability: a systematic review. In: Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, pp. 1–23 (2023)
9. Drazich, B.F., et al.: In too deep? a systematic literature review of fully-immersive virtual reality and cybersickness among older adults. J. Am. Geriatr. Soc. **71**(12), 3906–3915 (2023)
10. Frank, L.A.: Using the computer-driven vr environment to promote experiences of natural world immersion. In: The Engineering Reality of Virtual Reality 2013, vol. 8649, pp. 78–90. SPIE (2013)
11. Greengard, S.: Virtual Reality. MIT Press, Cambridge (2019)
12. Häkkilä, J., et al.: Reflections on the naturechi workshop series: unobtrusive user experiences with technology in nature. Int. J. Mobile Hum. Comput. Interact. (IJMHCI) **10**(3), 1–9 (2018)
13. Hartig, T.: Toward understanding the restorative environment as a health resource. In: Open Space: People Space. Engaging with the Environment (2004)
14. Hartig, T., Korpela, K., Evans, G.W., Gärling, T.: A measure of restorative quality in environments. Scand. Hous. Plan. Res. **14**(4), 175–194 (1997)
15. Jones, M.D., Von Feldt, M., Andrus, N.: Outside where? a survey of climates and built environments in studies of hci outdoors. In: Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, pp. 1–15 (2022)
16. Joona, T., Joona, J.: Toward just, ethical and sustainable arctic economies, environments and societies. In: Routledge Handbook of Polar Law. Routledge (2023)
17. Jyskä, I., et al.: Design and user experience of virne application: deep breathing exercise in a virtual natural environment to reduce treatment anxiety in pediatrics. In: Healthcare, vol. 11, p. 3129. MDPI (2023)

5.3 Limitations

We acknowledge that our study is limited by the small sample size and not balancing the presentation order of the A-B scenarios in the study. However, the main focus of our research was on exploring and evaluating the methodology of using VR for assessing nature landscapes and comparing it to paper-based presentations. Also, we noticed that repetitive questions and the use of the same pictures seemed to affect participants' perception of the virtual environment to some extent. As another limitation, the quality and realism of the AI-generated VR environments impacted participants' perceptions, including difference between the scenarios. This is however a methodological lesson learnt in preparing the visualizations. For instance, we cannot be sure whether people did not like the wind turbines or the lack of trees. Future research should focus on improving the realism and consistency of VR environments to better assess their impact.

In the future, to gain more insight into the phenomenon of perceptions of technology in nature, a comparison with a data set collected in-the-wild in the nature should be included. This is especially important, as there is generally a lack of nature and technology user experience studies that have been conducted in a wilderness context. Jones et al. report that of 101 HCI studies conducted outdoors involving a person using a computer, 82 took place in urban settings [15]. Including an in-the-wild study would also provide insight into the methodological feasibility of simulating the nature experience in VR.

6 Conclusion

Our research seeks to make two types of contributions. On one hand, it offers insight into user perceptions of integrating technology into nature scenes. On the other hand, it emphasizes the importance of creating research methods for assessing technologies that seek to create close-to-genuine nature experiences or simulate and study the disturbances in nature experiences in VR.

Comparing VR and 2D paper printouts revealed that VR was perceived as an immersive, interesting, and even exciting experience, which participants liked and which they perceived suitable to assess nature scenarios and technology embedded into it. However, 2D paper printouts were reported as giving more room for participants' imagination and reflections. The VR environment also led participants to pay attention to other details rather than the holistic landscape. Our findings comparing the landscape without and with windmills reveal that the landscape without technology was perceived more positively and as more restorative. We acknowledge that our findings are limited by the small study sample and the artificially generated content used.

Acknowledgements. This research has been supported by the project Reconceptualizing Boundaries Together Towards Resilient and Just Arctic Future(s) (REBOUND), grant number 358482 and 358498, funded by the Strategic Research Council (SRC) established within the Research Council of Finland, and ProtoXR project funded by ERDF.

5 Discussion

5.1 About the Methods VR vs 2D Printouts

The main focus of our research was to compare the methods of using VR and paper for studies concerning nature landscapes. Generally, VR versions of the scenarios were perceived as slightly more positive and less negative than the 2D version in both scales. VR was generally liked by the participants, and it was perceived as immersive and interesting. For instance, some participants who tested the VR first felt uninterested in watching the scenarios in 2D after they had already seen them in VR. Thus, we believe that the immersive and experiential power of VR can be utilized to capture people's attention to topics related to natural landscapes and technology. However, the unauthentic nature generated by AI should be carefully checked for inconsistencies.

Interestingly, the paper version was said to provide more flexibility to explore your feelings towards the setting, leaving more room for imagination. Prior research on using VR for user studies has reported that in VR, users' attention is easily captured by high-fidelity details [25]. This may be true also in our study. These findings highlight that paper illustrations and simple low-fi solutions can have their place when engaging citizens in discussions about technology and nature. We believe these methodological findings provide valuable insight when planning future studies addressing nature experiences.

5.2 About the Just Green Transition

Our research contributes to the topical discussion of just transition for green technologies [41]. Our research touches on the complex interplay between technological interventions and the preservation of genuine nature experiences. Sustainable technologies and their development are critical given the climate change crisis. However, creating and using technology that promotes environmental sustainability and reduces the ecological footprint creates conflicting responses. Some of the affected people are those who live in the areas that are subject to the implementation of large energy plants or mines. These are often remote areas, such as subarctic regions with indigenous people and their traditional lifestyle [30], and high recreational nature value for tourism. The transition to sustainable technologies already creates conflicts and societal tensions [6].

Behaviors related to eco-friendly and sustainable technological solutions are promoted as a green transition. On the other hand, locating windmills in wilderness areas is criticized for ruining the wilderness, harming the natural ecosystems including traditional occupations such as reindeer herding, and generally negatively affecting the nature experience. Our explorative study results are aligned with this, as the nature landscape without windmills was perceived more positively through the Positive and negative Affect Schedule (PANAS), the qualitative responses seconding this. Our findings suggest that immersive technologies like VR can be valuable tools for environmental impact assessments and stakeholder engagement, offering a more nuanced and richer understanding of public perceptions and acceptance of renewable energy projects.

unbalanced mixture of landscape elements and vegetation not found in the region made people wonder where they were. P10 described her experience in scenario B: “I must be at the seaside because the vegetation does not look like the vegetation of the fells. There is a strong wind there”. She made reasonable deductions based on what she saw, even though it might contradict the previous mountainous and forested environment.

Several participants felt that the environment was confusing because of the inconsistencies in the AI environment, such as rivers that disappeared and appeared in strange places, or branches hanging from the air. The AI’s weird design made it obvious that they were in the VR world. However, as participants were able to place themselves in the picture as if they were in real nature, the experience was more comprehensive. Some participants explained that they could imagine elements of real nature there, such as the sound of water and real changes in height. Some participants were impressed the how realistic the picture was. If you glanced at it fast it looked like a photograph, one participant described their first impression.

The AI-generated virtual environment made some of the participants cautious or skeptical. The virtual environment was exaggeratedly AI-like when viewed with VR glasses. The inconsistencies in the images noticed by participants (Fig. 7) and the variation in image quality disturbed the experience and moved the focus from the actual nature experience more toward other elements. One participant said that its unauthentic nature made them approach it with a certain reservation. It even felt a little annoying for them and they stated that they would rather choose “real” nature. Virtuality of the nature environment could affect participants’ perception of it. For example, P8 described their experience: “The fact that the landscape is virtual takes away the strongest edge from negative feelings. At the same time, the picture reminds us that this is a reality somewhere. Beautiful nature is being destroyed and we are all collectively guilty of it because of our energy needs”.

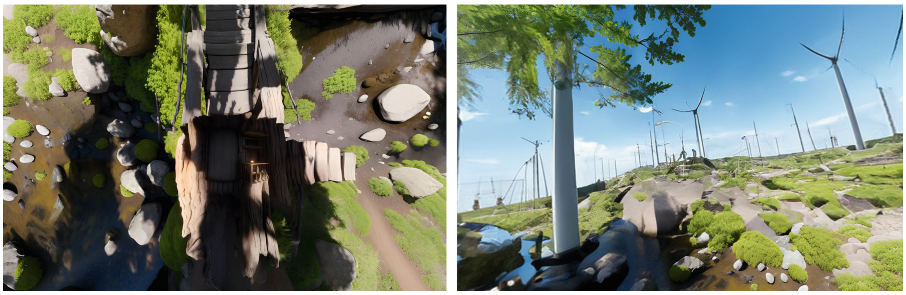


Fig. 7. Strange details in VR world generated by AI: a window on the bridge (left), half-finished wind turbines, and strange structures on the horizon (right)

4.4 VR Experience

On average, participants felt that VR as a testing method was interesting. It was mentioned that virtual nature was an interesting way to reflect on one's own nature experience. Comparing the same landscape in the picture and in VR brought up new perspectives. It made participants curious about the environment and feel like they were not in a small room. A positive feature of the VR world was being able to look everywhere around you which made the experience feel more authentic, e.g. "When working with VR glasses, you feel that you are somehow in control and the feeling is more authentic. Feels easier to belong to that place" (P13). One participant questioned the need for VR in this kind of test, e.g. "There wasn't anything to do in VR so I was wondering a bit if the VR aspect was necessary, but I was interested enough to look around the environment" (P7). Several participants mentioned that it would have been interesting to be able to move around in the VR environment, exploring the surroundings and interacting with it. One participant suggested that lying down and looking at the scenery could have been one option as well. P11 explained that her experience in VR helped her to get a general idea of the place, but at the same time she felt that she was mainly a spectator and did not feel like she could participate in the scenery.

Compared to other possible alternatives, VR was said to be the best method for this kind of use. Participants mentioned that VR helped them to imagine themselves in the setting. The 3D world and the relative scale of the objects around them were easier to understand in VR.

One factor that should be considered is the soundscape. During the experiment window was open and bird song could be heard from the outside. Some participants mentioned that fitting to the experience. During the testing, it started raining outside and the window was closed. Instead of the bird sounds, one participant heard the mechanical sound of ventilation and it seemed to affect her experience, e.g. "I feel like I hear a technical sound coming from the wind turbines. I wonder how low the wind turbines are" (P19).

Since several participants had used VR a lot, they were critical of the quality of the VR experience, e.g. "With VR, the user gets a good spatial experience, as long as the environment looks believable and not distorted" (P5). Poor quality, a fish-eye effect, and strange AI-generated elements disrupted the overall experience. Some participants also mentioned feeling dizzy or uncomfortable because of the distortion, e.g. "There were a lot of flaws in the place that broke the experience. The landscapes were disconnected from each other and were connected illogically" (P14). Seeing your body instead of hovering in the air was mentioned as one method to improve the experience.

4.5 AI-Generated Environment

Many participants were like-minded about scenario A being fitting for outdoor activities such as hiking or camping. However, it did not resemble the local landscape, making it more difficult to feel a deep connection to the place. The scenario A. Especially when there was another picture as a point of comparison, the difference was clear and the negative feelings were quite strong, e.g. "Wind turbines make you irritated and the landscape somehow remains empty" (P13). One participant described nature as a place where there are no worries and you need to have respect towards it.

4.3 Immersive VR Versus 2D Printouts

After the study session, each participant was asked which testing method they liked better. Everyone answered they preferred VR as a testing method over the 2D image. Still, a few of the respondents answered that the image printed on paper helped them to imagine themselves to the scene better. With the paper version, it was perceived that there was more flexibility to explore your own reflections and feelings towards the setting, and it left more room for imagination, whereas the VR could be overwhelming with its all confusing elements. Interestingly, VR environment could also be perceived as psychologically distancing, since everything was already given and you needed to observe the scenery as a floating outsider.

Some participants who tested VR first felt uninterested in watching the scenarios again in 2D after they had already seen it in VR. They stated that looking at the image they were not as observant as in VR. It was not possible to enter the picture and the landscape in the same way, which they felt limited their experience. Even if the picture was still beautiful, it remained uninteresting compared to VR: "After seeing the scenarios in VR, I don't really care about the image" (P7). The 2D image looked nice, but it did not make as strong impression as VR "It's hard to get anything out of the picture alone after wearing VR glasses" (P3).

The VR experience was perceived to be more forgiving of the inconsistencies in the AI design. Respondents said they paid less attention to little details when there was more to explore. In VR the virtuality of the environment felt less disruptive than on paper. This could be explained that virtuality feels more natural in Virtual Reality as it is automatically part of it. Virtuality in this case refering to the artificial nature of the environment. Vague unfinished AI structures were not visible on a printout. It helped participants to focus better, and some felt more active while looking at the paper image than in the VR world. The 2D picture was mentioned being more "cozy" than VR environment. It was easy for many to imagine the sounds in the scenery through the 2D image, e.g. water and birds in scenario A and the loud noise of wind turbines in scenario B.

The evaluation of the positive and negative feelings evoked by the scenarios produced conflicting answers. For example, P1 felt that the experience of scenery B was more positive in 2D than in VR. Whereas, P3 was surprised how negative feelings were also transmitted through just a picture.

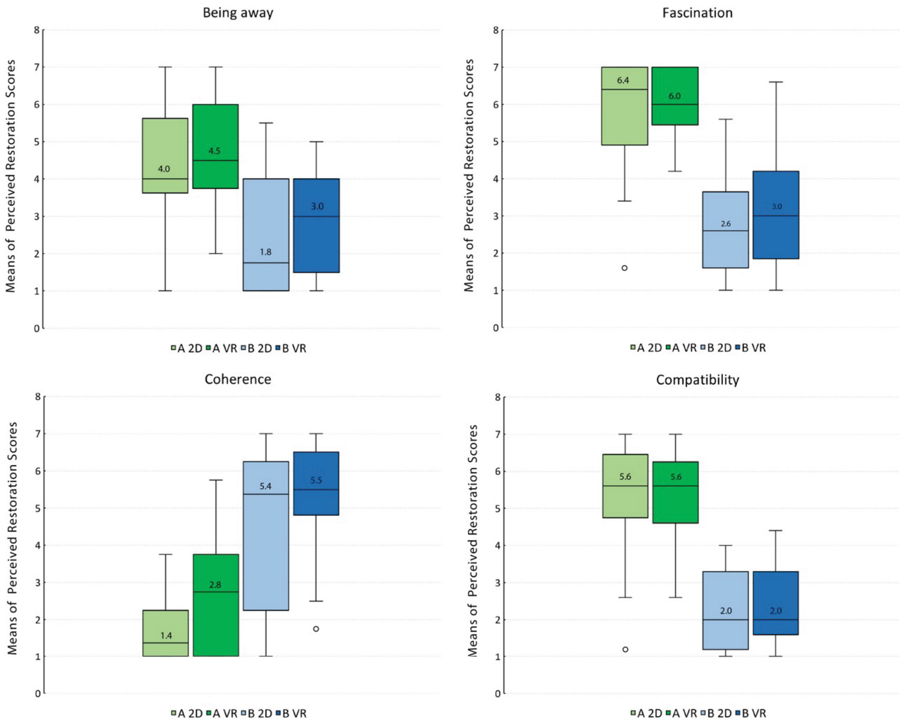


Fig. 6. Boxplot of perceived restoration divided by four categories in both scenarios with VR and 2D (n = 14)

On the negative side, the abundance and proximity of wind turbines were said to spoil the nature experience, e.g. "Wind turbines spoil the landscape. You wonder what kind of noise the turbines make if you walk among them" (P14). However, it was not seen to affect the fascination with the place itself since large-scale mechanical things can be as fascinating to watch as nature, e.g. "Wind turbines could also be fascinating objects, mainly to look at and wonder. Technology is also interesting along with nature" (P6).

A more neutral viewpoint argued that wind turbines were a surprising element after scenario A. When viewed from a distance, wind turbines were a somewhat neutral sight. But in the foreground of the picture, they arouse the viewer's desire to quickly pass by. The presence of wind turbines seemed somehow pervasive and disturbing. The presence of strange wind turbines was said to give the place a cursed impression which confused the viewer. Visiting there might be interesting but wind turbines were seen as somehow threatening as if they could attack you, e.g., "a dystopian landscape where I just want to cut down the wind turbines" (P12).

It was also mentioned that in scenario B human influence on the landscape was clearly present which made the place feel not as mentally relaxing as in

With PRS, the VR version got higher scores in each category, Fig. 5. The greatest difference was with coherence, where the difference between VR and 2D was 0.9 in scenario B and 0.78 in scenario A. Overall, scenario B was evaluated as more confusing, distracting and chaotic than scenario A. Also, compatibility with scenario A was between 5–6, whereas scenario B was between 2–3. Participant P9 explained that for them, an environment that was as natural as possible seemed to be the most interesting and suitable for their personality. Several responded similarly, e.g. P3 when describing Scenario B in VR: "although there was a lot of interesting things in this place, the scenery was depressing". P1 did not feel a connection to a place like presented in scenario B, but mentioned that seeing many wind turbines in the same place would be an experience itself. They could visit the place, but would not like to spend long periods of time there. More detailed differences of the perceived restoration can be seen in Fig. 6. For example, in coherence, there is a noticeable dispersion in the 2D version of scenario B. Some of the participants mentioned that confusion, distraction, or chaos is not always a negative thing. That might partly explain the split in the responses.

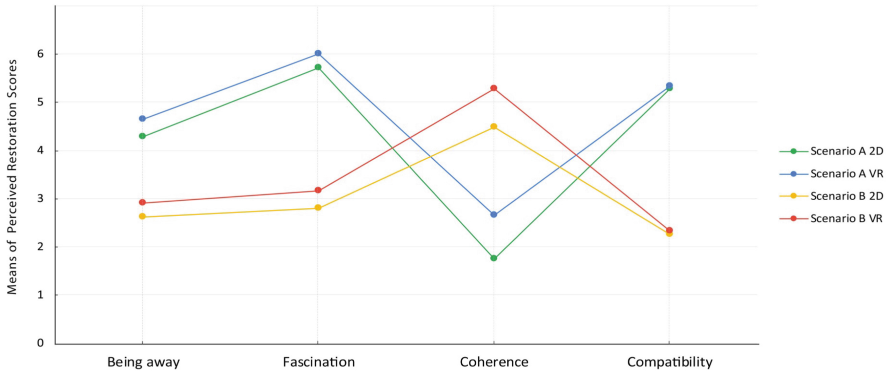


Fig. 5. Means of perceived restoration divided by four categories in both scenarios with VR and 2D (n = 14)

4.2 Green Energy and Sustainability

Scenario B who's landscape was dominated by wind turbines, aroused mixed feelings in the viewers. Sustainability issues came to mind for many and both pros and cons were shared in the answers. More on the positive side of opinions the progress in the use of wind power was seen as a good thing. Also, huge wind turbines were mentioned to arouse interest or curiosity, e.g. "The landscape and the view are new. I have never been near wind turbines built so close together. A confusing, but at the same time curious state of being" (P10). On the other hand, the built environment was also stated to be more boring compared to nature.

Table 1. Significant Pairs

Dataset	Scenario 1	Scenario 2	Statistic	p-value	Significant ($p < 0.0083$)
Positive	A 2D	A VR	13.0	0.040921	False
Positive	A 2D	B 2D	0.0	0.002200	True
Positive	A 2D	B VR	5.0	0.001221	True
Positive	A VR	B 2D	0.0	0.000122	True
Positive	A VR	B VR	0.0	0.000122	True
Positive	B 2D	B VR	38.0	0.936938	False
Negative	A 2D	A VR	10.0	0.495868	False
Negative	A 2D	B 2D	0.0	0.002209	True
Negative	A 2D	B VR	0.0	0.003346	True
Negative	A VR	B 2D	1.0	0.002852	True
Negative	A VR	B VR	1.0	0.002852	True
Negative	B 2D	B VR	16.0	0.439659	False

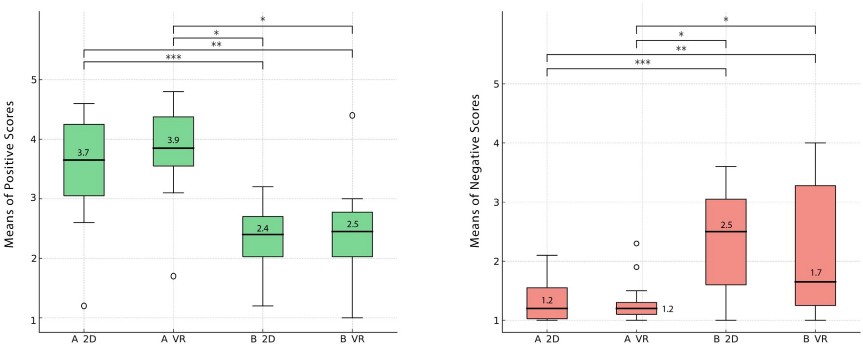


Fig. 4. Boxplot of Positive and Negative Affect Schedule in scenarios A and B with VR and 2D ($n = 14$); Significant Pairs *($p = 0.0001$), **($p = 0.001$), ***($p = 0.002$)

Table 2. Statistics (PANAS)

	Dataset	A 2D	A VR	B 2D	B VR
Mean	Positive	3.528571	3.857143	2.321429	2.378571
Median	Positive	3.650000	3.850000	2.400000	2.450000
Standard Deviation	Positive	0.940072	0.805476	0.609134	0.842321
Mean	Negative	1.321429	1.307143	2.342857	2.192857
Median	Negative	1.200000	1.200000	2.500000	1.650000
Standard Deviation	Negative	0.355568	0.370995	0.922967	1.125552

Fig. 3. Left a participant evaluation of the environment from a picture. Right a participant watching the scenery in VR.

their familiarity with VR, one had tried VR once, 4/14 a few times (1–5), and 9/14 had used VR more than five times.

4 Results

4.1 Comparing Scenarios Without (A) and with (B) Windmills

Statistical tests were run separately for positive and negative datasets (PANAS). First, a non-parametric Friedman test was conducted to examine whether there were significant differences in participant responses across the different scenarios and viewing methods: A 2D, A VR, B 2D, and B VR. The results of the Friedman test indicated a significant difference between the conditions, $x^2(3) = 29.82,\ \mathrm{p} < .001$. Similarly, the results of the negative dataset indicated a significant difference between the conditions, $x^2(3) = 24.93$, $\mathrm{p} < .001$. To further investigate these differences, pairwise comparisons were conducted using Wilcoxon Signed-Rank Tests with a Bonferroni correction applied to account for multiple comparisons ($\alpha = 0.0083$). The results are presented in Table 1.

On average, participants associated more positive words towards nature with minimal human impact than nature with extensive human impact. Figure 4 illustrates how scenario A without windmills scored higher (3.53; 3.86) on the positive affect schedule than scenario B with windmills (2.32; 2.38) Table 2. Scenario A was also perceived as less negative (1.32; 1.31) than scenario B (2.34; 2.19). The difference between positive and negative affect was seen in the case of scenario A where positive affect surpasses 3.5 and negative affect stays under 1.5. On the contrary, scenario B was perceived almost as positive as negative. Generally, VR versions of the scenarios were perceived slightly more positively and less negatively than the 2D version in both scales. However, in the case of VR version of scenario B there is great dispersion between answers.

Fig. 1. AI generated virtual environment, left Scenario A, right Scenario B

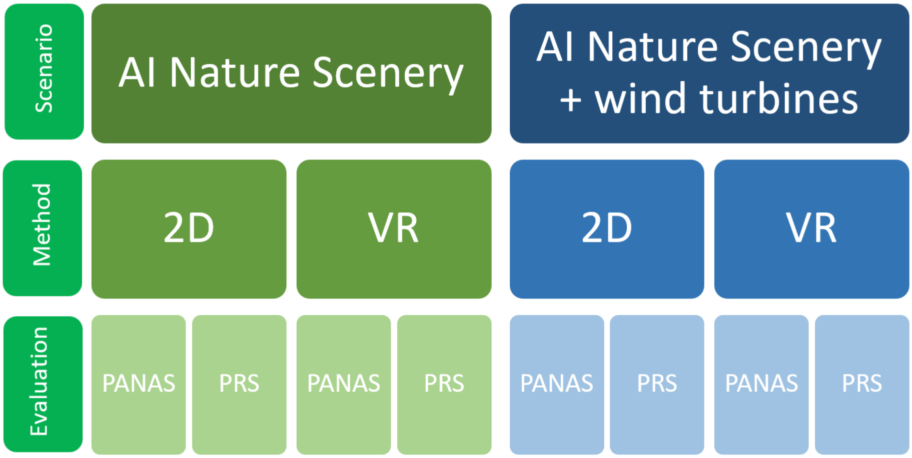


Fig. 2. Study structure

interaction with the software, with a researcher changing the images remotely using the pc when the participant indicated that they were ready to move to the next image. The wireless connection induced no significant latency that would affect the user experience. Half of the subjects were shown VR first (Fig. 2). After spending 5–10 min exploring the VR environments (scenario A and scenario B), the participants evaluated their experience using PANAS and PRS, and filled out the questionnaire on a computer. The other half of the subjects started by viewing 2D printed versions of the same scenarios and completing a paper version of the same questionnaires. The time participants spent in the study varied from 30 min to two hours, with an average of 45 min. The scenarios were shown to all the participants in the same order, scenario A first and scenario B second.

3.2 Participants

In total, the study included 14 participants (seven men, six women, and one non-binary person), with the ages between 18–24 (2/14), 25–34 (9/14), 35–44 (2/14), and 45–54 (1/14), with affiliation in different disciplines of design. Considering

3 Research Method

3.1 Study Set-up

The Virtual Nature Environment. The study used two different scenarios of nature environments generated by AI (Fig. 1). SkyboxAI was used to create the 360 image. The used prompt was: Northern Europe Forest landscape, European spruce, European red pine, birch, blue river with waterfall, subshrub, lush plants. The idea was to generate a virtual nature environment that resembled the environment that the subjects were used to seeing. After three rounds of generation, the result was satisfying enough. However, AI wanted to include mountains and vegetation that might distance the virtual nature from the natural setting of the study area. A 360 picture was then edited in Adobe Photoshop. Using Photoshop's generative fill tool the environment was modified. The used prompt was: Wind turbines park. This time the AI tool had some issues completing the task. The wind turbines were distorted and too small. After seven rounds of generation, the best option was chosen from the 21 edited images. The image quality deteriorated during the editing process, although the 360 perspective remained intact. Also, the picture itself was quite provocative, changing the landscape significantly from the unedited version (lack of trees and mountains). Both mentioned factors were expected to affect the VR experience.

Questionnaire with PANAS and PRS. In the study, two different scales were used to evaluate the experience. Positive and negative Affect Schedule (PANAS) [42] and Perceived Restoration Scale (PRS) [14] Both scales were offered in English and with the subjects' native language. As the scales are commonly used in studies exploring the restoration of virtual and real environments, they were deemed as suitable for comparing a virtual nature experience through VR and from the 2D printed image. In PANAS there were 10 positive words and 10 negative words that respondents estimated in what extent the virtual nature made them feel that emotion, on a five-point Likert scale where 1=Not at all/very slightly; 5= Extremely. The total score is calculated by finding the sum of the 10 positive items, and then the 10 negative items. Scores range from 10–50 for both sets of items. For the total positive score, a higher score indicates more of a positive affect. For the total negative score, a lower score indicates less of a negative affect. [42]

Four elements Being away, Fascination, Coherence, and Compatibility of Perceived Restoration were measured on a seven-point Likert scale with sixteen statements. (1=Not at all; 7=Completely). After each section, the respondent was asked to explain in a few words the reasons that made them feel the way they had described above.

The scenarios were shown to the subjects in two forms, as a 360° image in VR via a head-mounted display and a 2D image printed on A4-sized paper, Fig. 3. Subjects could hold the picture in their hand during the evaluation. The VR headset was the Meta Quest 3, ensuring sufficient graphical fidelity and field of view, which was connected wirelessly to a computer. The participants had no ments presented using VR video can alleviate stress to some extent. Although an artificial environment is not as effective in relieving stress physically as a natural environment, it can still relieve stress psychologically. The use of static 360 videos from peaceful natural locations with local cultural context and minimal visible or audible human influence is an effective approach when designing virtual natural environments for stress reduction [17].

2.3 Restoration and Measuring the Affect

One approach to studying the various positive effects of nature is restoration. Restoration means recovery from stress, and renewal of a person's physical, psychological, and social resources, which have decreased due to adaptation to stress factors triggered by the environment [13,19]. According to Ulrich et al.'s [39] Stress Reduction Theory (SRT), nature, green spaces, and images of nature support restoration. Attention Restoration Theory (ART) suggests that spending time in nature or viewing it can improve mental fatigue and concentration [18]. According to ART, restorative experiences consist of four elements: being away, fascination, coherence, and compatibility. These four categories are used as a base of the Perceived Restorative Scale (PRS), which is a tool developed by Hartig et al. [14] to measure the restorative quality of environments. One of the main goals is to give planners a measurement tool that could be used to assess the effects of current and future spaces. The scale uses ART properties as measurement attributes. The object is evaluated according to 16 statements with a seven-point scale.

Another scale commonly used to evaluate feelings is the Positive and Negative Affect Schedule (PANAS) developed by Watson et al. [42]. This mood scale consists of 20 words, half of which measure positive affect and the other half negative affect. Each item is rated on a five-point scale. Because the PANAS is a self-report questionnaire, it can be inaccurate in assessing people's mood. The answer is always subjective and depends on the reviewer's interpretation of the word and their ability to estimate their feelings. Also, not every word applies to every type of situation, so it must be taken into account when analyzing the results.

When estimating the restorative qualities of the environment, several measurements are often combined to gain a broader understanding of the factors affecting the entire experience. The research of Mattila et al. [27] examined the effects of restorative experiences in an immersive virtual reality forest environment by using the Subjective Vitality Scale (SVS), Positive and negative Affect Schedule (PANAS), Restoration Outcome Scale (ROS) and Perceived Restoration Scale (PRS). The results showed that the VR environment and a real forest were generally as restorative, but the virtual environment was perceived as more fascinating and coherent. Often virtual reality is considered to be a better method than traditional 2D media in delivering audiovisual stimuli. However, researchers have differing findings about the restorative effectiveness of VR when compared with nature photos or actual physical nature [24].

There is no single definition of VR. The field is dynamically evolving due to new research, developing technologies, and expanding application possibilities. Classical definitions of VR include, e.g. "real-time interactive graphics" [7]. However, many scholars consider VR as a broader concept [2]. Milgram and Kishino's virtuality continuum raises discussion on the distinction between real and virtual [29]. Kardong-Edgren et al. suggests immersion and presence as a way to define VR [20]. Since higher immersion results in higher presence, it is an important factor in the VR experience. Among the various VR definitions, three features are common: immersion, presence, and interaction with the virtual environment [7]. VR technology encompasses non-immersive, semi-immersive, and fully immersive spaces depending on the degree of presence and used equipment [9,11]. Non-immersive VR utilizes screens to deliver the VR experience. In this case, the virtual world does not obscure the real world and users do not feel complete presence in the scene [11,33]. Also, only some of a user's senses are stimulated. Semi-immersive experiences, e.g. a flight simulator combining both physical and virtual elements [7,11]. Fully immersive VR creates an illusion of "being there" by replacing the physical surroundings and making the person feel like they are present in the virtual world [9,31]. Typically, fully immersive VR is presented through head-mounted displays (HMD) and interaction is enabled via hand-held controllers. thus the definition of VR can slightly vary between different sources and use situations. Therefore, in this study, VR relies on a broader definition of virtual reality including non-interactive viewing of 360 pictures through an HMD.

2.2 Nature Connectedness

Humans have an evolution-based need to feel the connection with nature [21,44]. That concept is called biophilia-love of life, which Wilson [21,44] defines as the desire to connect with living beings and the natural environment. This natural tendency of humans urges them to seek connections with nature and other forms of life, including a longing to be close to nature and a preference for things that resemble it. Richardson and Butler [32] emphasize the problem of how biophilic properties commonly remain superficial in practical design projects as the most important result of biophilic design, i.e. a deeper and stronger connection with nature, is often overlooked.

Nature connectedness is defined as an individual's perceived relationship with the natural world [26]. Often it is discussed in a context of pro-environmental behavior [37], a variety of health and wellbeing outcomes, and overall happiness [4]. The basis for nature connectedness is created in childhood, but even short experiences in nature can increase connection with nature in adults [35]. A study by Calogiuri et al. [3] demonstrates that using 360 videos and computer-generated scenarios to create immersive virtual nature, can be equally effective in increasing nature connectedness, as long as the same level of immersion and interaction is offered.

Studies have presented that nature connectedness has a significant effect on health, wellbeing, and happiness [4]. Wang et al. [40] report that forest environ-such as windmills become a visible part of the landscape in many places. Despite their environmental benefits, these technologies harm the local natural ecosystems by replacing nature with a constructed environment, and affecting animals such as reindeer [36] and birds [22]. The green energy constructions also alter the visual and experiential qualities of natural environments. This raises the question about green transition technologies' impact on nature engagement and experience. Thematically, our research is part of a larger discussion of just transition for the green transition, highlighting the complex nature of sustainable technologies, green transition, and the effects on local and larger societal frameworks [16,23].

More research is needed on participatory design for pluriversal perspectives on sustainability. VR can be a useful tool in the domain, and its suitability for such studies needs to be evaluated. As the contribution of our work, we report the pros and cons of using VR compared to paper-based visualizations of nature landscapes without and with technology constructions. By exploring the methodologies to investigate green transition, we pave the way to better user research methods and research tools for citizen participation in green transition decision-making.

2 Related Work

2.1 HCI and Nature Experiences

In the area of Human-Computer Interaction, the combination of nature experiences and technology has been investigated from different viewpoints. Webber et al. [43] have presented typologies in use technology for nature engagement, and bring up dimensions of directness and distance in nature engagements. These dimensions of directness include direct, abstracted, and simulated nature experiences. It has been highlighted that technology has the potential to enhance engagement with nature, promoting wellbeing and awareness of natural environments as well as its fragility [12]. However, designing technology for nature encounters requires addressing the balance between support and intrusiveness, especially in mobile contexts, where devices can both enhance and disrupt the user's interaction with nature and outdoors [28].

VR and AR technologies can contribute to linking individual users with environmental issues by providing immersive experiences for learning, increasing users' self-efficacy, and influencing behavior change [8]. However, while technology enables simulated nature experiences, it often lacks the multisensory qualities of authentic nature. For connecting with nature, extended reality (XR) technologies have been used for immersive experiences with nature [10], embodying animals in immersive virtual environments [1], and for gamified experiences for environmental awareness [34]. A systematic literature review of 80 papers focusing on VR and AR with environmental sustainability revealed that most commonly the technologies were used for education and learning purposes, followed by promoting ecological behavior [8] such as for behavioral change in plastic consumption [5].

Exploring VR as a Method to Study User Perceptions of Challenges in Green Transition Technology in Nature

Petra Nurmela(✉), Juri Etto, and Jonna Häkkilä

University of Lapland, Rovaniemi, Finland
{petra.nurmela,juri.etto,Jonna.Hakkila}@ulapland.fi

Abstract. In this paper, we explore Virtual Reality (VR) as a tool for user studies assessing nature perceptions. We collect user perceptions of green transition technology in nature, and compare a natural landscape and one with windmills, both as paper and VR representations, in a user study (n = 14). Our salient findings indicate that while VR provides more immersive and engaging experiences, paper-based visualizations allow more freedom for the user's own imagination and reflections on personal experiences on green technologies in nature. Moreover, in VR, the participants tend to get more distracted by the visual details, for instance the implausibilities of the virtual world. The landscape without windmills was perceived as more positive (PANAS) and more restorative (PRS).

Keywords: nature · HCI · virtual reality · user studies · user experience · green transition · sustainability

1 Introduction

Nature connection has been reported to improve both physical and mental health and wellbeing [45,46], and also emerging technologies have been utilized for fostering this connection [12,38]. This paper explores the use of VR in assessing user perceptions of nature landscapes and compares how people perceive a natural landscape with a landscape containing built technology. Our research contribution is two-fold. Firstly, we investigate the method of using VR for assessing human perceptions of natural landscapes and compare the approach to paper-based visual presentations of nature landscapes. Secondly, we explore people's perceptions of integrating a green transition technology, windmills, into the landscape visualizations. The motivation of our research lies in evaluating and developing research methods to assess technology-mediated nature experiences.

Our work is partially motivated by the global trend of green transition, which includes setting up new large-scale technological solutions [41]. As we increasingly seek sustainable solutions to address environmental concerns, technologies

E. Brooks et al. (Eds.): DLI 2024, LNICST 604, pp. 51–68, 2025.
https://doi.org/10.1007/978-3-031-85663-1_4

18. Wickens, C.D.: Virtual reality and education. In: 1992 IEEE International Conference on Systems, Man & Cybernetics, pp. 842–847. IEEE (1992). https://doi.org/10.1109/ICSMC.1992.271688
19. Witmer, B.G., Jerome, C.J., Singer, M.J.: The factor structure of the presence questionnaire. Pres. Teleoper. Virtual Environ. **14**(3), 298–312 (2005)
20. Witmer, B.G., Singer, M.J.: Measuring presence in virtual environments: a presence questionnaire. Presence **7**(3), 225–240 (1998)
21. Zechner, O., Kleygrewe, L., Jaspaert, E., Schrom-Feiertag, H., Hutter, R.V., Tscheligi, M.: Enhancing operational police training in high stress situations with virtual reality: experiences, tools and guidelines. Multimodal Technol. Interact. **7**(2), 14 (2023)

References

1. Allcoat, D., Von Mühlenen, A.: Learning in virtual reality: effects on performance, emotion, and engagement. Res. Learn. Technol. (2018)
2. Apostolakis, K.C., Dimitriou, N., Margetis, G., Ntoa, S., Tzovaras, D., Stephanidis, C.: Darlene–improving situational awareness of European law enforcement agents through a combination of augmented reality and artificial intelligence solutions. Open Res. Europe **1** (2021)
3. Barkoukis, V., et al.: Virtual reality against doping: the case of project VIRAL. In: Auer, M.E., Tsiatsos, T. (eds.) IMCL 2021. LNNS, vol. 411, pp. 487–496. Springer, Cham (2022). https://doi.org/10.1007/978-3-030-96296-8_44
4. Caserman, P., et al.: Virtual reality simulator for police training with ai-supported cover detection. In: Joint International Conference on Serious Games, pp. 181–193. Springer, Heidelberg (2023). https://doi.org/10.1007/978-3-031-44751-8_13
5. Conges, A., et al.: Situational awareness and decision-making in a crisis situation: a crisis management cell in virtual reality. Int. J. Disast. Risk Reduct. **97**, 104002 (2023)
6. Kinateder, M., Warren, W.H.: Social influence on evacuation behavior in real and virtual environments. Front. Rob. AI **3**, 43 (2016)
7. Kleygrewe, L., Hutter, R.V., Koedijk, M., Oudejans, R.R.: Virtual reality training for police officers: a comparison of training responses in vr and real-life training. Police Pract. Res. **25**(1), 18–37 (2024)
8. Lønne, T.F., Karlsen, H.R., Langvik, E., Saksvik-Lehouillier, I.: The effect of immersion on sense of presence and affect when experiencing an educational scenario in virtual reality: a randomized controlled study. Heliyon **9**(6) (2023)
9. Narciso, D., Melo, M., Rodrigues, S., Paulo Cunha, J., Vasconcelos-Raposo, J., Bessa, M.: A systematic review on the use of immersive virtual reality to train professionals. Multimedia Tools Appl. **80**, 13195–13214 (2021)
10. Peffers, K., Tuunanen, T., Rothenberger, M.A., Chatterjee, S.: A design science research methodology for information systems research. J. Manag. Inf. Syst. **24**(3), 45–77 (2007)
11. Ponder, M., et al.: Immersive vr decision training: telling interactive stories featuring advanced virtual human simulation technologies. In: Proceedings of the Workshop on Virtual Environments 2003, pp. 97–106 (2003)
12. Pouliou, P., Ourda, D., Barkoukis, V., Palamas, G.: Empowering young athletes: elevating anti-doping education with virtual reality. EAI Endorsed Trans. e-Learn. **9** (2023)
13. Reis, R.S., Hino, A., Añez, C.: Perceived stress scale. J. Health Psychol. **15**(1), 107–114 (2010)
14. Rosenkvist, A., et al.: Hearing with eyes in virtual reality. In: 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 1349–1350. IEEE (2019)
15. Scorgie, D., Feng, Z., Paes, D., Parisi, F., Yiu, T., Lovreglio, R.: Virtual reality for safety training: a systematic literature review and meta-analysis. Saf. Sci. **171**, 106372 (2024)
16. Unity Technologies: Unity Game Engine [Computer Software], Version 2022.3.22f1 (2022). https://unity.com/
17. Voigt, L., Frenkel, M.O.: How officers perform and grow under stress: police training in virtual reality. In: Police Conflict Management, vol. II: Training and Education, pp. 187–211. Springer, Heidelberg (2023)

long-term impact of VR training to determine whether these initial gains in performance and engagement are sustained over time.

Another potential area for future work is the incorporation of advanced features such as eye-tracking technology. Eye-tracking could offer more precise data on where participants are focusing their attention, allowing for more detailed analysis of performance. This would also enable trainers to identify areas where participants might be struggling or distracted, providing opportunities for targeted interventions.

Lastly, while this study focused on apartment searches, VR training can be expanded to include other areas of law enforcement, such as conflict de-escalation, crowd management, or tactical operations. Expanding the use of VR beyond basic operational training would help prepare police officers for the diverse scenarios they may encounter in the field.

6 Conclusion

This study examined the effectiveness of a Virtual Reality (VR) simulator as a supplementary tool for developing situational awareness skills in police training, particularly situational awareness during apartment search operations. The findings demonstrate that while VR enhances user confidence and allows for quick adaptation to virtual environments, the usability of control devices and visual display quality play critical roles in determining task focus and performance outcomes.

Control device interference was found to significantly impact participants' concentration and overall task performance, highlighting the need for further optimization of control mechanisms. Additionally, visual interference was strongly correlated with control issues, indicating that improvements in both areas are essential for enhancing the VR training experience.

Although stress was shown to slow down task completion times, it did not significantly affect performance accuracy, suggesting that participants were able to maintain precision under pressure. This indicates that VR can effectively simulate high-pressure environments without negatively impacting task quality, making it a valuable tool for preparing police cadets for real-world challenges.

However, the novelty of VR technology and the small sample size used in this study suggest that further research is necessary. Future studies should focus on larger participant groups, extended real-world application, and potential improvements to control devices and visual displays. Incorporating advanced technologies such as eye-tracking could provide more precise data on participant focus, enabling more targeted training interventions.

Overall, the VR simulator presents a promising and scalable solution for enhancing soft skill training, particularly situational awareness, in police academies. By addressing the identified limitations, VR can play an integral role in preparing law enforcement officers for complex and high-stakes scenarios through immersive and efficient training environments.

The usability of the VR interface, which participants rated positively, highlights the importance of user-friendly design. Participants were able to adjust to the controls relatively quickly, but the moderate correlation between control device interference and adjustment difficulty ($r = 0.4$) suggests that even minor improvements in the intuitiveness of the interface could further enhance the user experience and training outcomes.

5.3 Effect of Stress on Performance

The study also revealed that while stress had a moderate negative correlation with task completion times ($r = -0.45$), it did not significantly affect task performance quality. This finding aligns with previous studies by Caserman et al. [4], which indicated that VR-induced stress might slow down decision-making but does not necessarily impair the ability to perform tasks accurately.

This is particularly relevant in police training, where cadets must be able to function effectively under high-pressure situations. The ability of VR to simulate stress-inducing environments without negatively impacting task accuracy demonstrates its value as a training tool. Future iterations of VR simulators should aim to manage stress levels to improve task efficiency without compromising performance quality.

5.4 Training Efficiency and Practical Implications

The relatively short average task completion time (180 s) indicates that VR can efficiently replicate critical elements of traditional training, such as apartment search operations, without requiring extensive time and resource investments. VR's adaptability and scalability allow for the rapid creation of varied training environments, making it a valuable tool for police academies that may face logistical challenges when providing frequent training opportunities.

The strong correlation between control device interference and visual interference emphasizes the need for improving both control mechanisms and visual display quality to ensure high levels of training fidelity. If addressed, these improvements could make VR an even more effective and scalable alternative to traditional physical setups.

5.5 Challenges and Future Directions

While the results are promising, there are several challenges to be addressed in integrating VR as a mainstream training tool for police academies. Control device interference was found to significantly affect participants' focus and task performance. Therefore, improving the intuitiveness of the control devices and minimizing visual interference should be a priority in future developments of VR training programs.

Additionally, the novelty of VR technology may have contributed to initial enthusiasm, which could influence the results. Future studies should explore the

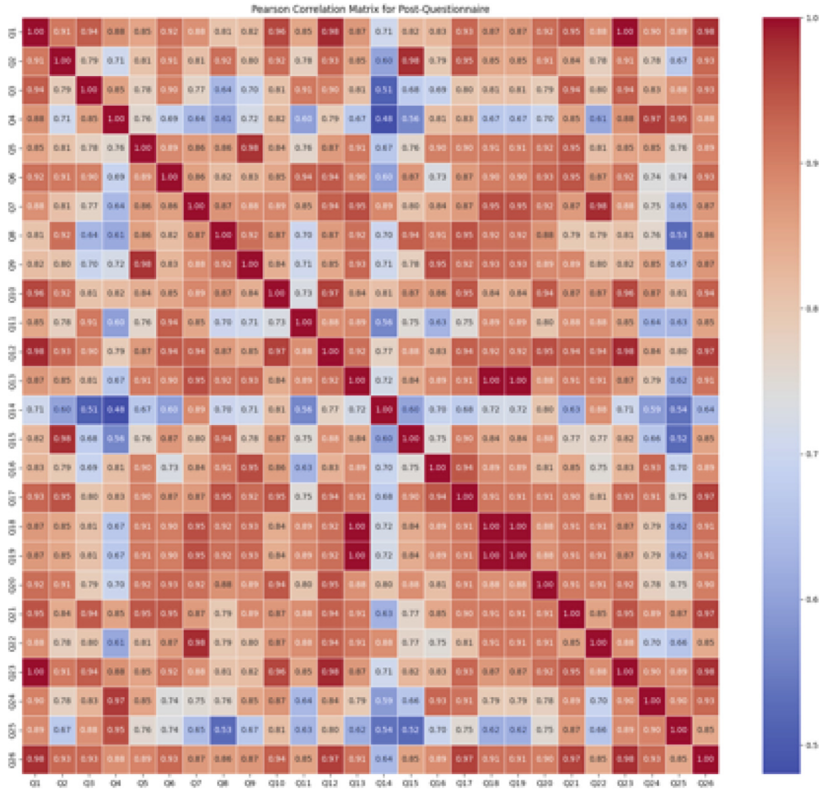


Fig. 9. Pearson correlation matrix for post-questionnaire results, illustrating relationships between control device interference, task performance, sense of immersion, and other factors. Strong correlations are in red, and weaker correlations are in blue. (Color figure online)

Moreover, the strong correlation between control device interference and visual interference ($r = 0.7$) suggests that these two factors may compound the overall difficulty of performing tasks in VR. This indicates that improving control mechanisms must go hand in hand with ensuring high-quality visual displays to minimize distractions and improve performance.

5.2 Role of Immersion and Usability

The sense of immersion plays a critical role in the effectiveness of VR training. As noted by Witmer et al. [19], immersion is key to engaging users deeply in simulated scenarios. In this study, participants who reported higher immersion levels also experienced better task performance. This reflects the importance of not only providing intuitive control devices but also ensuring that the overall VR experience is seamless, with minimal technical distractions.

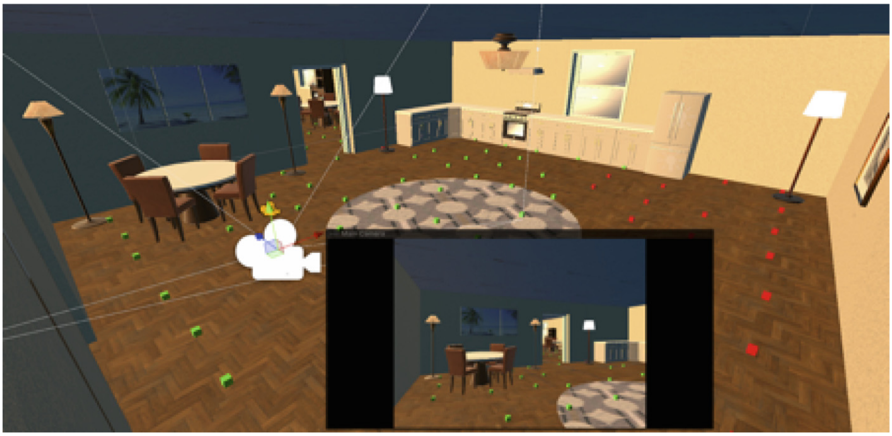


Fig. 8. Trainee's perspective during the training session, showing secured points in the virtual environment. This live scoring system allows the instructor to monitor the trainee's progress in real-time.

These findings suggest that improving control mechanisms and minimizing visual distractions could enhance task performance in VR training environments. Addressing stress management could further improve task efficiency without sacrificing performance quality.

5 Discussion

The results of this study suggest that Virtual Reality (VR) can be a viable tool for supplementing training in tasks such as apartment searches. By leveraging immersive environments, VR offers potential for improving both perceived and actual task performance. This section discusses the implications of these findings, aligns them with existing literature, and explores potential challenges and opportunities for integrating VR into police training programs.

5.1 Impact on Training Outcomes

The study results highlighted the importance of control device design and usability in influencing task performance in VR training. Participants who experienced less interference from control devices reported better focus, leading to improved task performance. The moderate negative correlation between control interference and task focus (r = -0.5) aligns with previous research by Narciso et al. [9], which emphasized the role of ease of use in enhancing the effectiveness of VR training. This finding suggests that optimizing control devices could significantly enhance training outcomes by enabling participants to better concentrate on task objectives rather than the mechanisms of interaction.

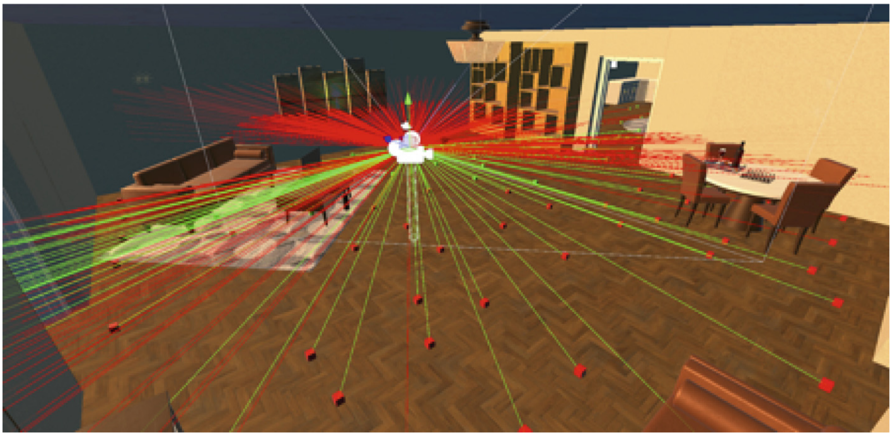


Fig. 7. Visualization of the operator's field of view and sensor rays used for tracking areas observed during the training session. These rays help the simulator detect which parts of the virtual apartment the operator has examined.

As shown in Fig. 9, the Pearson correlation matrix highlights significant relationships between various aspects of the VR experience. In particular, control device interference (*Q02*) shows strong correlations with task focus (*Q06*) and visual interference (*Q07*), suggesting that difficulties with control devices and visual display quality often co-occur and can negatively affect task performance.

4.2 Impact of Perceived Stress on Performance

A moderate negative correlation ($r = –0.45$) was found between perceived stress and task completion time, indicating that participants who experienced higher levels of stress tended to take longer to complete their tasks. However, the correlation between stress levels and performance quality ($r = 0.21$) was not significant, showing that while stress affected the speed of task completion, it did not reduce the overall quality of task execution.

4.3 Key Findings

The results of the study point to several key conclusions:

- Control Device Interference: Control device interference significantly impacted task performance and focus, with greater interference correlating with decreased concentration and a reduced sense of control.
- Visual Interference: Control device interference often coincided with visual display issues, compounding distractions and impairing task execution.
- Stress and Task Completion: Higher stress levels were associated with slower task completion times but did not affect task quality, indicating that participants maintained accuracy despite feeling stressed.

Fig. 6. Detailed view of a room with furniture in the VR simulator. This image highlights the intricate details included in the virtual environment to improve immersion and support cadets' situational awareness during training.

ronment. Question *Q02* ("How much did the control devices interfere with the performance of the assigned tasks?") revealed significant correlations with various aspects of the VR experience, indicating that control mechanisms played a critical role in shaping task performance and user experience.

A negative correlation ($r = -0.5$) between *Q02* and *Q06* ("How well could you concentrate on the assigned tasks rather than on the mechanisms used to perform said tasks?") indicates that greater interference from the control devices was associated with reduced task focus. Our findings align with prior studies showing VR's impact on focus and stress handling. For example, in anti-doping training, VR was found to support focus and situational awareness under pressure, a critical aspect of high-stakes decision-making [3]. This parallels the need for police officers to remain focused and effective in demanding training scenarios. Participants who experienced more difficulty with the control devices had greater trouble concentrating on the task objectives.

A strong positive correlation ($r = 0.7$) between *Q02* and *Q07* ("How much did the visual display quality interfere or distract you from performing the assigned tasks?") suggests that participants who reported interference from the control devices also experienced difficulties with the visual display quality. This highlights the potential interconnectedness between control and visual issues, which could amplify the overall interference with task execution.

A moderate positive correlation ($r = 0.5$) between *Q02* and *Q01* ("How much influence did you feel you had over interactions with the virtual apartment?") indicates that as interference from the control devices increased, participants reported feeling less control or influence over their interactions within the virtual environment. This further emphasizes the need for user-friendly controls to enhance participants' sense of agency.

Fig. 5. Room with basic furniture in the VR simulation. The inclusion of furniture increases the complexity of the virtual apartment, enhancing the realism of the training and challenging cadets to identify potential risks and obstacles.

by participants were reflected in their actual performance during the simulation. Furthermore, improvements in self-reported confidence post-training provided additional evidence supporting the effectiveness of the VR simulator as a supplementary training tool.

3.5 Limitations

Despite the promising findings, there were several limitations to this study. The small sample size of participants limits the generalizability of the results to a broader population. Additionally, there is the potential for novelty bias, as participants may have been more enthusiastic about using the VR system due to its novelty rather than focusing solely on the training content. Although every effort was made to mitigate this by clearly communicating the training objectives to participants, the influence of novelty on their responses remains a potential limitation.

The technical capabilities of the VR equipment also imposed certain restrictions. For instance, the simulator lacked advanced features such as eye-tracking, meaning that only head-tracking was used to determine where participants were looking. This limitation may have impacted the precision of the performance metrics, although the system still provided valuable insights into how well participants navigated and cleared risk zones.

4 Results

4.1 Control Device Interference and Task Performance

The analysis of post-questionnaire responses provided valuable insights into how control device interference affected participant performance within the VR envi-

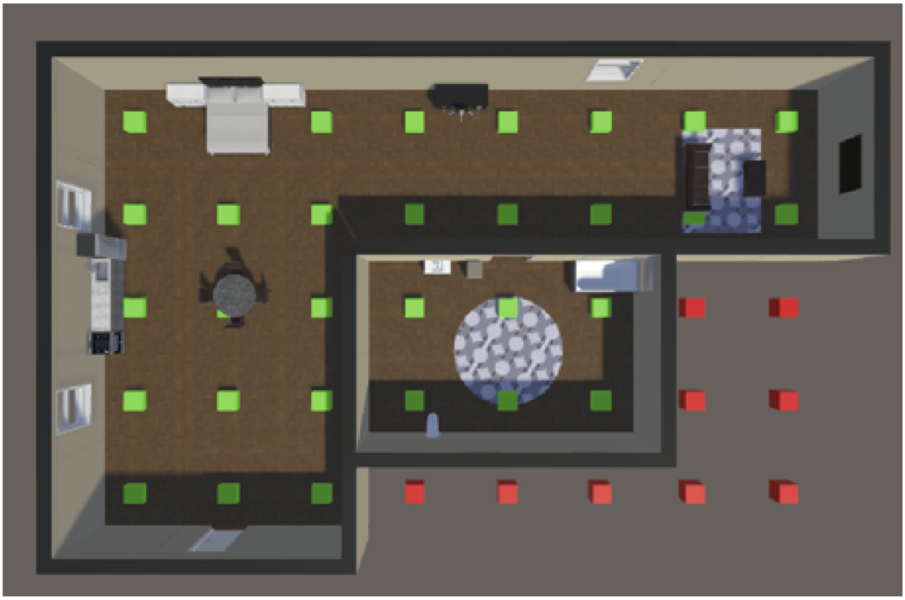


Fig. 4. 3D model of a room with checkpoints. This image shows the integration of checkpoints within the training environment, guiding cadets through key areas they need to secure during virtual apartment searches.

VR simulations. The primary aim was to develop the prototype and evaluate it by determining the correlations between the participants' self-reported confidence, perceived stress, and their objective performance scores and time metrics.

The analysis involved comparing pre- and post-questionnaire results to evaluate how the VR training impacted participants' confidence and sense of presence. For instance, the self-reported confidence levels from the pre-questionnaire were compared against those in the post-questionnaire, allowing for a measure of improvement after completing the VR training. Box plots and other visualizations were used to illustrate the spread and central tendency of responses, helping to identify trends in how participants perceived their training experience.

Additionally, correlation matrices were used to identify relationships between variables, such as the association between perceived stress and performance scores or time taken to complete the simulation. High correlation scores between these variables helped determine the extent to which stress influenced performance in the VR environment. Correlation matrices were particularly useful in revealing patterns, such as whether participants with higher initial confidence saw greater performance gains from VR training, or whether stress levels significantly affected task completion time.

To ensure that the findings were robust, the performance metrics from the simulator were cross-referenced with the subjective data. This cross-analysis enabled the study to explore whether improvements in confidence as reported

Fig. 3. Overhead floor plan of a virtual apartment. This image shows the layout used to guide cadets in navigating virtual environments, providing a clear view of risk zones and checkpoints within the simulation.

The pre-questionnaire aimed to gather information about the participants' prior experience with VR, their perceived stress levels using the Perceived Stress Scale (PSS) [13], and their confidence in conducting apartment searches. Additionally, participants were asked to estimate how effective they believed VR would be as a tool for improving their search abilities. The outcome of this question compared with the actual performance score and helped to determine the

After completing the VR training, participants filled out a post-questionnaire based on the Presence Questionnaire by Witmer et al. [20], which assessed their sense of presence and engagement in the virtual environment. Further questions were included to evaluate the usability of the control devices and how much the training experience improved their confidence in conducting apartment searches.

Objective data was collected directly from the VR simulator during the training exercises. Two key metrics were recorded: (1) the time taken to complete the apartment search and (2) the performance score, which was calculated based on the trainee's ability to correctly secure all risk zones in the virtual environment. Each risk zone was equipped with sensors, and the system automatically marked them as secure when they were observed by the trainee during the simulation.

3.4 Data Analysis

Data analysis focused on both the subjective responses from the pre- and post-questionnaires as well as the objective performance metrics collected during the

Fig. 2. Another view of a 3D room model used in the VR simulation. This provides a different perspective of the training environment, emphasizing the variability in apartment layouts for different training scenarios.

session. If a sensor is obscured by furniture, it will automatically be considered secure at the start of the session unless there is enough space between the sensor and the furniture to allow for proper observation. Each secured area contributes to the operator's score, which is assessed by the simulator (Fig. 8).

The automated assessment system was designed to accurately detect which zones in the apartment have been properly checked without compromising the simulator's performance. This allows instructors to provide live feedback based on the operator's score as they secure each risk zone.

3.3 Data Collection

To evaluate the effectiveness of the VR simulator as a training tool, both subjective and objective data were collected during the study. The subjective data consisted of pre- and post-questionnaires administered to the participants, while the objective data were automatically collected by the simulator during the training sessions.

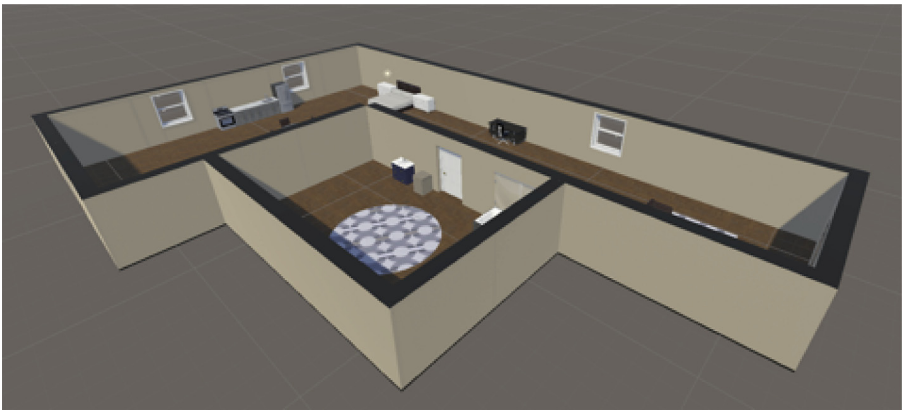


Fig. 1. 3D model of a room used in the VR simulator. This model represents the basic environment in which police cadets train for apartment searches, helping them develop situational awareness and decision-making skills.

helps cadets develop situational awareness and learn to focus on key objectives even when presented with cluttered or visually stimulating surroundings.

Although the visual fidelity of the simulator balanced simplicity and realism, the detailed models (see Figs. 5 and 6) ensured that the training environments were engaging without being overwhelming. Previous research by Wickens [18] showed that excessive realism could detract from learning by introducing unnecessary visual information. Therefore, the simulator maintained an optimal level of detail to help cadets concentrate on identifying risks, such as the checkpoints seen in Fig. 4, and improve their ability to secure each zone effectively.

Overall, the VR simulator's design aimed to maximize immersion while focusing on core training objectives, such as decision-making under pressure and the development of situational awareness, which is a critical skill for law enforcement officers.

3.2 Simulator Monitoring and Performance Scoring

The simulator was responsible for monitoring the various inputs from the operator and using these inputs to score performance through data collection. Inputs were collected via the VR headset and the two VR controllers held by the user.

The simulator determines which objects are within the operator's field of view using the headset's position and rotation sensors. Since precise eye-tracking equipment was unavailable, the simulator assumes that everything in the operator's field of view is being observed. This data was essential in facilitating the functionality that allows the operator to secure a risk zone (Figs. 7).

Whether an area of the apartment is secured or unsecured is determined by sensors placed in key risk zones. These sensors are considered secured once they have been observed at least once, and they stay secure for the remainder of the

3.1 Artifact Development

The development of the VR training simulator followed an iterative process, divided into two phases: the creation of a level editor and the development of the VR simulator itself. The level editor enabled easy assembly of diverse apartment layouts, while the VR simulator executed apartment search scenarios in real-time. This iterative approach allowed for continuous refinement based on feedback from the police academy instructors, ensuring the final artifact met the specific training needs of law enforcement.

Level Editor. The development of the VR simulator began with the creation of a level editor, which allowed for the rapid design and customization of virtual apartment layouts used during training. This editor was designed to enable instructors to easily configure rooms by adjusting the layout and positioning of various elements such as walls, doors, and windows. By using the editor, trainers could quickly generate diverse environments that simulated real-world apartment settings.

The 3D models of these rooms (see Figs. 1 and 2) demonstrate the basic structure and variability of the apartment search environments used in the VR simulation. These environments provide the foundation for training police cadets in situational awareness, an essential soft skill for identifying potential risks and hazards in unfamiliar spaces.

In addition to the 3D room models, an overhead floor plan (Fig. 3) was generated for each virtual apartment. This floor plan outlines key areas, such as risk zones and checkpoints, that trainees need to clear during the apartment search operation. The floor plan ensures that each simulation is well-structured, enabling cadets to navigate the environment efficiently and focus on securing critical areas.

The flexibility provided by the level editor allows trainers to modify environments as needed, ensuring that trainees encounter a wide range of scenarios. This capability is critical for helping police officers develop the quick decision-making and situational awareness necessary in real-life operations.

VR Simulator. The VR simulator was designed to run on the Oculus Quest 3, providing an immersive training experience for police cadets. The system tracked the cadets' head and hand movements, enabling them to interact with and navigate through virtual apartments while searching for risk zones. As demonstrated in previous studies, room-scale VR simulations can create a high level of immersion, which is critical for training exercises that require situational awareness and decision-making under stress [4].

The virtual environments used in the simulator featured various levels of complexity, starting from basic layouts and advancing to more intricate spaces furnished with obstacles. Figures 5 and 6 illustrate these environments, where cadets were challenged to identify and secure risk zones amid furniture and other potential distractions. This progressive increase in environmental complexity training emergency responders by providing them with realistic, stress-inducing environments that mirror real-world incidents. This suggests that VR's capability to create dynamic, responsive training environments is especially beneficial for police officers, who must remain calm and effective in unpredictable, high-risk situations.

Moreover, the use of VR for decision-making in crisis situations has shown significant potential, Conges et al. [5] emphasized the importance of training police officers and crisis managers in simulated environments where decision-making under stress is a key factor. This aligns with research by Witmer et al. [19], which showed that presence and immersion in VR directly impact how effectively trainees engage with the training scenarios, ensuring better retention of learned skills.

Despite the growing body of research on VR's effectiveness in various professional fields, there remains a gap in the literature regarding its specific application to soft skill training for police officers, particularly in apartment search operations [7]. This study seeks to address that gap by investigating how VR can be used to enhance situational awareness, decision-making, and risk management in such contexts. By utilizing a design science methodology, we aim to evaluate the extent to which VR can complement traditional training methods while providing additional flexibility and scalability [17].

This research builds on existing studies and aims to contribute new insights into the role of immersive technology in law enforcement training. By focusing on situational awareness skills, this study adds a critical dimension to the broader conversation about how VR can be leveraged to enhance the training of professionals who regularly operate in high-stress, life-threatening environments.

3 Methodology

This study employed a design science research methodology, which emphasizes the iterative development of artifacts through collaboration with stakeholders, ensuring the practical applicability of the results [10]. The primary goal of this research was to prototype a Virtual Reality (VR) simulator aimed at supplementing traditional training for police cadets. Specifically, the study focused on apartment search operations, where trainees must identify and secure risk zones under pressure, simulating real-world scenarios that require situational awareness and decision-making skills.

The study was conducted at Malmö University Police Academy in Sweden, where police instructors served as stakeholders and provided critical feedback throughout the artifact development process. The VR simulator was designed and implemented using the Unity game engine [16], and the hardware employed included the Oculus Quest 3 VR headset, which offered a portable and immersive environment for training.

can stimulate situational awareness by creating a sensory-rich experience. Such multisensory simulations play a crucial role in developing high-pressure decision-making skills essential for police officers in training. Allcoat et al. [1] found that VR contributes significantly to learning outcomes by enhancing engagement, immersion, and interactivity. Blacker et al. [21] demonstrated the effectiveness of VR in improving decision-making under stress, particularly during high-pressure military operations, further highlighting the potential for VR in law enforcement training.

Despite these clear advantages, the integration of VR into official training curricula has been slow due to logistical, technological, and financial constraints [15]. Traditional police training methods often involve the creation of physical environments, such as mock apartment complexes or training facilities, which are both resource-intensive and difficult to adapt to different scenarios. As police training continues to evolve to address increasingly complex threats, VR offers a flexible, cost-effective alternative capable of generating diverse training scenarios on demand.

The educational benefits of VR are well-documented beyond law enforcement. Wickens [18] argued that while VR environments should focus on key learning objectives, it is essential to avoid unnecessary visual complexity that could overwhelm trainees. Peffers et al. [10] further highlighted the importance of structured design in developing training systems to ensure that they align with pedagogical goals. This balance between immersion and simplicity has informed the design of many contemporary VR training systems, including those used for police training.

Skills training, such as situational awareness and decision-making, is a central aspect of police education. For example, in apartment search operations, officers must quickly identify and secure risk zones, an essential task in law enforcement operations [21]. However, traditional training often lacks the scalability and adaptability needed to prepare officers for the full range of environments they may encounter in the field. VR can address this gap by offering a platform where training scenarios can be endlessly modified and adapted to different contexts, thus providing a richer, more comprehensive training experience [8].

Previous research has highlighted the role of immersion in VR-based learning environments. Ponder et al. [11] emphasized that immersion and user interaction are critical factors for the successful transfer of skills from virtual to real-world scenarios. Their work on interactive storytelling in VR found that more immersive environments resulted in better user engagement and skill retention. Narciso et al. [9], in their systematic review of VR applications in professional training, concluded that VR is particularly effective in environments requiring complex decision-making, such as those faced by law enforcement officers.

Furthermore, advances in VR technology have made it possible to integrate real-time performance tracking and automated feedback into training sessions, providing trainers with valuable data on trainee performance. This real-time assessment allows for more precise evaluations of skill development, particularly in high-pressure scenarios. Kinateder et al. [6] found that VR was effective in training, where cadets are required to develop skills such as situational awareness, decision-making, and risk management in complex and unpredictable scenarios.

Traditional police training often involves physically replicating environments where trainees must practice techniques such as securing risk zones in apartment searches. These physical setups can be costly, time-consuming, and may not always provide the variety needed to adequately prepare cadets for the diverse situations they will encounter in the field. Additionally, ensuring psychological resilience in high-pressure situations requires repeated exposure to stress-inducing scenarios, something that can be difficult to achieve consistently through traditional means.

VR offers an alternative by providing immersive, interactive environments that can replicate these complex training scenarios with high fidelity. In a VR simulation, cadets can engage in tasks such as clearing rooms, identifying risk zones, and making split-second decisions in a controlled yet realistic virtual setting. These environments are highly customizable, allowing for varied scenarios to be presented without the need for extensive physical resources.

This study explores the use of VR as a supplementary tool for training in police academies, specifically within the context of apartment search operations. The primary goal of this research was to prototype a Virtual Reality (VR) simulator aimed at supplementing traditional training for police cadets. More specifically, to which degree can VR replicate the immersive experience of real-world scenarios, maintain training quality, and contribute to the psychological preparedness of police students?

The evaluation of the VR system focused on key factors such as user immersion, interactivity, and performance outcomes. The results of this study aim to contribute to the broader understanding of how VR can be effectively utilized as a supplement to traditional training in fields where situational awareness is critical to success under pressure.

2 Background

As Virtual Reality (VR) technology continues to evolve, its applications in professional training, particularly in law enforcement, have gained increasing attention. VR offers the ability to simulate complex, high-stakes environments that are difficult or expensive to replicate in the physical world, making it a powerful tool for training in areas such as situational awareness, decision-making, and risk management. These skills are critical for police officers in high-pressure field operations where the ability to make split-second decisions can have life-or-death consequences [2].

VR has shown great potential in the realm of police training, with multiple studies demonstrating its effectiveness. Caserman et al. [4] explored VR's role in tactical police training using AI-supported simulations for cover detection, showing how immersive environments can enhance critical thinking and tactical skills. VR enhances sensory immersion, a key factor for skill development in complex environments. In [14] Rosenkvist et al. (2019) demonstrated how VR

Utilizing Virtual Reality to Enhance Situational Awareness in Swedish Police Training

Hampus Hansen, Måns Holmgren, Carl Johan Gribel, Joakim Ingrell, and George Palamas(✉)

Malmö University, Malmö, Sweden
georgios.palamas@mau.se

Abstract. This study examines police students experience of using Virtual Reality (VR) as a tool for training situational awareness during apartment search operations. The study included both a qualitative and quantitative approach to evaluate a prototype aimed to supplement traditional training. The findings highlight that control device and visual display interference significantly affect task performance and concentration. While stress increased task completion times, it did not reduce accuracy, demonstrating the value of VR in simulating high-pressure environments. VR offers a flexible, scalable, and cost-effective alternative to traditional training methods. However, optimizing control mechanisms and visual fidelity remains essential. Future research should explore advanced features like eye-tracking to further enhance the training experience. These findings contribute to the growing body of research on VR's role in police and vocational training.

Keywords: Virtual Reality · Police Training · Situational Awareness · Decision-Making · Immersion · Crisis Management · Real-Time Performance Tracking · AI-Supported Training · Law Enforcement · VR Simulation · Training Technology · High-Stakes Environments

1 Introduction

Virtual Reality (VR) technology has seen significant advancements in recent years, leading to its increasing adoption across a range of sectors, including education, healthcare, and law enforcement. In particular, VR has shown potential as a valuable tool for training in high-stakes environments, where traditional training methods may be resource-intensive and limited in scope. Beyond traditional law enforcement applications, VR has been increasingly recognized for its educational value in high-stakes environments. For instance, VR-based anti-doping education for young athletes has shown that immersive environments can effectively promote ethical decision-making and situational skills [12]. This underscores VR's versatility as an educational tool, validating its application in diverse training scenarios such as police work. One such environment is police

E. Brooks et al. (Eds.): DLI 2024, LNICST 604, pp. 33–50, 2025.
https://doi.org/10.1007/978-3-031-85663-1_3

3. Bravou, V., Oikonomidou, D., Drigas, A.S.: Applications of virtual reality for autism inclusion. a review. Retos: nuevas tendencias en educación física, deporte y recreación (45), 779–785 (2022)
4. Carnett, A., Neely, L., Gardiner, S., Kirkpatrick, M., Quarles, J., Christopher, K.: Systematic review of virtual reality in behavioral interventions for individuals with autism. Adv. Neurodev. Disord. **7**(3), 426–442 (2023)
5. Fleury, S., Chaniaud, N.: Multi-user centered design: acceptance, user experience, user research and user testing. Theor. Issues Ergon. Sci. **25**(2), 209–224 (2024)
6. Kim, G.J., et al.: A swot analysis of the field of virtual reality rehabilitation and therapy. Presence **14**(2), 119–146 (2005)
7. Københavns Kommune: Klimainvestering ii - mindre kørsel af elever i specialtilbud og modtagerklasser (2022). https://www.kk.dk/sites/default/files/agenda/f1431fc0-ce1e-4a37-aa71-0a47d879f013/e4a05e77-9029-4479-8051-5b23d8fe10b7-bilag-7.pdf. Accessed 22 Apr 2024
8. Miller, I.T., Wiederhold, B.K., Miller, C.S., Wiederhold, M.D.: Virtual reality air travel training with children on the autism spectrum: a preliminary report. Cyberpsychol. Behav. Soc. Netw. **23**(1), 10–15 (2020)
9. Nikki, M., Skjoldborg, P.K.B., de López, K.M.J.: The efficacy of head-mounted-display virtual reality intervention to improve life skills of individuals with autism spectrum disorders: a systematic review. Neuropsychiat. Dis. Treat. **18**, 2295–2310 (2022). https://doi.org/10.2147/NDT.S331990
10. Parsons, S., Cobb, S.: State-of-the-Art of Virtual Reality Technologies for Children on the Autism Spectrum. Routledge, Abingdon (2016)
11. Pfeiffer, B., Davidson, A.P., Brusilovskiy, E., Feeley, C., Kinnealey, M., Salzer, M.: Effectiveness of a peer-mediated travel training intervention for adults with autism spectrum disorders. J. Transp. Health **35**, 101781 (2024)
12. Pfeiffer, B., Sell, A., Bevans, K.B.: Initial evaluation of a public transportation training program for individuals with intellectual and developmental disabilities. J. Transp. Health **16**, 100813 (2020)
13. Preece, J., Rogers, Y., Sharp, H.: Interaction Design: Beyond Human-Computer Interaction, 6th edn. Wiley, Hoboken (2023). https://www.williamdam.dk/interaction-design-beyond-human-computer-interact-ion-sixth-edition__2887867
14. Reger, G.M., Parsons, T.D., Gahm, G.A., Rizzo, A.: Virtual reality assessment of cognitive functions: a promising tool to improve ecological validity. Brain Inj. **7**, 24–26 (2010)
15. Rowland, D.: Redefining autism. J. Neurol. Psychiat. Brain Res. **2020**(01) (2020)
16. Simões, M., Bernardes, M., Barros, F., Castelo-Branco, M.: Virtual travel training for autism spectrum disorder: proof-of-concept interventional study. JMIR Ser. Games **6**(1), e8428 (2018)
17. Sudirjo, F., Dewa, D.M.R.T., Kesuma, L.I., Suryaningsih, L., Utami, E.Y.: Application of the user centered design method to evaluate the relationship between user experience, user interface and customer satisfaction on banking mobile application. Jurnal Informasi Dan Teknologi, 7–13 (2024)

of three sessions per participant, highlighting a significant deviation from our goals.

Student 10 received six sessions in a row, while Student 11 only received one VR session, both showing some improvements during post-observations. Despite the teachers' enthusiasm and dedication, the logistical difficulties and constraints faced by the teachers and pedagogues at Frejaskolen, such as time management and scheduling, posed significant barriers.

Future iterations should include some changes to the VR train station simulation. This includes scenarios like delayed or canceled trains and last-minute track changes. Additionally, the simulation does not accurately reflect the usual crowd at Anonymous station. Anonymous station is typically quite busy, not represented by the number of NPCs walking around in the current version of the application. The number of passengers on the trains is also lacking, as trains would be almost full during peak hours, and children would have to wait their turn to get on or off the train. Since the target group might have sensory issues, including this aspect in the simulation could prepare the participants for the sensory overload they might experience at a crowded station or on a packed train. This was, however, not possible in this version due to the limited computational capabilities of the Meta Quest 2.

Additionally, in real life, children would sometimes encounter a ticket inspector, which is not part of the current simulation. Including this element could provide a valuable learning experience, teaching children how to interact with the inspector and presenting scenarios where others might not have a ticket. These situations could lead to raised voices or other behaviors, creating unfamiliar situations for the children to navigate.

Our study demonstrates VR's potential to bridge gaps in practical skill acquisition for children with ASD, while highlighting g the need for robust and adaptable VR systems. Future work could explore the integration of AI to dynamically adjust scenarios based on real-time user feedback and behavior, enhancing the personalized learning experience. Additionally, creating an application on a different device, such as a tablet, would allow the teachers to follow the student's performance in real-time as well as enable them to make changes to the simulations, such as the number of NPC passengers, noise level or even introduce events such as train delays, cancellations and changes of tracks.

This short paper aims to explore VR's opportunities and illustrate its potential. It hopes that future research and development can make significant strides in utilizing VR to support and enhance the independence and quality of life for individuals with ASD and other special needs.

References

1. Attardo, D.: Kommunerne bruger 1,4 milliarder: Helt vildt (2023). https://ekstrabladet.dk/nyheder/politik/kommunerne-bruger-14-milliarder-helt-vildt/10003890. Accessed 22 Apr 2024
2. Autistic Self Advocacy Network: About autism (2015). https://autisticadvocacy.org/about-asan/about-autism/. Accessed 14 May 2024

and introduce them to the steps required for independently utilizing this form of public transportation. In this section, we will discuss the results of the two participants who went through all phases of the planned evaluation: pre-observation, VR training, and post-observation: student 10 and student 11.

The data collected from pre- and post-VR training observations demonstrated improvements in the participants' skills in key areas, such as recognizing transportation signs, understanding schedules, and managing check-in systems. These findings suggest that the VR intervention can potentially enhance independent public transportation skills.

During the pre-observational phase, participants exhibited varying levels of confidence and familiarity with the public transportation system. Notably, some participants relied heavily on habitual behaviors or required peer support. For instance, Student 10 focused exclusively on reaching the platform to catch the train, demonstrating an unawareness of the need to take a different train. Conversely, in the post-observational phase, the same student displayed marked improvements in confidence and attentiveness, consistently checking relevant screens, successfully navigating to the correct platform, and entering the correct train. This transformation, observed after six VR training sessions with Student 10, underscores the effectiveness of VR training in altering habitual behaviors and enhancing situational awareness.

Similarly, Student 11 exhibited challenges during the pre-observational phase, including a complete lack of awareness regarding when to disembark from the train. Pedagogues had to intervene as the student had traveled one stop too far. During post-observation, however, Student 11 demonstrated considerable improvement by independently getting off at the correct station. The progress after just one training session highlights the potential for further advancements with additional training.

Interestingly, the students spent more time in the real train station after VR training compared to the pre-training observations. Student 10's time increased from 2 min to 5:44 min, and Student 11's time increased from 3 min to 6:42 min. This increase in time suggests that the students were perhaps more attentive to their surroundings during the second attempt, likely because they had trained in the VR simulation. The VR training may have made them more aware of their environment and more diligent in following the steps necessary to navigate the station independently. However, it is also possible that unknown factors influenced their performance, and further investigation would be required to understand these changes entirely.

The special education school participating in this study has VR and gaming on their schedule for their students. Therefore, the teachers received complete control of the VR training sessions, and the authors had no interaction with the students during the whole process. This, however, removed the ability to control the training phase, resulting in training not being performed as planned due to scheduling issues at the school. Out of the 11 participants initially participating in the pre-observation phase, only five proceeded to the training phase, with varying numbers of sessions. Only one participant met the expected minimum

- **Student 6**: Conducted one session, spent 4 min and 4 s, asked for help, entered the correct train on the first attempt but missed one task, and noted a lack of realism.
- **Student 10**: Conducted six sessions over 9 days. In the first session, the student spent 10 min and 57 s, did not ask for help, and entered the correct train on the second attempt. In subsequent sessions, the student consistently entered the correct train on the first attempt, noted task completion discrepancies, and discovered glitches.
- **Student 11**: Conducted one session, spent 34 min and 53 s, asked for help initially, entered the correct train on the second attempt, completed most tasks, had issues with the virtual school transportation card, and seemed to enjoy the experience.

In summary, 12 sessions were conducted by 5 participants. Most boarded the correct train on the first session, with Students 10 and 11 requiring a second attempt. Participants generally completed the tasks, though Student 6 missed one. Technical issues included glitches and incorrect displays, with varied participant behaviors observed.

3.3 Post-observations

Due to scheduling issues, only two participants, Student 10 and Student 11, were observed in this phase. The following details summarize their actions and behaviors during the observation.

- **Student 10**: Checked the departure screens at the entrance, outside 7-Eleven, and at Platform 5. Successfully checked in and boarded the correct train. No conversation was recorded during the observation. The observer noted that Student 10 was very aware of their surroundings, checked all screens, and felt more confident and attentive after the training. The student spent 5:44 min from entering the station to walking onto the right train compared to 2 min in the pre-training observation phase.
- **Student 11**: Checked the departure screens at the entrance, outside 7-Eleven, and at Platform 5. Successfully checked in and boarded the correct train. During the observation, Student 11 asked, "Which side of the travel card is the correct side?" The observer noted some confusion between virtual and real experiences, but the student used the tools learned in the simulation to navigate successfully. The student spent 6:42 s in the station during the post-VR training observation compared to 3 min during the pre-VR training observation.

4 Discussion

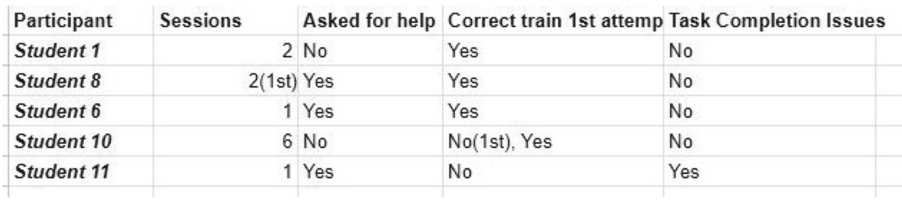
This paper explored whether a VR intervention can be used to familiarize autistic children attending a special education school with their local train station

- **Participant 6**: Recognized the stop at Carlsberg station but needed assistance to get off.
- **Participant 10**: Initially went to the wrong platform and was guided back by the accompanying teacher
- **Participant 11**: Zoned out, missed the correct stop and did not get off, according to the accompanying teacher.

All participants successfully boarded the correct train. One participant (11) did not get off at the right station.

3.2 VR Training Sessions

Due to scheduling issues at the school, not all students who participated in the observation phase received VR training. Five students tried the VR application following the observation phase. Each participant was tasked with navigating a virtual train station, entering the correct train, and getting of at the current station. A total of four subtasks were tracked by the VR application: Looking at the information screen, going to the right track, using the travel card to purchase a ticket, and walking onto the correct train. The aim was to assess their ability to complete these tasks independently and to observe their behaviors and any difficulties encountered (Fig. 4).



Participant	Sessions	Asked for help	Correct train 1st attemp	Task Completion Issues
Student 1	2	No	Yes	No
Student 8	2(1st)	Yes	Yes	No
Student 6	1	Yes	Yes	No
Student 10	6	No	No(1st), Yes	No
Student 11	1	Yes	No	Yes

Fig. 4. Training phase results

Session Summaries.

- **Student 1**: Conducted two sessions 14 days apart. In the first session, the student spent 25 min and 52 s, did not ask for help, entered the correct train on the first attempt, and noted a wall clipping glitch. In the second session, the student spent 17 min and 42 s, did not ask for help, entered the correct train on the first attempt, and noted a glitch with external elements intruding into the train.
- **Student 8**: Conducted two sessions 7 days apart. In the first session, the student spent 4 min and 3 s, asked for help due to difficulty reading the phone, entered the correct train on the first attempt, and noted a technical issue. In the second session, the student spent 13 min and 14 s, did not ask for help, and entered the correct train on the first attempt but encountered an incorrect station name display, causing a premature exit.

study. Out of the 11 participants who participated in the pre-observations, only five received VR training due to issues such as scheduling conflicts, student and teacher illnesses, and other logistical constraints. Ultimately, only two participants could participate in the post-VR training observations at the real train station. While these challenges altered our original study design, they highlight the complexities and realities of conducting research in natural settings, where flexibility is often necessary to accommodate unpredictable variables.

3 Results

3.1 Pre-observations

The pre-observational study was conducted with 11 participants aged between 11 and 16 years who were tasked with navigating the Anonymous train station to assess their ability to utilize public transport independently. For clarity and confidentiality, each participant was assigned an ID number during pre-observation. These ID numbers correspond to their student numbers throughout the study (e.g., Student 1 was ID 1, Student 2 was ID 2, etc.).

The main goal was to evaluate each participant's ability to interact with the environment and other individuals and to check departure screens, locate the right platform, and board the correct train.

Screen Checks. Of the eleven participants, six (54.5%) were observed checking the departure screens. Among these, three individuals checked the screen outside the 7-Eleven store, while the remaining three participants checked it at the entrance. The average duration for these checks was approximately 5 s, indicating a quick interaction with the digital information displays.

Platform Identification and Boarding. All participants successfully identified and moved towards the correct train platform and boarded the correct train. A notable exception was one participant, Student 10, who initially walked down to platform 5, contrary to the task requirements. This was explained by the student's habitual use of platform 5 for their daily travel, illustrating a reliance on routine over task-specific instructions.

Time. The time taken by participants from entering Anonymous station (start observation) to boarding the train (end observation) varied. The minimum time recorded was between one minute, and the maximum time was three minutes seconds.

- **Participant 1**: Struggled with navigation and asked strangers for directions.
- **Participant 2**: Demonstrated independent awareness and readiness.
- **Participant 3**: Displayed familiarity with the train system, checking screens and boarding with minimal hesitation.

The school card is used to purchase train tickets, and the phone tracks objectives. The main objective is to take a specific train and get off at the correct station, with several sub-objectives like checking departure screens, navigating to the correct track, and checking in before boarding.

Upon boarding the correct train, players transition to a new scene inside the train. The game spawns them in the corresponding train cart and requires them to stay attentive to red dots on the screen indicating journey progress. Additionally, the player could look out via the windows to see signs indicating which station has been reached. Successfully getting off at the correct station leads to a congratulatory room displaying the number of completed subtasks, with options to restart or quit the game. Missing the stop or getting of at a wrong stop results in a room encouraging a retry.

2.2 Evaluation

A before-and-after training evaluation employing a quasi-experimental design measured the VR simulation's impact on children with ASD's ability to navigate public transportation independently. This evaluation took place in real-world train stations to ensure authentic behavior observation, focusing on interactions with informational screens, schedule verification, platform safety procedures, and overall navigation.

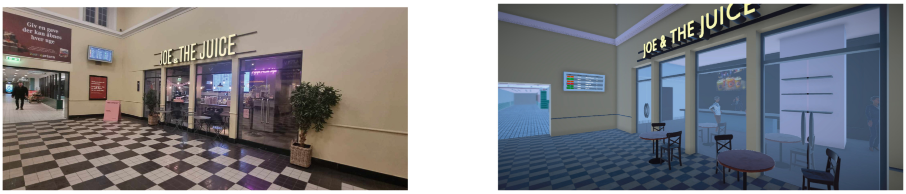
The first part of the evaluation involved initial observations at Annonymus train station with teachers accompanying the children to the Anonymous train station. Two authors, unfamiliar to the children, were strategically positioned at the station to observe from a distance without influencing behavior. They recorded interactions with the environment, such as checking departure screens and the time to board the train. The children only met and interacted with their teachers throughout the study, with whom they were already familiar. The teachers received signed parental approval for the children participating in the research and approval from the anonymous school ethical counsel.

After the observation session, a debriefing meeting was held at the Annonumos school to combine the teachers' insights with the observers' data, ensuring an accurate understanding of each child's behavior. This collaborative approach is a core component of UCD, enhancing the reliability of collected data [5].

A total of 11 observations were conducted on students aged 11 to 16. Following the initial observations, teachers were introduced to setting up the VR intervention, including establishing a guardian system, starting the application, setting NPC and ambient sound levels, and restarting the app. They were provided with a comprehensive setup manual and an online questionnaire to complete after each session, including items on subtask completion and observation notes. The training was planned to be conducted once a week for three weeks.

Post-training observations followed the same procedure as the pre-training observations, ensuring consistency and comparability of the data collected.

Conducting a study in a natural, real-world environment without interference from the researchers inherently brings unpredictable challenges [13]. In our case, despite initial plans, several unforeseen events affected the execution of the



(a) Real life (b) Virtual

Fig. 1. Comparison of real-life and the virtual juice shop by the entrance of the train station and a departure information screen

(a) Real life (b) Virtual

Fig. 2. Comparison of real-life and virtual train station elements

Interactive elements within the game, such as interacting with train doors and ticket machines using VR controllers, were implemented to simulate real-life interactions. Each session starts at a control panel, allowing teachers to switch on and off elements such as the presence of other passengers and ambient sounds to control sensory stimuli.

The Non-Player Characters (NPCs) are designed to wander around the station, wait, or stand together in conversations, creating a realistic environment. Ambient sounds include traffic noise, background d diegetic music from the shops, and announcements similar to those at real train stations in Anonymous.

Players control a human avatar with inverse kinematics-managed arms, equipped with a school card in the right hand and a phone in the left hand.

(a) Real life (b) Virtual

Fig. 3. Comparison of real-life and virtual journey progress indicators

with a smartphone [8]. Over three weekly sessions, participants showed improvement in navigating check-in, security, and boarding processes in a real-world airport.

The benefits of VR in teaching transportation skills to individuals with ASD are multifaceted. It can enhance independence and societal integration and provide a cost-effective solution to the escalating expenses associated with their transportation needs [6]. Given the significant investment in transportation for students with ASD and the innovative capabilities of VR technology, this approach warrants thorough exploration as a sustainable and effective educational tool. Additionally, VR offers ecological validity in training interventions as the tasks and experiences in VR-based simulations can be designed to be similar to those that are required in the real world [14].

In contrast to previous studies, this short paper presents a VR intervention simulating a virtual train station, mirroring a real-world station's appearance and functionality. Our VR environment is designed to replicate essential tasks such as checking departure times, purchasing tickets, finding the correct track, and boarding and exiting the train-offering an immersive experience that parallels the actual procedures required in a real station. This localized, detailed simulation specifically focuses on train travel, representing a novel contribution to the field by providing a practical, real-world scenario for autistic children to practice independent transportation skills

2 Methods

The development of the VR intervention for public transportation training in autistic children was grounded in User-Centered Design (UCD) principles. UCD prioritizes the needs, preferences, and constraints of end-users throughout the design and development phases to ensure the final product is both functional and user-friendly [5,17].

In collaboration with Annonymus school, a specialized institution for children with special needs, our development process involved iterative feedback loops with teachers and pedagoges at the school. Several design workshops were held at the school to gather input and feedback. Based on these workshops, it was decided that the VR simulation should realistically mimic the Anonymous S-train station frequently used by the students for their daily commutes.

2.1 The VR Intervention

The VR simulation was developed using Unity3D to run on a Meta Quest 2 and was designed to closely replicate the environment of the Anonymous S-train station. To ensure a lifelike experience, 3D models of real station elements-such as ticket check-in stands, departure screens, and various interiors and shops-were meticulously crafted to look like their real-life counterparts (see Figs. 1a, 1b, 2a, 2b, 3a, 3b).

ing approximately 1.4 billion (anonymous currency) annually [1]. This expenditure has been increasing; for instance, Anonymous's budget for student transportation grew from 47.9 million (anonymous currency) in 2018 to 78.2 million (anonymous currency) in 2022, largely due to the rising costs of individual taxi services and an increase in the number of diagnosed children [7]. Despite efforts to manage these costs through centralizing services and encouraging collective transportation solutions, significant financial and logistical challenges remain.

Personalized support and interventions are crucial to promote independence and improve the quality of life for individuals with ASD. Pfeiffer et al. [11] investigated the effect of peer-mediated travel training to help autistic individuals achieve independent travel skills and community mobility. The results showed that peer-mediated training significantly improved the travel skills of the participants. Another study by Pfeiffer et al. [12] showed the effectiveness of the Kennedy Center's travel training guide and curriculum (TCG), where individualized training with educated travel coaches helped autistic individuals gain the necessary skills for independent travel. These methods are, however, resource intensive, requiring trained peers or educators. Another disadvantage of using trained peers or coaches with autistic individuals is the social barriers to interacting with another person, which is one of the most common difficulties of autistic individuals [11,12].

Virtual Reality (VR) can provide a more cost-effective intervention, offering a socially safe environment where autistic individuals can practice essential skills without the pressure or discomfort of direct social interactions.

Previous studies have demonstrated the potential of VR in teaching DLS to autistic children and adolescents [3,4]. VR allows individuals with ASD to engage in immersive simulations of real-world scenarios in a controlled and safe environment [10]. This technology facilitates repeated practice and mastery of DLS, enabling personalized learning experiences that accommodate the unique needs and learning paces of individuals with ASD. VR simulations offer error-free learning and self-directed exploration opportunities, which are crucial for building confidence and competence in navigating public transportation systems [9].

A recent review by Carnett et al. highlights the efficacy of VR in behavioral interventions aimed at enhancing independence among autistic individuals [4]. This review supports VR's use in teaching specific skills like driving and interview techniques, advocating for its inclusion as an evidence-based practice. Of the 23 studies reviewed, two address transportation difficulties using VR.

One study by Simoes et al. describes a VR intervention for teaching public bus usage to individuals with ASD [16]. This game provided a three-dimensional city environment where participants practiced tasks associated with bus travel, such as finding the appropriate bus, purchasing a ticket, finding a seat, and getting off at the correct stop. Results indicated significant improvements in participants' knowledge and comfort with bus travel procedures.

Another study involved practicing air travel by exposing participants to 360-degree videos of airports and airplanes using Google Cardboard in combination

Virtual Station: Virtual Reality as a Bridge Towards Real Independence in Public Transportation for Autistic Children and Adolescents

Ali Adjorlu(✉), Christian Sonne Rosendahl, Maria Barbro Lanther, and Pawe Karman Ahmad

Aalborg University, Copenhagen, Denmark
adj@create.aau.dk

Abstract. Public transportation can be a significant challenge for autistic adolescents, who often face difficulties with navigating complex environments, managing schedules, and interacting with unfamiliar systems. In this short paper, we explore the potential of Virtual Reality (VR) as an intervention to address these challenges. Specifically, we developed a VR simulation of a local S-train station in collaboration with a specialized school, allowing autistic students to practice essential transportation tasks such as checking schedules, purchasing tickets, and navigating platforms in a safe and controlled environment.

Our study employed a quasi-experimental design with pre- and post-training observations to evaluate the effectiveness of the VR intervention. Results demonstrated improvements in students' abilities to understand schedules, recognize transportation signs, and manage check-in systems. Post-training observations also revealed increased time spent navigating real train stations, suggesting greater attentiveness and confidence. Despite logistical challenges and the need for more immersive elements, such as handling crowded environments and interacting with ticket inspectors, our findings highlight the promise of VR in preparing autistic adolescents for independent public transportation.

Keywords: Everyday living skills · Virtual Reality · Autism Spectrum Disorder

1 Introduction

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental condition characterized by a spectrum of symptoms affecting social interaction, communication, and sensory processing. These challenges can significantly impede daily living skills (DLS), such as using public transportation [2,15].

In Anonymous country, the financial burden of accommodating the transportation needs of students with ASD is substantial, with municipalities spend-

E. Brooks et al. (Eds.): DLI 2024, LNICST 604, pp. 22–32, 2025.
https://doi.org/10.1007/978-3-031-85663-1_2

18. Neustaedter, C., Sengers, P.: Autobiographical design: what you can learn from designing for yourself. Interactions **19**(6), 28–33 (2012)
19. O'Kane, A.A., Rogers, Y., Blandford, A.E.: Gaining empathy for non-routine mobile device use through autoethnography. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 987–990 (2014)
20. Osterwalder, A., Pigneur, Y.: Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers, vol. 1. John Wiley & Sons, Hoboken (2010)
21. Rapp, A.: Autoethnography in human-computer interaction: Theory and practice. In: New Directions in Third Wave Human-Computer Interaction, vol. 2-Methodologies, pp. 25–42. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-73374-6_3
22. Reis, E.: The Lean Startup. Crown Business, New York (2011)
23. Rodríguez-Abad, C., et al.: A systematic review of augmented reality in health sciences: a guide to decision-making in higher education. Int. J. Environ. Res. Public Health **18**(8), 4262 (2021)
24. Sangeethaa, S., Jothimani, S.: Blockchain in the metaverse. In: Cultural Marketing and Metaverse for Consumer Engagement, pp. 51–70. IGI Global, Hershey (2023)
25. Shanbhag, N., Pardede, E.: The blitz canvas: a business model innovation framework for software startups. Systems **10**(3), 58 (2022). https://doi.org/10.3390/systems10030058
26. Singh, M.: Pokemon go changes everything and nothing for arvr (2016). https://techcrunch.com/2016/08/12/pokemon-go-changes-everything-and-nothing-for-arvr/
27. Souchet, A.D., Lourdeaux, D., Pagani, A., Rebenitsch, L.: A narrative review of immersive virtual reality's ergonomics and risks at the workplace: cybersickness, visual fatigue, muscular fatigue, acute stress, and mental overload. Virt. Real. **27**, 19–50 (2023)
28. Thiel, P., Masters, B.: Zero to One: Notes on Startups, or How to Build the Future, 1st edn. Currency, New York (2014)
29. Van Der Land, S., Schouten, A.P., Feldberg, F., van Den Hooff, B., Huysman, M.: Lost in space? cognitive fit and cognitive load in 3d virtual environments. Comput. Hum. Behav. **29**(3), 1054–1064 (2013)

References

1. Alford, H.: 3 industries that will be disrupted by pokémon go and ar. Medium (2016). https://harryalford.medium.com/3-industries-that-will-be-disrupted-by-pok%C3%A9mon-go-and-ar-402f2715306f
2. Bambušek, D., Materna, Z., Kapinus, M., Beran, V., Smrž, P.: Handheld augmented reality: overcoming reachability limitations by enabling temporal switching to virtual reality. In: Proceedings of the 2022 17th ACM/IEEE International Conference on Human-Robot Interaction (HRI), pp. 698–702. IEEE (2022)
3. Buchner, J., Buntins, K., Kerres, M.: The impact of augmented reality on cognitive load and performance: a systematic review. J. Comput. Assist. Learn. **38**(2), 285–303 (2022)
4. Chen, D.: The metaverse is here...but is the hardware ready? Spiceworks (2022). https://www.spiceworks.com/tech/hardware/guest-article/the-metaverse-is-here-but-is-the-hardware-ready/
5. Dionisio, J.D.N., Burns, W.G., III., Gilbert, R.: 3d virtual worlds and the metaverse: current status and future possibilities. ACM Comput. Surv. (CSUR) **45**(3), 1–38 (2013)
6. Glaser, B.G.: Theoretical Sensitivity. Sociology Press, Mill Valley, CA (1978)
7. Glaser, B.G., Strauss, A.L.: The Discovery of Grounded Theory: Strategies for Qualitative Research. Aldine, Chicago (1967)
8. Gomes, A., et al.: Extended by design: a toolkit for creation of xr experiences. In: Proceedings of the 2020 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct), pp. 57–62. IEEE (2020)
9. Graser, S., Nielsen, L.H., Böhm, S.: Factors influencing the user experience of mobile augmented reality apps: An analysis of user feedback based on app store user reviews. In: Godulla, A., Böhm, S. (eds.) Digital Disruption and Media Transformation, pp. 109–128. Springer, Heidelberg (2023). https://doi.org/10.1007/978-3-031-39940-4_9
10. Hegde, S.: Defining your customer engagement strategy: Which game are you playing? (2023). https://amplitude.com/blog/customer-engagement-strategy#defining-your-customer-engagement-strategy-which-game-are-you-playing
11. Heshmat, Y., Neustaedter, C., DeBrincat, B.: The autobiographical design and long term usage of an always-on video recording system for the home. In: Proceedings of the 2017 Conference on Designing Interactive Systems, pp. 675–687 (2017)
12. Matney, L.: Investments in vr/ar have already hit $1.1 billion in 2016 (2016). https://techcrunch.com/2016/03/07/investments-in-vrar-have-already-hit-1-1-billion-in-2016/
13. Maurya, A.: Running Lean, 3rd edn. O'Reilly Media, Inc., Newton (2022)
14. Metinko, C.: Vr/ar investments increase just as metaverse talk heats up—but that may not be the only reason (2022). https://news.crunchbase.com/startups/metaverse-augmented-reality-virtual-reality-investment/
15. Montes: What is spatial computing and how is it revolutionizing our world? (2022). https://www.verses.ai/blogs/what-is-spatial-computing-and-how-is-it-revolutionizing-our-world
16. Munro, A.J.: Autoethnography as a research method in design research at universities. In: Proceedings of the 20/20 Design Vision Conference, p. 156 (2011)
17. Naess, M.: The metaverse in retail: a game-changer that's not ready yet (2022). https://venturebeat.com/datadecisionmakers/the-metaverse-in-retail-a-game-changer-thats-not-ready-yet/

as blockchains, artificial intelligence, and the Internet of Things [24] continue to shape the metaverse landscape, future research could explore the integration of these advancements into the MIC, enabling a more comprehensive and future-proofed ideation process. Conducting empirical studies to validate the efficacy of the MIC in real-world scenarios could provide quantitative evidence of its impact on the success rates of AR/VR startups.

7 Concluding Remarks

This research made several notable contributions to the understudied domain of augmented reality (AR) and virtual reality (VR) entrepreneurship. First, it identified prevalent failure factors based on an in-depth investigation of unsuccessful AR/VR startups, elucidating common pitfalls that can lead ventures in this space to fail.

Understanding these factors can provide valuable lessons for aspiring entrepreneurs seeking to increase their chances of success. Second, grounded in design research methods such as autoethnography, autobiographical design, and insights from industry expertise, this study presented the novel MIC as a strategic ideation toolkit tailored to addressing unique considerations of extended reality ventures.

This specialized canvas guides founders through prompts that encourage the consideration of critical factors such as the user experience, the technological feasibility, the problem-solution fit, and the business viability starting from the earliest stages. Third, the proposed MIC framework prompts a human-centered, problem-driven approach to conceive products and services that leverage the differentiating capabilities of immersive technologies such as AR and VR.

Its tailored blocks push entrepreneurs to ideate solutions that provide value propositions exclusive to XR, going beyond simply replicating non-XR experiences. Fourth, the research methodology synthesized mixed qualitative techniques such as focus groups, content analyses, and external evaluations by startup consultants to produce actionable and valid insights. The triangulation of perspectives enhanced the reliability and applicability of the findings.

Overall, this work combined an insightful analysis of the real-world challenges faced by failed AR/VR startups with an innovative design output-the MIC-aimed at enhancing the viability of future ventures in this space through a tailored, reflective ideation process. The MIC provides a model for human-computer interactions and design researchers seeking to bridge conceptual contributions with practical entrepreneurial impact to drive the adoption of novel technologies.

ogy, suggesting that founders may need the assistance of an XR specialist to accurately complete this field. This highlights the technical knowledge required to address usability concerns and design effective user experiences within the AR/VR domain.

Furthermore, two participants emphasized that the lack of scalability within a short timeframe was a prominent failure factor for two of the startups. One participant pro-posed the addition of a timeline block to the MIC to address this concern. By incorporating a timeline, startups would be prompted to consider and plan for the scalability of their ventures over time, recognizing the potential threats and opportunities that may arise in the future.

Overall, the engagement of the startup consultants in completing the MIC high-lighted key areas of focus, such as the XR value propositions, usability considerations, and scalability.

6 Limitations and Future Work

One limitation of this study was the sole reliance on qualitative data from startup consultants to evaluate the MIC. While the feedback of these consultants provided valuable insights, incorporating quantitative metrics to objectively measure key factors such as the XR value propositions, usability considerations, and scalability could further strengthen the evaluation. Future research should explore the development and validation of quantitative instruments to assess these critical elements within the context of XR business modeling. By combining qualitative expert feedback with quantitative measurements, a future study could triangulate the findings and provide a more comprehensive understanding of the canvas's efficacy in enhancing the viability of metaverse startups.

Another limitation of this study was the lack of an analysis on the success factors for thriving AR/VR startups. While our investigation of failed ventures provided valuable insights into common pitfalls, incorporating an examination of successful cases could further enrich the findings and provide a more comprehensive understanding of the critical factors influencing a startup's success in the AR/VR domain. Future research could extend this work by analyzing prosperous AR/VR startups and integrating the identified success factors into the MIC framework.

The analysis of market dynamics and user adoption patterns in the AR/VR industry may have been oversimplified in this study. A more in-depth exploration of these factors could yield additional insights and nuances that were not captured in the cur-rent scope of this research. The data collection for this study was conducted in the previous year, and may not have fully captured the rapidly evolving nature of the AR/VR industry. As new technologies and market trends emerge, the identified failure factors and the applicability of the MIC may require further validation and refinement.

Expanding the research scope to include AR/VR startups from diverse cultural and geographical contexts could enhance the understanding of region-specific factors that influence startup success or failure. As new technologies such

Table 1. Analysis of five startups

Category	Start Year	Stop Year	Summary
Startup #1 Shopping	Q3 2022	Q2 2022	This startup was an AR android application for buying home decor. The revenue model was based on selling commissions. The app included a Web back end, and shop owners were able to list their products. The shop included more than 1000+ products and achieved 100,000+ installations
Startup #2 Shopping	Q2 2019	Q2 2021	This startup was a VR app with 10,000+ installations that simulated shopping malls. The app's revenue model relied on selling subscriptions to shop owners. The users needed to have Google Cardboard VR to use the app
Startup #3 Social Network	Q2 2018	Q3 2021	This startup was an AR-only location-based social network that allowed people to meet other people around them and evaluate. It crossed 5K users. The app's revenue model relied on selling ad-spaces for sending AR gifts and AR. The app was available for phones, tablets and never models, and it was installed on more than 100,000 devices
Startup #4 Gaming	Q1 2018	Q1 2022	This startup developed a location-based AR mobile game available on iOS and Android, generating 200,000+ installation. Revenue was generated through in-app purchases. Despite a successful launch, the game faced a swift decline in user retention. The gameplay required physical movement, incorporating the player's actual locomotion as a core mechanic
Startup #5 Productivity	Q3 2017	2021	This app was released for iPhone and iPad, and most features required the constant use of AR mode. The app aimed to facilitate the organization of to-do lists by augmented reality by animating 3D objects. The users were able to use the app for free and it crossed 20,000 installations

modification in expanding the possibilities for innovations within the XR space. When the designers were queried about the usability blocks, there was a general consensus among the participants that these blocks are crucial for effectively communicating ideas prior to the development phase. However, they also noted that filling this section may require a solid understanding of AR/VR technol-

The "existing scalability limitations" and "future threats" counter the myth and difficulty of short-term planning by pushing founders to forecast the obstacles to long-term growth. "Future opportunities" guides the consideration of how evolving technology and trends can enable the XR solution to be scaled over time.

4.7 Measurable Metrics

To account for the critical role of usability in the profitability of XR products and services, we incorporated predefined metrics into the MIC. These metrics included the expected usable session (minutes), representing the anticipated duration of each user session; the expected daily engagement for each user (sessions), capturing the project-ed frequency of user engagement; and the expected revenue per user, providing in-sights into the anticipated revenue generated from individual users.

5 Testing the Model with Startup Experts

This study included an analysis of the five startups presented in Table 1: two developed a shopping application, another specialized in gaming, one ventured into social networking, and the final one concentrated on productivity solutions.

The consultants had no prior knowledge of the specific reasons behind the failures of these startups. They were provided with the summary, main usage scenario, and start and stop dates of these ventures.

A common theme emerged among all the participants that emphasized the significance of XR value propositions. It was collectively observed that three out of the five failed startups did not offer value propositions that leveraged the unique capabilities of XR systems, missing out on the potential benefits that the technology could provide. This highlights the importance of creating value propositions that are exclusive to XR experiences in order to fully capitalize on the potential of the technology.

The shopping app, VR social network, AR social network, and productivity app startups faced challenges that justified the value of their solutions against the cognitive and physical demands placed on the users. All the participants emphasized the need to justify motion-based interactions. One consultant suggested that XR startups should avoid brief, buzzword-focused pitches centered on being "AR/VR," and in-stead clearly articulate their unique value proposition. For example, the shopping app only implemented an AR display feature. As its competitors had integrated similar in-room display capabilities, this startup lacked a defensible advantage. One participant stated that pointing out future threats prompted the founders to think beyond the short-term trends and consider sustainable differentiation.

One of the participants expressed appreciation for the modification made to the existing alternative block, recognizing its ability to stimulate ideation and inspire new ideas during the design process. They acknowledged the value of this

- **VR UX opportunity:** How does this solution help users in a fully immersive environment?
- **Social opportunity:** How does this solution create value for users via social interactions?
- **Virtual economy opportunity:** How does using the virtual world economy paradigm create value for customers?
- **Interoperability features:** How does the solution adopt interoperability or achieve the interoperability needs of users?
- **Minimum viable experience scenario**: This is a written form of a user storyboard that explains an ideal usage story in a short manner, which may include all or some pieces of the usability elements.

The **motion-based interaction load** addresses the mistake of deferring usability considerations by prompting the upfront justification of motion interfaces versus physical/cognitive burdens. The "AR UX opportunity" and "VR UX opportunity" guide the ideation of AR and VR use cases distinctly. The "social opportunity" and "virtual economy opportunity" promote the consideration of the novel social and economic models afforded by XR worlds. The "minimum viable experience scenario" narrative description helps convey and refine the envisioned user experience holistically.

4.5 Viability Elements

The viability blocks of the MIC encompass essential elements such as channels, costs, and revenue streams, which were derived from the Lean Canvas framework. These blocks allow startups to strategically plan and analyze their distribution channels, estimate the costs associated with their metaverse ventures, and identify potential revenue streams. These elements inherited from the Lean Canvas address the difficulties around premature scaling by starting with a minimally viable offering before expanding.

4.6 Future Scalability

The future scalability block within the MIC includes various crucial aspects, including the existing scalability limitations, future threats, and future opportunities.

By considering these elements, founders can assess the potential for scaling their metaverse ventures over time. This block enables startups to identify and understand any existing limitations or challenges that may hinder their scalability, allowing them to proactively strategize and overcome such obstacles. Additionally, by considering future threats and opportunities, startups can anticipate the market dynamics, emerging technologies, and changing user preferences that may impact the scalability of their metaverse solutions. This forward-thinking approach empowers startups to position themselves for future growth, adapt to evolving trends, and seize new opportunities within the rapidly evolving metaverse landscape.

tasks or areas of interest. Solutions in this category address this need by offering value in the form of information, entertainment, or self-expression. Netflix, social media, and video games are examples of solutions that address focus drive problems [10]. The myths around only considering digital/XR alternatives and the thought that bringing an app to XR is a value proposition are addressed by separating "existing XR alternatives" from "existing non-XR alternatives" and "existing non-digital alter-natives." This prompts founders to consider a broader set of solutions beyond just XR. The difficulty in defining the core problem is mitigated by the "user engagement goal" checkboxes that guide problem framing in terms of the focus drive, productivity, or transaction needs.

4.3 Solution

The concept of a unique value proposition has been adapted to the context of XR, resulting in the XR unique value proposition. This shift is essential for startup designers to recognize and emphasize the value propositions that users can exclusively experience through XR solutions, distinguishing them from non-XR alternatives.

In the XR landscape, it is crucial to identify and leverage the immersive and trans-formative qualities that XR technologies offer. Startups need to go beyond replicating existing non-XR solutions and instead focus on harnessing the unique capabilities of XR to provide novel and engaging experiences that cannot be achieved through traditional means.

The "XR unique value proposition" block directly counters the myth that simply bringing something to XR is valuable by pushing founders to articulate the value enabled specifically through XR capabilities.

4.4 Usability

We aimed to minimize the usability ideation in a text-based manner by creating the following blocks. Filling all the fields is not mandatory for each startup, but it can give a quick overview about the position of a startup in the metaverse landscape. Motion-based interaction load:

The motion-based interaction load encompasses the physical and cognitive demands imposed on users as they interact with XR experiences using gestures and body movements. The value proposition of motion-based inter-actions lies in their ability to provide a more immersive and intuitive user experience, enhancing engagement and enabling new possibilities in fields such as training simulations and gaming. However, it is crucial to strike a balance between the benefits and the associated load, considering factors such as user comfort and the learning curve. By justifying their value proposition and addressing challenges, startups can leverage motion-based interactions to create compelling XR experiences that captivate users and drive the adoption of this transformative technology.

– **AR UX opportunity:** How does this solution help users in a semi-immersive environment?

use face computers such as AR/VR HMDs for multiple hours. These considerations directly im-pact the sustainability of the business model.

In response to these concerns, we developed a one-page business plan template specifically tailored for XR startups, known as the Metaverse Innovation Canvas, as depicted in Fig. 1. The MIC comprises five distinct types of blocks, with each serving a unique purpose: problem (red blocks), solution (green blocks), usability (blue blocks), viability (yellow blocks), and future scalability (purple blocks).

Fig. 1. Metaverse Innovation Canvas

4.2 Problem

The problem section includes blocks that describe a problem and the people who have the problem. In order to help designers and founders define their problems more effec-tively, we added user engagement goal checkboxes to the problem section, which included focus drive, productivity, and transaction. We adopted this from an article about the Three Games of Customer Engagement Strategy [10].

Focus drive represents users' inherent need to direct their attention and concentration towards specific subjects or activities. It reflects individuals' natural motivation or inclination to concentrate their mental resources on particular

4.1 Myths, Difficulties and Mistakes

A common mistake during idea development is only considering digital and XR alternatives, while neglecting non-digital options. For example, when conceptualizing an XR shopping app, the founders may focus solely on existing digital solutions such as online shopping websites. However, they should also consider brick-and-mortar stores as a non-XR alternative that users may currently utilize. The tendency is to view the landscape strictly within the XR application space, but founders need to look beyond this and analyze all potential digital and non-digital alternative solutions to the problem they are trying to solve.

Bringing an application to XR is a value proposition. This is wrong; it might pro-vide an early blessing in an untapped market, but XR brings extra costs and additional physical and even cognitive loads [29] for users, so these extra costs need to be justified by providing value propositions for end users. Pokémon Go motivated [26] its users to move outside and follow location-based interaction practices because the users were collecting Pokémon cards before that. Niantic did not need to justify this extra load for the users, since years of marketing by Nintendo had already accomplished this for them.

Problem definition is the toughest job for every entrepreneur and product designer, and the problem is further complicated by the fact that most people do not have clear understanding of what can be considered a problem. For example, the case of Angry Birds may not immediately seem relevant to the problem-solution definition. How-ever, the main issue that Angry Birds addresses is people's need to maintain their attention on something, and this game accomplishes this in an entertaining and user-friendly manner.

The primary aim of the Lean Canvas is to help founders validate their idea as soon as possible, and for AR/VR startup founders, it is ideal to refine their ideas into viable, desirable, and feasible solutions. However, many AR/VR solutions struggle to achieve feasibility or scalability in a short time due to the lack of advancements in enabling technologies. Therefore, the perfect business plan for AR/VR startups should consider the impacts of predictable future market events.

The entreprenurs have demonstrated two common mistakes in desiging startups: Large customer segment, and lack of attention to usability considerations:

Entrepreneurs tend to expand their customer segments and write more items in this segment; it may sound more interesting for some investors because it can increase the size of their market and the valuation of the company, but it can be a fatal mistake in the XR industry. This is because it increases the development costs exponentially and will postpone idea validation for a long period.

It would be wise to limit the early adopters and find a niche market for the minimum viable products. Thiel and Masters [28] argued that only monopoly profits can help a business to survive, since a monopoly provides the profits to continue the innovation.

Postponing the usability considerations until the minimum marketable product is reached. UX issues in XR environments are far more complex than screen-based applications. Handheld AR can cause hand fatigue [3], and users cannot our proposed MIC provides specific fields to prompt the consideration of these critical factors.

The experiences of 14 of the startups imposed high physical and cognitive loads on their users through excessive motion-based interactions. The benefits did not out-weigh the burdens of these demanding natural user interface requirements.

An AR productivity startup failed after the users reported physical strain from the extended motion-tracking required for 3D modelling. An App Store review stated: "It's innovative but using hand gestures for more than 10 min is very tiring. I can't see people using this daily." The startup could not justify the interaction load versus mouse/keyboard inputs.

3.5 Failure to Address a Clear Problem

Successful startups often solve tangible problems or fulfill specific needs. However, some AR/VR startups failed to address a clear problem or failed to effectively communicate the problem they were solving. This lack of focus on a defined problem reduced the perceived value of their offerings and hindered their ability to attract and retain customers.

A total of 11 of the analyzed startups did not have a well-defined central problem that their AR/VR solution effectively solved for users. A lack of focus on addressing real user needs undermined their perceived value.

A VR startup for remote communication had no clear user workflow or pain-point that their solution addressed better than video calls. As one reviewer stated: "It's novel tech but I don't understand when I would actually use this instead of a Zoom call."

By recognizing these key failure factors, future AR/VR startups can learn from the mistakes of their predecessors and take proactive measures to mitigate these challenges. Addressing issues related to long-term planning, hardware limitations, usability, the value proposition, motion-based interactions, and problem-solving can significantly increase the chances of success in the competitive AR/VR landscape.

4 Development of the Metaverse Innovation Canvas

The Lean Canvas, as a perfect one-page business plan template for brainstorming business ideas, was introduced in the Running Lean book [13] based on an extension of the Business Model Canvas [20], and it has helped a countless number of startups around the globe. However, since the Lean Canvas [22] is a general-purpose framework, entrepreneurs may not use it correctly. The following is a list of common myths, mistakes, and difficulties that AR/VR startup founders usually encounter when trying to deconstruct their business assumptions with the Lean Canvas.

immersive technologies, their work stopped short of outlining actionable strategies tailored to the practical context of XR startups and product development. Specifically, their review did not translate their insights on ergonomic pitfalls into a coherent framework for mitigating issues starting from the early stages of business modeling and design. Our research built upon their analysis by proposing the MIC as an entrepreneurial toolkit for embedding a consideration of critical usability and user experience (UX) factors directly into the ideation process. While [23] systematic review highlighted the usability and physical burden issues with augmented reality in health sciences education, their work did not provide an actionable framework for addressing these concerns during business ideation for AR/VR ventures. Our proposed MIC aims to bridge this gap by directly incorporating human-centered experience scenarios and prompting the justification of motion-based interactions from the start.

A total of 17 of the failed startups exhibited poor usability of their AR/VR offerings, with unintuitive or cumbersome user experiences that diminished the value proposition. Additionally, 16 of them failed to clearly articulate a compelling value proposition that justified the use of AR/VR over non-immersive alternatives.

An AR home decor app received widespread complaints about poor usability, with a 2.1/5 rating on the App Store. The users cited issues such as "keeps crashing" and "difficult to place objects naturally." Without a compelling value-add over browsing decor websites, the app struggled with engagement.

3.4 Motion-Based Interactions and Physical Load

Some failed AR/VR startups struggled with motion-based interactions and physical load. While these startups offered innovative motion-based experiences, the physical demands and discomfort associated with prolonged use did not justify the value propositions for users. The disparity between the expected advantages and the physical burden on users eroded the feasibility and attractiveness of their offerings.

Although the Extended by Design Toolkit [8] acknowledges physical and perceptual strain as challenges in XR, it lacks constructs prompting developers to justify motion-based UX choices versus less-demanding interaction methods. Our canvas guides teams to weigh the benefits and burdens of natural user interfaces while considering the long-term feasibility. Although the review by Buchner et al. [3] described the physical burdens associated with augmented reality, their analysis lacked guidelines for mitigating these demands during design and development. Studies have shown that demanding augmented reality experiences increase the strain, reducing the com-fort and performance over time [2]. Similarly, research has found significant fatigue from the extended use of augmented reality glasses compared to mobile devices, limiting their feasibility for daily tasks. Similar to the usability issues, the problems with motion-based interactions and physical load for AR/VR systems [9] are not being accounted for in current generalized startup planning models such as the Lean Canvas, whereas contributed to a deeper understanding of the reasons behind the failures of these startups. The following factors emerged as significant contributors to the failure of AR/VR startups:

3.1 Short Timeframe and Lack of Future Planning

Many AR/VR startups faced difficulties due to a short-sighted approach and a lack of clear plans for future trends. The rapidly evolving nature of the AR/VR industry demands foresight and adaptability. Startups that failed often lacked the ability to anticipate market shifts, technological advancements, and changing consumer preferences, ultimately leading to their downfall.

This factor was observed in 18 out of the 29 failed startups analyzed. Many of these companies focused on short-term trends or gimmicks without accounting for longer-term market shifts or technological advancements.

3.2 Lack of Scalability and Hardware Limitations

The lack of scalability in the AR/VR industry can be attributed to the limited availability of AR/VR head-mounted displays (HMDs), preventing the creation of a mass market service. The shortage of AR/VR HMDs hampers the scalability of startups, as there is not yet a sufficient consumer base to support widespread adoption. The hard-ware limitations and the industry's challenge in providing affordable, accessible, and high-quality devices have further hindered the scalability of AR/VR startups.

A total of 22 of the 29 startups struggled with scalability issues stemming from the limited availability and high cost of AR/VR headsets and other enabling hardware during their active years. Their solutions could not achieve mass consumer adoption due to these hardware constraints.

Quantifying this constraint, only 8.1 million AR/VR headsets were shipped globally in 2018 (source: IDC Worldwide Quarterly AR/VR Device Tracker). With limited device penetration and high costs, such as USD 599 for the Oculus Rift, 15 of the 29 failed startups (52%) directly cited hardware availability and pricing as a key factor hampering the scalability of their AR/VR solutions.

3.3 Lack of Usability and Value Proposition

Usability plays a crucial role in the success of AR/VR startups. The startups that neglected the importance of intuitive and user-friendly experiences faced significant challenges. Additionally, the lack of a compelling value proposition, considering non-AR/VR alternatives, contributed to the failure of some startups. When users could find similar solutions outside the AR/VR environment that were more accessible, more cost-effective, or easier to use, the value proposition of the AR/VR startups became diminished.

While [27] comprehensively reviewed the risks of visual fatigue, cybersickness, and other physical discomforts that undermine the usability and value of in advising early-stage ventures and were identified by searching the websites of startup accelerators in Iran. Each consultant was presented with the Lean Canvas and background information for the five failed AR/VR startups identified in stage 1. They were then asked to fill out the MIC for each startup.

These consultants were asked to evaluate the usability and feasibility aspects of the MIC by reviewing the startup cases and providing feedback. Their insights from an expert perspective contributed to assessing the potential and usability of the proposed framework. Semi-structured interviews were conducted to gather feedback on the usefulness and usability of the canvas. The sessions were audio-recorded and transcribed.

It is important to note the limitations of this approach. We did not have access to proprietary internal information for Startups 2, 3, and 4, since we did not interview their founders directly. Our perspectives on these startups were based on publicly available information, which may have lacked key insights. There was also an element of subjectivity in how we interpreted and synthesized the data on the startups based on our own prior knowledge and experiences.

Furthermore, the participants in this study had access to limited information about the startups and reviewed this information in a compressed timeframe. During the MIC testing session, three startup consultants were brought in to analyze and com-plete the canvas for five different failed AR/VR startups.

2.4 Analysis Method

The analysis of the collected data in this study was guided by Glaserian grounded theory methodology, which is a systematic approach for generating a theory from empirical data [6,7]. This methodology recommends the constant comparative method, where data collection and analysis occur simultaneously, and the researcher continuously compares incidents, codes, and categories to construct a coherent theoretical framework grounded in the data [7].

2.5 Ethical Considerations and Limitations

Ethical considerations were carefully addressed throughout the research process. Con-fidentiality and anonymity were maintained when referencing specific startup cases or individuals within the startup studio. Informed consent was obtained to protect individuals' identifiable information and prevent potential harm to their reputation during the research. After the analysis, the collected data were destroyed. The authors main-tained reflexivity throughout the study by acknowledging their positional ties to the startup community and the potential influence it may have had on their observations and interpretations.

3 Key Failure Factors of AR/VR Startups

During the analysis of AR/VR startups, several key failure factors were identified, shedding light on the challenges that led to their downfall. These factors

Additionally, we utilized online startup directories such as Crunchbase, AngelList, and local startup groups to identify relevant AR/VR ventures operating within the specified timeframe of 2016–2022. We then contacted the founders or leadership teams of these startups, explaining the purpose of our research and requesting their participation by sharing relevant business documentation and data. For startups that had ceased operations, we attempted to contact former employees or stakeholders to obtain access to archival materials. Throughout this process, we ensured the anonymity and confidentiality of the participating individuals and companies.

2.2 Stage 2: Autoethnography and Autobiographical Design

The objective of this stage was to develop a startup business-modeling framework that aimed to mitigate the mistakes made by entrepreneurs when using the Business Model Canvas (BMC) and the Lean Canvas, which have been identified as contributing factors to the failure of AR/VR startups. By recognizing and addressing the key failure factors identified in Sect. 3, the MIC framework sought to provide entrepreneurs with a comprehensive and effective tool for strategically planning their AR/VR startups, thus increasing their chances of success in the competitive extended reality industry.Autoethnography has gained popularity in the field of human-computer interactions in recent years [11,19,21].

This method is also employed in universities for conducting design research, as it allows for the collection of "creative and innovative processes" experienced by designers [16]. Autobiographical design, a form of design research, utilizes autoethnography primarily for the creation of solutions that are intended to be used extensively by their creators [18].

The primary source of data for this research included the authors' personal and extensive experience with the BMC [20] and the Lean Canvas [22]. We provided consulting and design services to startups and utilized strategic design toolkits such as BMC and its adaptations. Additionally, as the strategic designers and heads of a startup studio, we shared firsthand accounts and insights gained from extensive experience working with AR/VR startups. We conducted autobiographical design interviews to gather rich and personal narratives, focusing on the challenges, successes, and lessons learned in the context of AR/VR startup ventures.

In addition, the involvement of other authors in this research played a crucial role in facilitating ethnography and enabling data triangulation. The authors collaborated in conducting a comprehensive literature review and netnography of the startup community on Twitter, which served to triangulate the findings. This cross-validation approach enhanced the reliability and accuracy of identifying the factors contributing to failure in this study.

2.3 Stage 3: Evaluation

In the third stage, the MIC was evaluated through expert testing with three startup consultants. These participants were recruited based on their expertise

2 Methodology

This research consisted of three main stages. In the first stage, data from domestic and international AR/VR startups were collected and analyzed to identify the key factors contributing to their failure. Four focus group sessions were conducted to discuss the data, and the factors were coded based on the analysis.

In the second stage, the authors applied autoethnography [21] and autobiographical design [18] to create an innovation tool for startup founders. By leveraging their more than a decade of experience in entrepreneurship, the authors developed the MIC. This canvas serves as a framework for investors and entrepreneurs in the metaverse field. Finally, in the third stage, we recruited experts to evaluate five failed startups with the MIC and interviewed them about the MIC's potential for use in the AR/VR industry.

2.1 Stage 1: Analyzing the AR/VR Startups

The first stage of the research involved analyzing AR/VR startups. The first author's startup studio actively monitored the AR/VR industry and collected data on startups operating in various sectors, including content creation, gaming, social media, education, healthcare, tourism, and retail. The data spanned from 2016 to 2022, with 2016 being a significant milestone in AR/VR history due to the commercial success of Pokémon Go, which validated the XR market and led to the widespread adoption of computer-mediated reality technology [4].

The collected data included the Lean Canvas of the startups, which was developed based on the principles outlined in [20]. Additionally, the data encompassed the logs of usability testing sessions, led by the first author. To filter out failed startups, the authors examined the recent status of these ventures and identified 29 startups as failures. Participants were recruited through searching on LinkedIn. In order to reduce the bias, the participants were not recruited from the connections of the authors.

To evaluate the reasons behind the failure of these startups, the authors conducted focus group sessions. There were five group sessions in total, and four participants were recruited through searching on LinkedIn. In order to reduce the bias, the partici-pants were not recruited from the first connections of the authors. These focus group sessions were conducted with the same participants. The sessions took between 60 and 90 min and were conducted in Q1 2023.

The analysis was based on the collected data, the current status of the startups obtained from the Crunchbase directory, and the application of stress-testing desirability [13]. This qualitative test focused on evaluating the problem rather than the solution, providing valuable insights into the marketability of the product or service. Finally, through a content analysis and codification, the key themes of AR/VR startup failures were identified.

The selection of AR/VR startups for the analysis was conducted through multiple channels. First, we leveraged the authors' extensive network within the startup ecosystem, reaching out to companies they had previously advised or collaborated with.

acknowledges challenges such as physical fatigue and increased cognitive load, it lacks specific constructs prompting developers to justify motion-based user experience choices versus less-demanding interaction methods. Specialized business model frameworks such as the Blitz Canvas [25] have been proposed for specific domains like software startups, but there remains a need for tailored tools addressing the unique considerations of extended reality ventures.

Successful implementations of AR/VR have the potential to revolutionize user experiences through immersive gaming, intuitive 3D designs, interactive remote collaboration, digitally-enhanced shopping environments, and many other applications. How-ever, achieving sustainable, scalable ventures in this space requires addressing key issues such as hardware limitations, creating compelling XR-exclusive value propositions, justifying physical/cognitive interaction loads, and planning for interoperability and ecosystem forces [17].

This has motivated the need for tailored business modeling and design tools that can guide entrepreneurs in ideating viable, usable, and scalable AR/VR products and services by embedding these critical considerations starting in the initial stages.

This research proposed the MIC, a novel framework for developing XR products and services. The MIC addresses the limitations of existing tools such as the Lean Canvas in capturing unique considerations for XR ventures. The key advantages of the MIC include the following: 1) emphasizing problem solving, with blocks dedicated to framing the problem and articulating XR-exclusive value propositions; 2) incorporating usability metrics and scenario writing to communicate user experiences; 3) considering scalability issues specific to XR, such as hardware constraints; and 4) guiding ideation about the social interactions and virtual economies afforded by XR. Overall, the MIC provides a holistic, human-centered approach to ideation, enhancing the viability of XR startups by bridging the gaps between design and business modeling. Its tailored blocks prompt entrepreneurs to leverage the distinctive capabilities of immersive technologies. This research made several notable contributions to the understudied domain of augmented reality (AR) and virtual reality (VR) entrepreneurship. First, it identified prevalent failure factors based on an in-depth investigation of unsuccessful AR/VR startups, elucidating common pitfalls.

Second, grounded in design research and industry expertise, it presented the novel MIC as a strategic ideation toolkit tailored to addressing the unique considerations of extended reality ventures. Third, the proposed framework prompted a human-centered, problem-driven approach to conceiving prod-ucts/services that leverage the differentiating capabilities of immersive technologies. Fourth, the methodology synthesized mixed qualitative techniques and an external evaluation to produce actionable, valid insights. Overall, this work combined an insightful analysis of real-world challenges with an innovative design output, enhancing the viability of future AR/VR startups through a tailored, reflective ideation process. It provided a model for human-computer interactions and design researchers seeking to bridge conceptual contributions with practical entrepreneurial impact.

The emergence of AR/VR applications, services, and tools has had a profound im-pact on shaping the metaverse into a dynamic and immersive digital realm. AR applications overlay digital information onto the real world, enriching our physical environment with virtual elements, while VR applications create entirely simulated environments.

Over the past few decades, there has been a significant inflow of billions of dollars in investments into the AR/VR startup ecosystem [12,14]. However, despite the substantial financial backing, a considerable number of these startups have faced insurmountable challenges and have ultimately failed to thrive. This trend piqued our curiosity and motivated us to embark on an in-depth exploration of the underlying reasons behind the failure of these companies. While it is commonly acknowledged within the industry [1,17] that technological and hardware limitations have played a pivotal role in these setbacks, we recognized the importance of delving deeper into the diverse array of factors that may have contributed to these failures. Thus, our research aimed to unravel the complexities surrounding the demise of AR/VR startups, going beyond the prevailing notion of technological constraints.

Through an exhaustive investigation, we sought to broaden the understanding of the dynamics at play within the AR/VR startup landscape. Our analysis encompassed a comprehensive examination of market dynamics, user adoption patterns, funding challenges, regulatory hurdles, and competition dynamics. Through a meticulous examination of these multifaceted factors, we aimed to attain nuanced insights into the intricate challenges confronted by these startups.

By leveraging the insights obtained from our research, we moved beyond a theoretical understanding to develop a practical solution. This solution aimed to assist founders and investors in refining their business ideas within the distinctive context of extended reality (XR) environments. While the Lean Canvas serves as a useful starting point for business model development, our analysis identified critical gaps when applying it to augmented and virtual reality ventures, including an inadequate emphasis on validating the problem-solution fit and accounting for the user MIC, an innovative tool designed to facilitate the iterative refinement of business concepts. The MIC serves as a structured framework for founders and investors, enabling them to identify and address the specific needs and intricacies of XR environments. By leveraging this canvas, entrepreneurs can systematically explore various dimensions such as the user experience, the technological feasibility, the market viability, monetization strategies, and the scalability potential within the metaverse ecosystem.

Our approach of examining failed startups specifically aimed to avoid survivor-ship bias, a common pitfall in entrepreneurship research where only successful cases are studied, as highlighted in [28]. Previous research has highlighted potential pitfalls in AR/VR adoption, such as visual fatigue, cybersickness, muscular fatigue, acute stress, and mental overload [27]. However, these studies have primarily focused on examining ergonomic and physiological risks rather than providing actionable strategies tailored to the practical context of XR startups and product development. Similarly, while the Extended by Design Toolkit [8]

Metaverse Innovation Canvas: A Tool for Extended Reality Product/Service Development

Amir Reza Asadi[1](✉), Mohamad Saraee[2], and Azadeh Mohammadi[2]

[1] School of Information Technology, University of Cincinnati, Cincinnati, OH 45221, USA
asadiaa@mail.uc.edu

[2] School of Science, Engineering and Environment, University of Salford, Manchester M5 4WT, UK
{m.saraee,a.mohammadi1}@salford.ac.uk

Abstract. This study investigated the factors contributing to the failure of augmented reality (AR) and virtual reality (VR) startups in the emerging metaverse landscape. Through an in-depth analysis of 29 failed AR/VR startups from 2016 to 2022, key pitfalls were identified, such as a lack of scalability, poor usability, unclear value propositions, and the failure to address specific user problems. Grounded in these findings, we developed the Metaverse Innovation Canvas (MIC) a tailored business ideation framework for XR products and services. The canvas guides founders to define user problems, articulate unique XR value propositions, evaluate usability factors such as the motion-based interaction load, consider social/virtual economy opportunities, and plan for long-term scalability. Unlike generalized models, specialized blocks prompt the consideration of critical XR factors from the outset. The canvas was evaluated through expert testing with startup consultants on five failed venture cases. The results highlighted the tool's effectiveness in surfacing overlooked usability issues and technology constraints upfront, enhancing the viability of future metaverse startups.

Keywords: Lean Canvas · Mixed Reality · AR · VR · Innovation · Entrepreneurship

1 Introduction

The concept of the metaverse has been around for decades, but it has been the subject of renewed interest and excitement in recent years as technology has advanced and virtual reality has become more accessible. The metaverse can be understood as an integrated network of spatial realities and virtual worlds, where users can engage with each other and digital elements within a three-dimensional environment, often utilizing personalized avatars [5,15].

E. Brooks et al. (Eds.): DLI 2024, LNICST 604, pp. 3–21, 2025.
https://doi.org/10.1007/978-3-031-85663-1_1

Using Immersive Technologies for Learning, Accessibility, and Technological Innovation