“Reality Anchors”: Bringing Cues from Reality into VR on Public Transport to Alleviate Safety and Comfort Concerns

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Abstract

Virtual Reality (VR) headsets have the unique capability to create private virtual content anywhere around the user, going beyond the capacities of traditional devices, but are not widely used while travelling, due to safety and comfort concerns. Showing objects from reality - "Reality Anchors" - could help reduce these concerns. We present a user study (N=20) that investigates how the use of real-world cues and different VR environments affect users' feelings of safety, social acceptability, awareness, presence, escapism and immersion, which are key barriers to VR adoption. Our findings show that knowing where other people are on the bus could significantly reduce concerns associated with VR use in transit, resulting in increased feelings of safety, social acceptability and awareness, but with the concession that the user's immersion may be reduced. The VR environment also affected the level of immersion and the feelings of escapism, with a 360-video environment returning higher scores than a 2D one.

CCS CONCEPTS • Human-centered computing → Virtual reality • Human-centered computing → User studies

Additional Keywords and Phrases: Reality-Virtuality Continuum, Virtual Reality, Passengers, Buses, Public Transport, Public Context, Reality Awareness

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1 Motivation and Background

Public transport is part of modern-day living, providing mobility to an increasing volume of passengers. Pre-pandemic, the average number of local bus journeys in England reached 4.07 billion [6], taking over an hour for an average commute to work [44]. A common routine for passengers is to use this travel time for entertainment or productivity with the help of electronic devices, such as phones and laptops [11, 26], which can often act as a "defence" [32], that helps reduce discomfort during travel, created by proximity to other travellers. The latest developments in Virtual Reality (VR) headsets open opportunities for using these devices on the go. VR could be a solution to making better use of travel time, providing passengers with experiences that let them escape confined spaces and immerse themselves in entirely different environments. VR technology is not limited by device screen size and can render private virtual content anywhere around the user, increasing privacy and immersion that cannot be achieved by traditional devices [5]. However, VR use in transit also creates barriers to the outside world. By blocking out reality, belongings and other people, we bring safety and social acceptability concerns, making the adoption of VR in these contexts a challenge.

The idea of VR headset use in public space has been studied by the HCI community, revealing key challenges that need to be overcome for wider VR adoption in social settings. Engaging with VR in public evokes worries and creates risks for safety, including physically colliding and accidental bumping into other people [17,7,35,3,29], especially those in close proximity [18]. Although little research has looked at VR use whilst travelling, several authors have discussed the challenges that these contexts add. The lack of awareness of one's belongings [3] and surrounding furniture [29], missing a destination stop, or an important travel announcement [3,35] were among key concerns for passengers. Social acceptability was another challenge found to be a barrier for wider VR adoption in public [19,20,28,35], showing that the action of using the headset also needs to be seen as appropriate by the passengers themselves and observers, preventing the concerns for privacy [9,35] or feeling like you look "stupid" [3]. Preserving users' sense of presence is another key requirement [18,31,38] of an engaging VR experience, and taking off the headset to have a look around can break the illusion and engagement in the virtual world. To maintain the ability to feel present, the experience requires a balanced inclusion of the real world [10]. Too much of it can lead to an increase in distraction [18] and reduce immersion [38] in the virtual content.

Currently, commercial headsets provide abrupt ways of displaying real-world information to the VR user. The solutions include showing visible boundaries, designed for static environments rather than a constantly changing public setting [14], or a pass-through camera view of the real world, breaking presence and thus disturbing the experience [38]. To reduce this disturbance, some researchers have investigated the potential ways of providing real-world information to VR users in a more subtle manner. The majority of solutions have focused on the awareness of other passersby [8,12,16,25,36], including augmenting VR with an overlay of the real-world [18,36], integrating real-world objects to match the tone of the virtual experience [9,22], providing a "window" or a "gate" to other realities [10,35], or even immersive notifications that match the tone of the experience [38]. The choice to show this information to the VR user could be based on the proximity of the other passerby [21] or the urgency of the information [14]. However, it is not known if these solutions are also applicable to VR use in transit, as set public or private spaces do not pose the same challenges as a constantly changing travelling environment. To understand how the cues could be presented in such social situations, we first need to investigate what cues and why are needed.

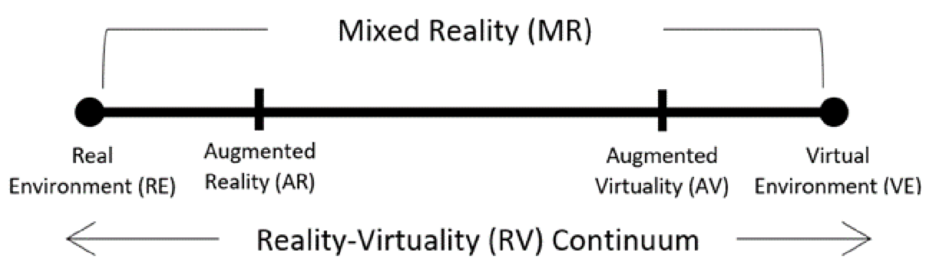

Figure 1: Integration of different levels of virtuality and reality on the RV continuum proposed by Milgram [22].

Virtual Reality is at one end of the Reality-Virtuality continuum (Figure 1) that proposed by Milgram [22], describing a fully virtual environment, not including any information from the real surroundings. Depending on the amount of real-world information, a Mixed Reality experience can take a unique place on this continuum. Propositions for bringing virtual worlds into public spaces have mostly focused on the Augmented Reality (AR) part of the scale [4,24,34]. AR devices have received more interest from the community due to reduced safety concerns [2] but do not provide the privacy and escape from the current environment that could be beneficial on public transport. This paper focuses on the use of Augmented Virtuality (AV) opportunities for in-transit contexts, that can incorporate only the information most useful to the passengers, thus preserving the sense of immersion and presence in the virtual world.

In this paper, we present a study that explores the idea of bringing cues from reality into VR, with a focus on people, furniture, and one's belongings, in a travelling scenario. We focus on these cues as they have shown to be key concerns for in-transit contexts [3,7,20,35]. We measure how these cues perform using six different factors that are based on the background research and have shown to be important barriers to VR adoption.

2 Reality Anchors in VR User Study

In this work, we introduce "Reality Anchors" as a concept of presenting cues that serve as a reference point to the objects from the real world, closest to the user. The Anchors are presented consistently regardless of the VR content, similarly to "Spatial Anchors" introduced by Oculus, which are used for adding persistent virtual objects to your physical world [39].

Our study investigated how seeing cues from reality in VR affect the attitudes towards using headsets in travel contexts. More specifically, we measured how participants' feelings of safety, social comfort, awareness, presence and immersion change when exposed to various degrees of information from their physical surroundings in a public bus. In addition, we wanted to compare a more dynamic 360 scene versus a more fixed, 2D-content set-up that resembles a cinema room, as the type of VR content can influence which cues are preferred by the users [16] and can affect the sense of presence [1].

Understanding these considerations is crucial if we want to design VR experiences that can be adopted for in-transit contexts. We formalised our aims in the following two research questions:

RQ1 – Reality cues: How does seeing information from reality in VR, whilst travelling on public transport, influence users' feelings of safety, social acceptability, awareness, presence, escapism and immersion?

RQ2 – VR environment: Does the format of VR content affect users' attitudes towards cues from reality?

2.1 Experimental Design

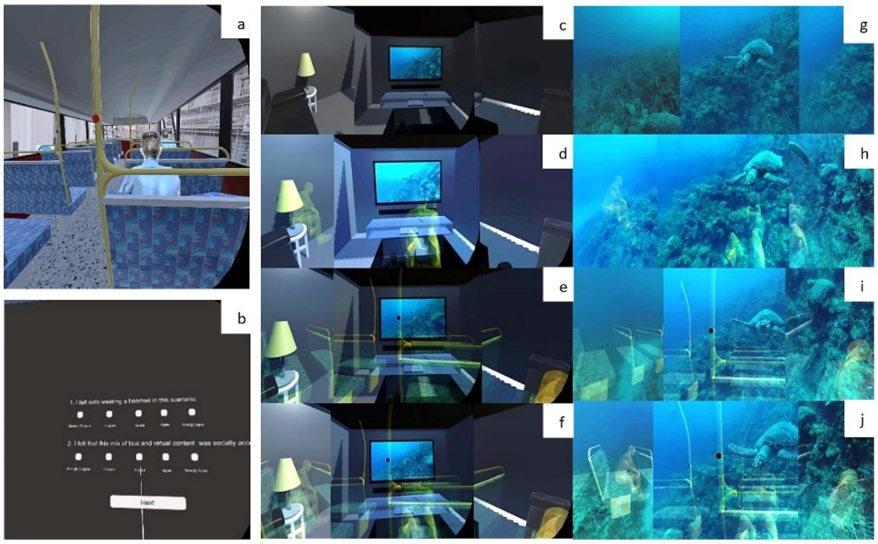

Figure 2: Experiment set-up in Unity. a) the bus scene, shown at the start of each condition; b) questionnaire screen; c) No Cues condition in the 2D-fixed video in a room; d) People visible in the 2D-fixed video in a room; e) Furniture (including belongings) visible in the 2D-fixed video in a room; f) People and Furniture (including belongings) visible in the 2D-fixed video in a room; g) No Cues condition in the 360-degree video; h) People visible in the 360-degree video; i) Furniture (including belongings) visible in the 360-degree video; j) People and Furniture (including belongings) visible in the 360-degree video.

Due to COVID-19 restrictions, we could not conduct a study in the wild and instead decided to simulate a bus journey in a VR environment. Simulation is a common strategy in the HCI community when studying potentially dangerous or explorative VR designs [23,30], making it easier to control random variables in the experiment and keeping participants safe. Moreover, images and video scenarios have been commonly used as a way to research topics related to different social contexts [15], and our work takes this further by making those scenarios feel more realistic in VR. To simulate the trip, a high-fidelity model of a London bus [40] was used in Unity with a combination of a 360-degree video, showing a drive through London streets [27] visible out of the windows. Virtual avatars from the Adobe Mixamo library [41] were placed around the VR user to simulate a social setting, which would be expected in a public space. The simulated avatars stayed static and in fixed positions throughout the experiment to avoid introducing additional bias.

The study's conditions also used simulated environments: a streamed 360 video of a nature documentary [33] and a cinema room, created using freely available assets [42,43] with a 2D-fixed video of the same documentary with a variety of cues from reality (Figure 2). After each condition, participants were given a questionnaire to complete and then taken back to the main menu for a break. The sound of the bus was kept at a consistent level throughout the whole experiment, including when the participant was watching the documentary. The conditions that included bus furniture (which included a backpack that represented passenger's belongings) or people were based on the objects' proximity to the passenger, covering a radius (measured as a 2.5m in Blender) within the social zone, a distance that is appropriate for public and casual social interactions [13]. The radius was kept consistent throughout the experiment.

The study used a two-way repeated-measures design with the two factors being: a) the visible Reality Cues (*no cues, people visible, furniture visible or people and furniture visible*), b) the VR Environment (*360-degree video or*

2D-fixed video in a room). The order of conditions was counterbalanced for the flow of the cues and order of the VR environments so that the flow of the cues would remain logical (from *no cues* to *people and furniture*, or vice versa) and would be presented in a counterbalanced order of VR environments (*360-degree video* or *2D-fixed video in a room*).

2.2 Participants

In total, 20 participants (10 females, 10 males, mean age = 28 years, SD = 5) took part in the study. The majority were students, 17 have used a VR headset at least once, 3 have never used one before; all participants had previous experience using a bus and 8 were frequent bus travellers. The experiment took approximately 90 minutes to complete, and participants were compensated by their time with £10 Amazon vouchers. We ensured the participants took a rest between conditions to minimise any possible VR-induced sickness.

2.3 Task and Data Collection

The experiment ran on an Oculus Quest 2 headset connected to a desktop PC via Oculus Link to guarantee that the bus journey and avatars were in maximum resolution and ran at maximum frame rate to reduce motion lag. The experiment was conducted in a large room during the COVID-19 pandemic with appropriate precautions taken. Each participant sat on a non-swivel chair in front of a desk, with the experimenter at a socially distanced desk across from them. The participant was greeted, presented with an information sheet and filled in a short questionnaire to collect demographic information and previous experience of using a VR headset and travelling on a bus.

During the experiment, participants were asked to imagine that they were travelling on a public bus whilst using the VR headset. Each condition started on a public bus ride through London, which participants were to consider as 'reality', and which then faded out through a black screen into different conditions. All the study's conditions started in the bus environment which lasted 45 seconds each time before transitioning into a condition. Participants were asked to imagine they were putting a headset on when the fade-out appeared. They were then presented with a condition, lasting for 1 minute, with a total of 8 conditions, four in a 360-degree video setup and four in a 2D-fixed video in a room setup. Once all conditions were over, a semi-structured interview was conducted to capture additional thoughts on the presented cues and VR environments. The qualitative analysis of the interviews is part of the ongoing work and is not included in this paper.

2.3.1 Quantitative Data Collection.

Participants responded to 5-point Likert-type questions after each condition, collecting their responses to feelings of safety, comfort, awareness, presence, escapism and immersion (RQ1). Participants completed the questionnaire in VR and were asked to rate the following six statements (answers ranging from Strongly Disagree to Strongly Agree): "I felt safe wearing a headset in this scenario" (Safety), "I felt that this mix of bus and virtual content was socially acceptable" (Social Acceptability), "It was useful to have this mix of bus and virtual content in this scenario" (Awareness), "It was distracting to have this mix of bus and virtual content in this scenario" (Presence), "I felt I could escape from the bus environment in this scenario" (Escapism) and "I felt immersed in the documentary in this scenario" (Immersion). Usefulness was used as a proxy to measure Awareness, specifically to find out how useful it was to be aware of physical objects from the bus. The measurement for Presence used Distraction as a proxy for the metric, as an overload of cues could disrupt the VR experience, thus breaking the feeling of Presence. The question for measuring Immersion asks about the documentary to prevent answers that reflect on the overall VR experience, including the conditions with reality cues. The collected data were logged in a file on the PC and later used for quantitative analysis.

2.4 Results

To conduct the analysis, the answers "Strongly Disagree" to "Strongly Agree" were converted to scores 1 to 5 respectively. To further prepare the data for analysis, the data were transformed with an Aligned Rank Transform (ART) [37] and then a two-factor repeated-measures ANOVA was performed with the cues from reality (for RQ1) and VR environments (for RQ2) as factors. Post hoc analysis was conducted to further compare different conditions for the factors that showed significant main effects. Figure 3 presents the median values for participant answers to six questionnaire statements.

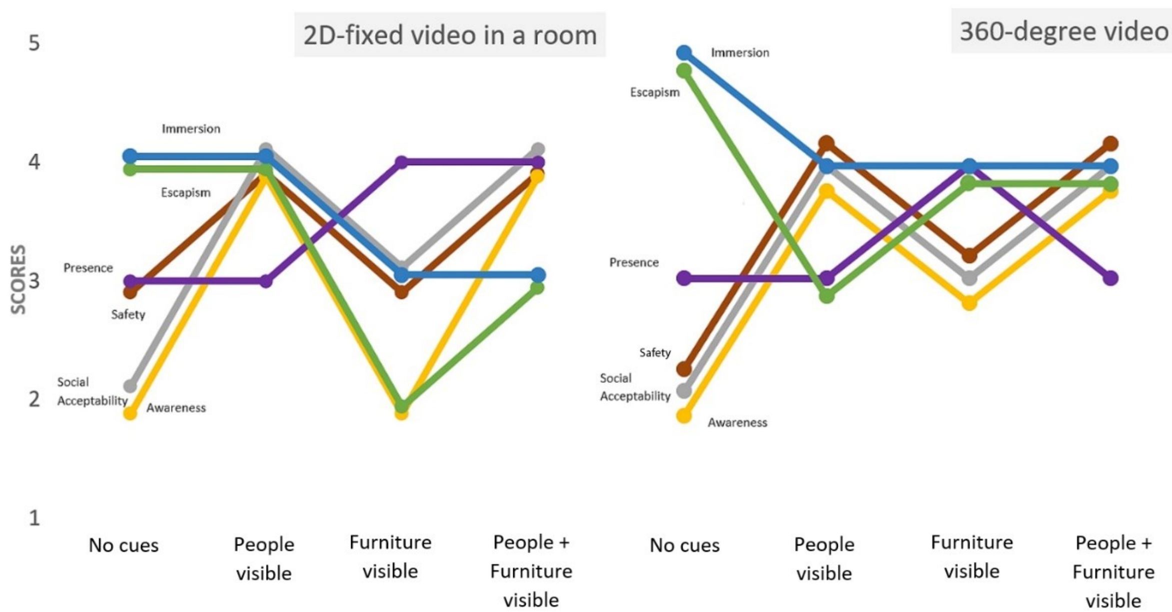

Figure 3: Median scores of participants' ratings to the six questionnaire statements, split by the VR environment.

2.4.1 Safety.

Reality Cues showed a significant main effect on feelings of *Safety* (F(3,57)=15.40 p<.0001). There were no interaction effects between the factors. Post hoc comparison (t(57)=-4.56, p=0.0002) showed that viewing *People* (Mdn=4, IQR=3.25-4) led to a significantly greater feeling of safety than viewing No Cues (Mdn=2, IQR=1.25-4). Comparisons also showed users also felt safer (t(57)=-5.75, p<.0001) when they saw *People and Furniture* (Mdn=4, IQR=3.25-4.75), compared to *No Cues*. Interestingly, seeing just *People* was also seen as safer (t(57)=3.63, p= 0.0033), than seeing just *Furniture* (Mdn=3, IQR=2-3.75), but seeing *People and Furniture* was seen as safer (t(57)=-4.81, p=0.0001) than just seeing *Furniture*.

2.4.2 Awareness.

The analysis showed that *Usefulness* was significantly affected by the *Reality Cues* factor (F(3,57)=14.15, p<.0001), with no interaction between the two factors. Further post hoc analysis (t(57)=-4.29, p=0.0004) showed that being aware of *People* (Mdn=4, IQR=3-4) was more useful than having *No Cues* (Mdn=2, IQR=2-3) from reality.

Comparison between *People and Furniture* and *No Cues* (t(57)=-5.97, p<.0001) showed that being aware of *People and Furniture* (Mdn=4, IQR=3.25-5) was still more useful than not seeing any cues from the bus. People was a crucial element for usefulness, as being aware of *People and Furniture* (t(57)=-4.29, p=0.0004) was perceived as more useful than just seeing the *Furniture* (Mdn=2.5, IQR=2-4) on its own.

2.4.3 Social Acceptability.

Reality Cues also returned a significant main effect on the *Social Acceptability* metric (F(3,57)=19.10, p<.0001). The analysis did not show any interaction effects between the factors. Post hoc comparisons (t(57)=-5.46, p<.0001) showed that users felt that it was more socially acceptable to see *People* (Mdn=4, IQR=4-4) than have *No Cues* (Mdn=2, IQR=2-4) from reality. *People and Furniture* (Mdn=4, IQR=4-4) were also seen as more socially acceptable (t(57)=-6.27, p<.0001) than having no information from the bus. Seeing *People* (t(57)=4.24, p=0.0005) or *People and Furniture* (t(57)=-5.05, p<.0001) also returned higher scores than just seeing *Furniture* (Mdn=3, IQR=2-4) in terms of social acceptability.

2.4.4 Presence.

We found that *Reality Cues* showed a significant main effect for *Distraction* (F(3,57)=2.93, p=0.0410), with no interaction between *Reality Cues* and *VR Environments* factors. Post hoc comparisons revealed that seeing just the *Furniture* (Mdn=4, IQR=3.25-4) was found to be more distracting (t(57)=-2.66, p=0.0487) than having *No Cues* (Mdn=3, IQR=2-4) brought into the environment.

2.4.5 Escapism.

Both, the *Reality Cues* (F(3,57)=8.15, p=0.0001) and *VR Environments* (F(1,19)=12.42, p=0.0023) factors showed significant main effects for *Escapism*. Interaction effects between *Reality Cues* and *VR Environments* were also significant (F(3,57)=3.45, p=0.0223). The participants felt that they could escape the bus environment more (t(57)=3.33, p=0.0081) when No Cues (Mdn=4.5, IQR=4-5) were present, compared to seeing People (Mdn=4, IQR=2.25-4). Comparisons (t(57)=3.14, p=0.0139) also showed that *People and Furniture* (Mdn=4, IQR=3-4) reduced escapism more than *No Cues*. The final significant comparison (t(57)=4.80, p=0.0001) of *Furniture* (Mdn=3, IQR=2-4) versus *No Cues* revealed that *Furniture* reduced escapism the most. For *VR Environments*, the *360-degree video* (Mdn=4, IQR=3-4) condition performed better in making users feel like they escaped the bus environment than the *2D-fixed video in a room* (Mdn=3.5, IQR=2-4).

2.4.6 Immersion.

The *Immersion* statement was also significantly affected by *Reality Cues* (F(3,57)=8.43, p=0.0001) and *VR* Environments (F(1,19)=21.30, p=0.0001). Interaction effects between *Reality Cues* and *VR Environments* were also significant (F(3,57)=3.49, p=0.0213). *Immersion* was strongest when *No Cues* (Mdn=5. IQR=4-5) were visible and showed a significant difference in comparison (t(57)=3.01, p=0.0200) to seeing *People* (Mdn=4, IQR=3-4). Seeing *People and Furniture* (Mdn=4, IQR=3-4) was also less immersive (t(57)=4.30, p=0.0004) than seeing *No Cues.* However, seeing just the *Furniture* (Mdn=3.5, IQR=2-4) was least immersive of the three, compared to *No Cues* (t(57)=4.41, p=0.0003). For *VR Environments*, *360-degree video* (Mdn=4, IQR=4-5) also led to greater immersion than a *2D-fixed video in the* room (Mdn=4, IQR=2-4).

3 Discussion

The results of the questionnaire analysis indicate that bringing in cues from reality had significant effects on the six metrics tested. Based on the results, we saw that participants felt most safe when *People* or *People and Furniture* were present in the VR environment, with both conditions returning increased scores for the usefulness of the information. Interestingly, even though *Furniture* provided information on where the physical objects were, it did not perform as well in regard to safety and usefulness on its own. Some participants noted that people are a more important factor for increased usefulness and safety because they are the dynamic element in the journey that can change, or do something, whilst the furniture stays put, which explains the possible reason for low score in this condition. Conditions that include *People* also performed better than *Furniture* with respect to social acceptability. This was also commented on by several participants, who said that they would like to know if or when the other passengers need their attention for VR use to be acceptable.

Presence, escapism and immersion showed differences between the two different VR environments. The *People* condition was seen to be less distracting than the condition that just showed the *Furniture*, in the *2D fixed video in the room* environment. However, for the *360-degree video*, *People* and *People and Furniture* were equally distracting but less than seeing just *Furniture*. Finally, we saw that escaping the bus was hardest with the *Furniture* visible for the *2D fixed video* scenario, and when seeing *People* in the *360-degree video* scenario. Immersion also went down as we brought in more cues, which is to be expected, yet performed the best with *Peop*le in both VR environments, compared to just *Furniture*. Further qualitative analysis will be needed to understand why the different VR environments resulted in different scores for the six metrics. Some of the participants provided further insight into why this might have been, by commenting that cues of *People* felt like they belonged in the cinema-room scenario, matching the virtual scene, and felt out of place in the 360 sea-world videos. This adds to the findings by McGill et al. [18] who noted that seeing people in virtual scenarios, where they are expected, is more natural than objects. Finally, we saw that overall, the *360-video scenario* resulted in higher immersion scores and escapism than the *2D-fixed video scenario*. Therefore, through these results, we were able to answer RQ1 of this study, and partially answer RQ2, which will be answered through the ongoing qualitative analysis.

Overall, our findings confirm that knowing where people are on the bus could significantly reduce concerns associated with VR use in transit. Further analysis is needed to understand if and when showing people is sufficient in travelling contexts, especially on different modes of transport. Moreover, it would also be important to understand how the change in other passengers' location or movement throughout the journey would influence this, as this study used static avatars.

4 Conclusions

In this paper, we presented a study that investigated the use of reality anchors, cues from reality that help anchor a user in immersive applications, in travelling contexts. We performed a user study that simulated a journey on a public bus to measure how the introduction of other passengers, furniture, or both together, influenced users' feelings of safety, awareness, presence, escapism, immersion and social acceptance. Our work showed that bringing the cues into VR had a significant effect on these factors, with conditions that included *People* performing best overall. This suggests that the visibility of people could improve VR acceptance in transit situations. However, further research is needed to understand if users would feel the same way in different modes of transport and social contexts.

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REFERENCES

[1] Alexandre Abbey, Thibault Porssut, Bruno Herbelin, and Ronan Boulic. 2021. Assessing the Impact of Mixed Reality Immersion on Presence and Embodiment. *Proc. - MIG 2021 14th ACM SIGGRAPH Conf. Motion, Interact. Games* (2021). DOI:https://doi.org/10.1145/3487983.3488304

[2] Ronald T. Azuma. 2019. The road to ubiquitous consumer augmented reality systems. *Hum. Behav. Emerg. Technol.* 1, 1 (2019), 26–32. DOI:https://doi.org/10.1002/hbe2.113

[3] Laura Bajorunaite, Stephen Brewster, and Julie R. Williamson. 2021. Virtual Reality in transit: how acceptable is VR use on public transport? In *2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, IEEE, 432–433. DOI:https://doi.org/10.1109/VRW52623.2021.00098

[4] Kumar Bhatta, Arkadiusz Niedzi, Andrzej Krasnod, Michał Roman, and Robert Kosi. 2022. Virtual and Space Tourism as New Trends in Travelling at the Time of the COVID-19 Pandemic. April 2020 (2022), 1–26.

[5] James J. Cummings and Jeremy N. Bailenson. 2016. How Immersive Is Enough? A Meta-Analysis of the Effect of Immersive

Technology on User Presence. *Media Psychol.* 19, 2 (2016), 272–309. DOI:https://doi.org/10.1080/15213269.2015.1015740

[6] Department for Transport. 2020. *Annual Bus Statistics: 2019/20*. Retrieved from https://www.gov.uk/government/collections/bus-statistics

[7] Pouya Eghbali, Kaisa Väänänen, and Tero Jokela. 2019. Social acceptability of virtual reality in public spaces: Experiential factors and design recommendations. In *ACM International Conference Proceeding Series*, Association for Computing Machinery. DOI:https://doi.org/10.1145/3365610.3365647

[8] Isamu Endo, Kazuki Takashima, Maakito Inoue, Kazuyuki Fujita, Kiyoshi Kiyokawa, and Yoshifumi Kitamura. 2021. A Reconfigurable Mobile Head-Mounted Display Supporting Real World Interactions. *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/3411763.3451765

[9] Nikos Frangakis, Giannis Karaseitanidis, Mirabelle D'Cruz, Harshada Patel, Betty Mohler, Matthias Bues, and Kaj Helin. 2014. *VR-HYPERSPACE Research Roadmap*. DOI:https://doi.org/10.13140/RG.2.2.14183.88481

[10] Ceenu George, An Ngo Tien, and Heinrich Hussmann. 2020. Seamless, Bi-directional Transitions along the Reality-Virtuality Continuum: A Conceptualization and Prototype Exploration. *Proc. - 2020 IEEE Int. Symp. Mix. Augment. Reality, ISMAR 2020* (2020), 412–424. DOI:https://doi.org/10.1109/ISMAR50242.2020.00067

[11] Mattias Gripsrud and Randi Hjorthol. 2012. Working on the train: from 'dead time' to productive and vital time. *Transportation (Amst).* 39, 5 (September 2012), 941–956. DOI:https://doi.org/10.1007/s11116-012-9396-7

[12] Jan Gugenheimer, Evgeny Stemasov, Julian Frommel, and Enrico Rukzio. 2017. ShareVR: Enabling co-located experiences for virtual reality between HMD and Non-HMD users. In *Conference on Human Factors in Computing Systems - Proceedings*, Association for Computing Machinery, 4021–4033. DOI:https://doi.org/10.1145/3025453.3025683

[13] Edward T. Hall. 1966. *The Hidden Dimension*. The Bodley Head, London.

[14] Jeremy Hartmann, Christian Holz, Eyal Ofek, and Andrew D. Wilson. 2019. RealityCheck: Blending virtual environments with situated physical reality. *Conf. Hum. Factors Comput. Syst. - Proc.* (2019), 1–12. DOI:https://doi.org/10.1145/3290605.3300577

[15] Marion Koelle, Swamy Ananthanarayan, and Susanne Boll. 2020. Social Acceptability in HCI: A Survey of Methods, Measures, and Design Strategies. DOI:https://doi.org/10.1145/3313831.3376162

[16] Yoshiki Kudo, Anthony Tang, Kazuyuki Fujita, Isamu Endo, Kazuki Takashima, and Yoshifumi Kitamura. 2021. Towards Balancing VR Immersion and Bystander Awareness. *Proc. ACM Human-Computer Interact.* 5, ISS (2021). DOI:https://doi.org/10.1145/3486950

[17] Christian Mai, Tim Wiltzius, Florian Alt, and Heinrich Hußmann. 2018. Feeling alone in public: investigating the influence of spatial layout on users' VR experience. In *Proceedings of the 10th Nordic Conference on Human-Computer Interaction*, ACM, New York, NY, USA, 286–298. DOI:https://doi.org/10.1145/3240167.3240200

[18] Mark Mcgill, Daniel Boland, Roderick Murray-Smith, and Stephen Brewster. 2015. A dose of reality: Overcoming usability challenges in VR head-mounted displays. *Conf. Hum. Factors Comput. Syst. - Proc.* 2015-April, (2015), 2143–2152. DOI:https://doi.org/10.1145/2702123.2702382

[19] Mark McGill and Stephen Brewster. 2019. Virtual reality passenger experiences. In *Adjunct Proceedings - 11th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2019*, Association for Computing Machinery, Inc, 434–441. DOI:https://doi.org/10.1145/3349263.3351330

[20] Mark Mcgill, Julie Williamson, Alexander Ng, Frank Pollick, and Stephen Brewster. 2020. Challenges in passenger use of mixed reality headsets in cars and other transportation. *Virtual Real.* 24, 4 (2020), 583–603. DOI:https://doi.org/10.1007/s10055-019-00420-x

[21] Daniel Medeiros, Rafael Dos Anjos, Nadia Pantidi, Kun Huang, Mauricio Sousa, Craig Anslow, and Joaquim Jorge. 2021. Promoting reality awareness in virtual reality through proxemics. *Proc. - 2021 IEEE Conf. Virtual Real. 3D User Interfaces, VR 2021* (2021), 21–30. DOI:https://doi.org/10.1109/VR50410.2021.00022

[22] Paul Milgram. 1999. Mixed Reality. *Mix. Real.* December (1999), 0–26. DOI:https://doi.org/10.1007/978-3-642-87512-0

[23] Mehdi Moussaïd, Mubbasir Kapadia, Tyler Thrash, Robert W. Sumner, Markus Gross, Dirk Helbing, and Christoph Hölscher. 2016. Crowd behaviour during high-stress evacuations in an immersive virtual environment. *J. R. Soc. Interface* 13, 122 (2016). DOI:https://doi.org/10.1098/rsif.2016.0414

[24] Anton Nijholt. 2021. Experiencing Social Augmented Reality in Public Spaces. *UbiComp/ISWC 2021 - Adjun. Proc. 2021 ACM Int. Jt. Conf. Pervasive Ubiquitous Comput. Proc. 2021 ACM Int. Symp. Wearable Comput.* (2021), 570–574. DOI:https://doi.org/10.1145/3460418.3480157

[25] Joseph O'Hagan and Julie R Williamson. 2020. Reality aware VR headsets. In *Proceedings of the 9TH ACM International Symposium on Pervasive Displays*, ACM, New York, NY, USA, 9–17. DOI:https://doi.org/10.1145/3393712.3395334

[26] Nobuaki Ohmori and Noboru Harata. 2008. How different are activities while commuting by train? A case in Tokyo. *Tijdschr. voor Econ. en Soc. Geogr.* 99, 5 (2008), 547–561. DOI:https://doi.org/10.1111/j.1467-9663.2008.00491.x

[27] Martin Perrett. 2018. 360 Trip through London December 2018 - YouTube. Retrieved March 10, 2022 from https://www.youtube.com/watch?v=yLLyEpe5hbc&t=2s

[28] Daniel Pohl and Carlos Fernandez De Tejada Quemada. 2016. See what i see: Concepts to improve the social acceptance of HMDs. *Proc. - IEEE Virtual Real.* 2016-July, (2016), 267–268. DOI:https://doi.org/10.1109/VR.2016.7504756

[29] Thereza Schmelter and Kristian Hildebrand. Analysis of Interaction Spaces for VR in Public Transport Systems. DOI:https://doi.org/10.1109/VRW50115.2020.00055

[30] Helmut Schrom-Feiertag, Christoph Schinko, Volker Settgast, and Stefan Seer. 2014. Evaluation of guidance systems in public infrastructures using eye tracking in an immersive virtual environment. *CEUR Workshop Proc.* 1241, (2014), 62–66.

[31] Valentin Schwind, Jens Reinhardt, Rufat Rzayev, Niels Henze, and Katrin Wolf. 2018. Virtual reality on the go? A study on social acceptance of VR glasses. In *MobileHCI 2018 - Beyond Mobile: The Next 20 Years - 20th International Conference on Human-Computer Interaction with Mobile Devices and Services, Conference Proceedings Adjunct*, Association for Computing Machinery, Inc, 111–118. DOI:https://doi.org/10.1145/3236112.3236127

[32] Jared Austin Peter Kay Thomas. 2009. THE SOCIAL ENVIRONMENT OF PUBLIC TRANSPORT. Victoria University of Wellington.

[33] AirPano VR. 2018. 360°, Diving with turtle, stingray and jellyfish. 4K underwater video - YouTube. Retrieved March 10, 2022 from https://www.youtube.com/watch?v=NYpFW4InfN0

[34] Luyao Wang and Tong Wu. 2022. Application of Augmented Reality Technology for Age-Friendly Travel. . 454–461. DOI:https://doi.org/10.1007/978-3-030-85540-6_58

[35] Julie R. Williamson, Mark McGill, and Khari Outram. 2019. PlaneVR: Social acceptability of virtual reality for aeroplane passengers. In *Conference on Human Factors in Computing Systems - Proceedings*, Association for Computing Machinery. DOI:https://doi.org/10.1145/3290605.3300310

[36] Julius Von Willich, Markus Funk, Florian Müller, Karola Marky, Jan Riemann, and Max Mühlhäuser. 2019. You invaded my tracking space! Using augmented virtuality for spotting passersby in room-scale virtual reality. *DIS 2019 - Proc. 2019 ACM Des. Interact. Syst. Conf.* (2019), 487–496. DOI:https://doi.org/10.1145/3322276.3322334

[37] Jacob O. Wobbrock, Leah Findlater, Darren Gergle, and James J. Higgins. 2011. The aligned rank transform for nonparametric factorial analyses using only anova procedures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, New York, NY, USA, 143–146. DOI:https://doi.org/10.1145/1978942.1978963

[38] André Zenner, Marco Speicher, Sören Klingner, Donald Degraen, Florian Daiber, and Antonio Krüger. 2018. Immersive notification framework: Adaptive & plausible notifications in virtual reality. *Conf. Hum. Factors Comput. Syst. - Proc.* 2018-April, (2018), 1–6. DOI:https://doi.org/10.1145/3170427.3188505

[39] Spatial Anchors Overview | Oculus Developers. Retrieved January 14, 2022 from https://developer.oculus.com/experimental/spatial-anchors-overview/

[40] London Bus | 3D Characters | Unity Asset Store. Retrieved March 17, 2022 from https://assetstore.unity.com/packages/3d/characters/london-bus-62744

[41] Mixamo. Retrieved March 10, 2022 from https://www.mixamo.com/#/

[42] Low Poly Isometric - Room free VR / AR / low-poly 3D model | CGTrader. Retrieved March 10, 2022 from https://www.cgtrader.com/free-3d-models/interior/living-room/low-poly-isometric-room-1

[43] lamp lamp free 3D model | CGTrader. Retrieved March 17, 2022 from https://www.cgtrader.com/free-3d-models/furniture/lamp/lamp-lamp--13

[44] 2019. Annual commuting time is up 21 hours compared to a decade ago | TUC. Retrieved November 3, 2020 from https://www.tuc.org.uk/news/annual-commuting-time-21-hours-compared-decade-ago-finds-tuc