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ScienceDirect

Transportation Research Procedia 72 (2023) 2760–2767

Transportation Research Procedia

www.elsevier.com/locate/procedia

Transport Research Arena (TRA) Conference

Virtual Reality as a tool for designing accessible public transportation services

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Abstract

Due to the ability to deliver realistic experiences in fully simulated environments, Virtual Reality (VR) can be applied to aid various design activities. Nevertheless, in the context of public transportation, the application of VR as a tool for accessibility design is not fully explored. This article presents the concept of re-utilizing VR software to design for accessibility in the early phases of the design lifecycle in the context of public transportation and related service design. We investigated how VR can be applied to service design through workshops with academic and industrial experts, focusing on the accessibility aspects. Our findings demonstrate the value of VR in designing and rapidly testing services related to public transportation, ensuring accessibility for various user groups. We further formulated guidelines to support the adoption of VR for designing accessible services.

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Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference

Keywords: Accessibility; Public Transport; Virtual Reality; Service Design

1. Introduction

Transportation infrastructure is rapidly developing and becoming intelligent to catch the pace of population growth and increased demand for mobility, introducing the concept of Intelligent Transport Systems (ITS). The application of Information and Communication Technologies (ICT) is one of the aspects that can positively affect the deployment and evaluation of intelligent public transportation services and, in particular, improve accessibility (van Wee, 2016). Accessibility represents the practices that environments, products, and services should follow to be understandable, usable, and functional for all people. (Battarra et al., 2018; Rivera et al., 2021; Smith, 2020)

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Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference
10.1016/j.trpro.2023.11.818

Furthermore, accessibility, as the attitude to equality and respect towards humanity in social interaction (United Nations, 2006) does not concern only people with disabilities. It concerns a broader group of people with some *special needs* – temporary, situational, or long-term functional limitations or conditions – such as parents with children and prams, reduced mobility due to aging, pregnancy, or mobility limitations caused by accident. As an approach, accessibility enables people with disabilities to live independently and participate fully, providing equal opportunities for all. To achieve this in the context of public transpiration, a special attention should be paid to planning and designing barrier-free transport systems. (Regulation (EU) 2019/882, 2019; World Health Organization, 2021)

The novel emerging technologies of Extended Reality (XR), such as Virtual Reality (VR) and Augmented Reality (AR), can be utilized as design tools to aid the development of truly inclusive and accessible services. Due to the possibility of blending the real and virtual, XR can be used already in the conceptualization and design phases to provide methodological ideas for design and define the needs and requirements of various user groups and the related testing processes. VR proves to be a valuable tool to aid designers in delivering realistic interactions and helps understand impaired users' challenges in virtual environments (Krösl et al., 2018, 2019), while AR facilitates verification and testing of design solutions in realistic contexts.

This research explores the application of VR to address the design for accessibility in the context of public transportation. To investigate the value of VR for service design and testing, we conducted a series of workshops with multidisciplinary experts, focusing on accessibility-related aspects. We also re-utilized a platform, called VIRRAKE, to create and evaluate the tram virtual environment and *filters of visual impairments* as a part of workshop activities. The novelty of our study lies in the combination of VR-based design and evaluation tools with the needs of the transportation sector, facilitating the design for accessibility from early phases and, thus, enhancing the development of ITS (Amditis, 2004). The contribution of this article is presented in the form of guidelines to support the adoption and development of VR technology in this sector, answering the research question: "*What should be considered when designing VR systems to enable the design for accessibility in the context of public transportation services?"*.

2. Related Work

With a growing interest in the Smart City paradigm to make cities safe, sustainable, and accessible (Rivera et al., 2021), ICT is becoming widely used to enhance transportation services. Following the agenda for sustainable city development, Tampere region in Finland recently started deploying a tram transportation system to partly replace the existing bus system (Tampere City Board, 2020). This prompted the direction of the research - to explore and integrate the use of ICT and emerging technologies to scale the importance of accessibility and make it an integral part of new infrastructure deployment in the future.

2.1. VR as a testing environment

With a rapid digitalization and wide adoption of design thinking, the application of VR technology is becoming a prominent topic for academic and industrial research in various fields. Overall, VR can be a powerful design tool (Jamei et al., 2017), benefiting from the first design phases and enhancing decision-making and multidisciplinary collaboration practices. The flexibility of virtual environments and the availability of virtual tools allow one to explore and analyze previously impossible matters, accessing the environment from anywhere. Due to increased visualization capabilities and natural interaction with virtual objects, VR has been investigated from the perspective of smart city design and urban planning (Jamei et al., 2017; Meenar and Kitson, 2020), which are linked to ITS concepts. Among the main benefits, VR has been found 1) *to support the design and planning phases by providing equal access to an immersive 3D environment despite physical location, which in turn reduces costs and timespan*, 2) *to enhance communication of different stakeholders*, and 3) *to promote participatory planning* (Jamei et al., 2017). VR can also be used to support sustainable behavior change (Scurati et al., 2021), which would positively affect people's environmental knowledge and potentially help achieve sustainable goals.

Multiple research projects have already demonstrated the appliance of VR in the context of public transportation and ITS (Amditis, 2004; Dion et al., 2011), detailing resulting opportunities and challenges. For instance, Amditis (2004) investigated the impact of VR on ITS infrastructure, society, and users and claimed that it delivers significant benefits. Similarly, VR is seen as a suitable tool for evaluating safety and comfort from the pedestrians' viewpoint, demonstrating no difference in the perception of distance when comparing to real-world (Iryo-Asano et al., 2018).

2.2. VR and design for accessibility

To make public transportation accessible for everyone, mobility and accessibility requirements should be considered by planning and designing barrier-free transport systems. VR, and other related technologies, is a promising tool to address this and aid the development of truly inclusive and accessible services. One of the key points of using VR is that the interaction with the virtual world reassembles real-world interactions; therefore, VR allows the simulation of different spaces and situations for physical accessibility (Ojala et al., 2020; Selin et al., 2019;) and provides means to educate on how people with various impairments experience the environment (Krösl, 2020; Krösl et al., 2018, 2019; Zhao et al., 2019). Therefore, simulation and evaluation of various accessibility-related factors in VR may improve the design for accessibility and overall, positively influence the establishment of inclusive and safe transportation systems. Additionally, such virtual environments can be re-utilized to educate designers and industrial practitioners, collect insights from different user groups with special needs and systemize gained knowledge into practical implications. To achieve this, we need to add the ability to use multimodal and assistive technologies in VR for users with certain needs. However, design of multimodal systems is complex and does not, in fact, persuade people to interact multimodally (Oviatt, 1999), since multimodal interaction may be challenging for many people – especially for people with physical disabilities.

Despite the growing number of users of VR, the accessibility of VR itself is an issue, as people's accessibility needs vary based on their abilities in the VR scenes and scoping the different tasks (Thiel and Steed, 2021; Zhao et al., 2019). Accessibility-related research is active in many traditional technology fields and is growing exponentially in research related to playing VR games (Beeston et al., 2018; Gerling et al., 2020; Holloway et al., 2019; Thiel and Steed, 2021; Zhao et al., 2019). Notably, the systems or devices are not designed to consider all kinds of impairments but instead provide tools to make the usage more accessible. Nevertheless, as the user's body is a primary input device for VR applications, it makes VR inaccessible for users with certain disabilities without proper interaction solutions. We think this research is vital in the given context, and it stands to reason *not to limit the use of VR to non-disabled people*, which points out that there is still a clear need to address the unique accessibility challenges and gain systematic knowledge on how to do it.

3. Methodology and Materials

This research was performed in line with the *Smart Campus* program (2022), aiming to connect research institutes, such as universities and industries and boost sustainable design and development in the Tampere region. The main goal is to provide an environment, methods, and tools for knowledge sharing and data exchange. The article is based on a series of workshops where academic and industrial experts from diverse fields and organizations were jointly working toward a common understanding of how VR can be used to address the needs of the public transportation sector. This section firstly introduces the *VIRRAKE* software and public transportation scenario utilized throughout the workshops and further details the methodology and outcomes of the conducted workshops.

3.1. VIRRAKE – VR platform for collaborative design and evaluation

VIRRAKE is a game-alike VR platform primarily created to gamify construction plans or other similar projects (Ojala et al., 2020; Selin et al., 2019). A plan of any building or area can be imported into the platform as a whole or in parts. It is sufficient that there is a data model for the object, which usually means one or more 3D models. The system includes several tools for editing virtual environments and displaying the information. For instance, the system allows adding and manipulating virtual models and objects, measuring distances, voting, leaving textual and audio notes, and taking photos, thus, facilitating individual and collaborative tasks in VIRRAKE. The system is accessible via a less immersive desktop user interface and via fully immersive Head-Mounted Displays (HMDs).

As part of this work, VIRRAKE was re-utilized to address the needs of the public transportation sector and the related service design. Figure 1 (a) demonstrates a virtual tram environment consisting of a tram and platform with public displays. The environment allows to adjust environmental parameters (e.g., sunlight based on time and season) and simulate the people flow. Furthermore, the *filters of visual impairments* (Figure 1, (b)) were deployed, which makes it possible to test several scenarios (navigation in VR, visibility, accessibility of large public displays, etc.) from the perspectives of people with visual impairments. The implementation of visual impairments for the VIRRAKE application platform takes advantage of Shaders and the Post Processing stack of Unreal Engine. It is possible to build an extra image layer created with Shaders that covers all other layers in all Post Processing effects. This layer is always on top and can affect all the graphics on the screen.

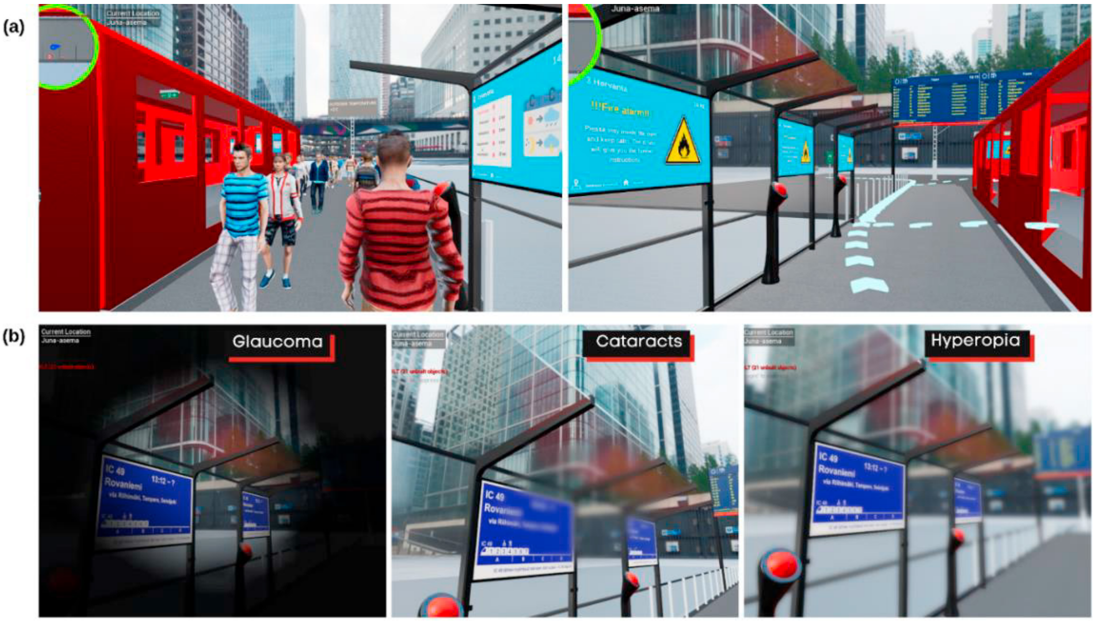

Fig. 1. (a) VIRRAKE tram environment and (b) Filters of visual impairments

3.2. Series of Workshops: Methodology & Results

The workshop series was designed to investigate the role of ITC in the public transportation sector from a broader perspective and then narrow it down and concentrate on specific points, i.e., accessibility, based on the results of the preceding workshop. As a method, a workshop is a well-known data-gathering activity to facilitate multidisciplinary collaboration and investigate the matter in question from different perspectives, and it is widely utilized in Human-Computer Interaction (HCI) and transportation fields (Chandesris and Nazem, 2018; Ma et al., 2020). Next, we describe the aims, methods, participants, and outcomes demonstrating how they affected the topic development.

3.2.1. Workshop 1: XR in the context of public transportation

The first workshop was held remotely in June 2021. It was hosted in Zoom, where 16 participants (14 academic and 2 industry representatives) contributed to the workshop's topic. Jamboard – a tool for remote collaboration – was used for group work. The main goal was to create a list of digital services related to ITS and further identify the role of industries in developing these services and how to involve them in the co-creation process. Therefore, the workshop consisted of two parts. Firstly, a presentation on how ICT can be used for the needs of public transportation, and secondly, group work. The group work was also split into two parts. First, the participants were divided into three groups for ideation activity built around the question: "*What novel and digital services would be useful for the public transportation case?*" Next, new groups were reformed to initiate a discussion around the following questions: "*How industries can benefit from these services? How can industries contribute to these services?*".

As an outcome, we defined the following areas where XR technologies should be deployed: 1) *holistic (transportation) service planning in general*, 2) *designing, testing, and optimization of traffic planning, scheduling,* *and design of tourist-related digital services (e.g., personalized AR-navigation)*, 3) *evaluation of user experience and user engagement*, and most discussed, 4) *accessibility*. The benefits of VR were seen in the ability to simulate and change various parameters of the environment (e.g., weather conditions, light conditions, and people traffic) to test design solutions rapidly and cost-effectively. Additionally, testing would become more realistic once accurate real-world data could be integrated and visualized in VR – practically creating a digital twin of a tram station.

3.2.2. Workshop 2: VR as a testing environment for public transportation service design and evaluation

The second workshop was held in February 2022 and consisted of three parts: key-note speakers' presentations, a VIRRAKE demo, and group work. The opening presentations by industrial experts introduced the context of public transportation and VR as a tool for design and collaboration. The demo session was video-based: The functionality of virtual environments and virtual tools were presented in addition to the filters of visual impairments. During the group work, the participants were split into two groups, where they performed a sequence of tasks on the "accessibility" topic. In total, 30 experts from academia and industry participated in the presentations and discussions, and 10 contributed to the group work. The tasks for the group work were: 1) ideate digital services related to the topic and list them in two categories (influencing services and all other services), 2) select five services and describe how they can be tested in VR, and 3) design a virtual tool to enable the testing of digital services in VR.

As an outcome, both groups came up with an extensive list of digital services and how they can be tested in VR. Further, both groups (unintentionally) designed virtual tool(s) to support the testing of emergencies or situations in which danger is present. The first group presented a concept of the "Crisis Information Tester" tool, which would help to ensure that emergency information is relevant, up-to-date, and accessible for all user groups based on the combination of real-world data (sensors) and virtual data (eye-tracking, movements) analysis. The other group, in turn, presented the concept of three tools ("Emergency simulation", "Personas", and "Alarm tools") which ensures design for safety by simulating various emergency situations and evaluating the best possible ways to alarm people with special needs. Both groups mentioned that realistic simulations (e.g., lighting, surroundings, physical obstacles, and user group characteristics) would be critical to extract the value of this VR-testing scenario.

3.2.3. Workshop 3: VR as a design tool for accessibility

The third workshop was held in April 2022, with the topic of "*VR as a design tool for accessibility*". The workshop was hybrid, meaning that some participants met face-to-face, while some joined via Teams connection remotely. The participants represented two user groups, *accessibility experts* (3 persons) and *VR developers* (3 persons). The workshop consisted of an introductory presentation followed by experiencing the VIRRAKE tram environment in a hybrid setup (via HMDs and desktop user interface) and followed a group interview. The planned evacuation scenario in VR was replaced with a guided video session on a large screen due to some sound issues in multi-user VR. Though, all the participants experienced the VIRRAKE before the group interview. One of the accessibility experts was a wheelchair user, and, due to mobility restrictions in hands, had experienced the VR via the desktop user interface.

The goal of the group interview was to facilitate a discussion between the accessibility experts and VR software developers to get relevant and feasible insights on how to use VR for accessibility design purposes in the given context. The interview took about 1.5 hours and resulted in a high-quality multi-perspective discussion on the following topics: 1) *usability of VR systems and the difference between HMD and desktop versions*, 2) *the value of VR for design and testing of accessibility-related aspects*, 3) *current technological limitations and how the situation might change within 5 years*, 4) *re-utilization of VR environments and other use cases, such as training, as well as expansion toward XR*, and 5) *the critical aspects to ensure accuracy and usefulness of evaluations in VR*.

As a result, the participants found VR to be a promising technology for designing and evaluating services and digital products as well as educating about the nature of disabilities. Although the participants faced several usability issues in multi-user VR, they discussed that it does not take long to learn how to use the system and felt confident when trying the virtual tools. The need for a natural and smooth training process with contextual information, and confusion minimization, was mentioned among practitioners as an important aspect of adopting technology. The filters of visual impairments were found to be useful. However not sufficient to arrange full-scale evaluations. One of the experts said that in real-life evaluations, they gather people of various user groups, for example, *people of various heights, users with mobility restrictions, such as of manual and electric wheelchairs, visually impaired persons using a white stick and with a guide dog, people with hearing impairments, people with a bicycle, large luggage or objects* *like skies, baby trolley, shopping bags, etc.* Moreover, they would need to gather up to 300 people for specific evaluation scenarios because of governmental policies. Despite the potential, VR still cannot address all the testing scenarios. Factors such as physical accuracy and freedom of movement are not yet entirely possible in VR environments. However, these can be achieved when synchronizing virtual environments with low-fidelity physical prototypes. Another factor mentioned is the lack of social cues and proper representation of emotions in HMDs. Experts mentioned that as a part of real-life observations, they pay attention to facial expressions and behavior patterns, which would be hard to track in VR.

In summary, the workshops demonstrated the potential of VR to address many of the needs of the public transportation sector while supporting the goals of smart city development. Virtual environments with realistic surroundings and tools for collaboration may be utilized as testing environments for service design. Meanwhile, the data exchange between academia and industries would support the rapid development and accuracy of VR systems.

4. Discussion and guidelines

In this article, we have presented a workshop-based investigation on *how VR can be utilized to enhance service design and design for accessibility in the context of public transportation.* With the deployment of environmentally sustainable tram-based public transportation systems in the Tampere region (2022), we highlight the importance of enabling ICT use as part of this deployment. In correspondence to previous studies (Amditis, 2004; Jamei et al., 2017; Meenar and Kitson, 2020), our study demonstrated that the use of virtual reality technologies has the potential to promote sustainable design processes prior to the implementation and ensure the accessibility of services for all. Through the series of workshops among academic and industrial researchers, we gathered professional and weighted perspectives on the role of VR for designing and testing services for public transportation in VR, its advantages, and drawbacks, and discussed many application cases.

Overall, the experts announced "*great potential*" in VR technology to experiment, design, and evaluate public transportation services. Immersive experiences in virtual environments may address the challenges present in the transportation sector and provide an alternative work environment and methods of advanced flexibility. Multi-user VR already provides opportunities to virtually gather different user groups and allows natural collaboration, enforcing sustainability by reducing traveling and costs. VR may further positively affect the design phase by facilitating global customer representations and enabling rapid change of design choices (e.g., colors, surface textures, lighting). Additionally, virtual environments can be re-utilized to allow evaluations related to transportation metrics, thus contributing to the holistic development of transportation systems, and related services (designing, testing, and optimization of traffic planning, scheduling, and tourist services and evaluations of user experience and user engagement). In addition to more efficient design and evaluation methods to ensure accessibility for all, VR could help designers to experience the services from the end-user perspective and, thus, raise awareness of and general knowledge of the specific needs of certain user groups. Nevertheless, there is still no generalizable knowledge to support the development of VR platforms to aid design and other collaboration activities in the given context, where physical accuracy is a critical aspect. Despite this article being focused on VR, the potential of one data flow between VR and AR was recognized: bringing the opportunity to re-utilize VR elements, such as filters of visual impairments, via AR over a realistic context.

The immaturity of VR technology is still a significant limitation. The absence of physical barriers and lack of co-creation feeling coupled with still limited visual capabilities of current HMDs restrict the number of application cases and the reliability of evaluations in VR. On the other hand, our study suggests that the lack of physical boundaries in VR may be partly addressed by shifting into XR by, for example, combining high-quality visualization in VR with low-fidelity physical prototypes, which still would be a more convenient and resource-efficient method of testing. Furthermore, with the development of Artificial Intelligence, the Internet of Things, and VR hardware and wearables, we may expect that innovative technologies will get adopted similarly to smartphones and will become an integral part of our lives and work tasks. Therefore, it is essential to guide researchers and industrial practitioners toward experimenting with VR and defining the cases and scenarios where it would have the most significant impact. It would affect the development of technologies positively and uncover the challenges to be addressed but also may demonstrate more sustainable and cost-efficient ways to design and develop products and services. To address these shortcomings, we summarized the workshop series' findings in the following list of guidelines:

1. **Provide seamless and natural training, including built-in guidance.** Although VR environments still reassemble the familiar interactions of the real world, its functionality may be reviewed as a novel operating system that requires sufficient support for one to become a confident user. To avoid negative effects for novel users, special attention should be paid to the training process already at the design phase when deploying VR systems. The training instructions should be considered when adding a new tool or feature, while the training itself should correspond to the actual tasks, introducing the system functionality and preparing future users for their work activities within VR. Additionally, built-in instructions and help should always be accessible.
2. **Involve stakeholders and target users in the design process.** Despite being an integral part of the design process for traditional user interfaces, the idea of including stakeholders and target users in the design of VR systems is sometimes ignored. This may be partly explained by a somewhat complex development process and testing procedures with VR hardware. Stakeholders and target users possess critical knowledge to ensure validity, efficiency, and usefulness of designed systems. Therefore, novel methods of involving them and allowing rapid testing of design solutions should also be considered during the design phases of VR systems. Our case demonstrated the usefulness of guided video sessions with the possibility to ask questions and interact with an expert presenter to communicate the ideas rapidly as one method.
3. **Identify all relevant user groups and develop associated VR personas**. When it comes to the design for accessibility, the design solutions should be developed and tested with many user groups. Similar to the filters of visual impairments, which allow experiencing the virtual world from the perspective of visually impaired persons, other personas (including the needs of temporary, situational, or long-term functional limitations or conditions) should be developed based on the involvement of these diverse user groups. The flexibility of VR enables simulating many of the unique needs of the mentioned user groups and re-utilize VR systems to test various aspects. However, simulations must be based on actual and realistic representations and features, which would not be possible to verify without the end-users.
4. **Consider asymmetry when designing a VR solution**. With various devices and ways to access VR (e.g., via a desktop user interface or an HMD), the asymmetric use of VR software should be considered. VR-based software should support access from various devices with different levels of control and immersion to provide a good user experience despite the device in use or the certain needs of the user. In any cases, this would also allow people with physical disabilities to access VR and be included in the design process.
5. **Apply VR only to address real-world challenges.** Developing VR solutions should always be reasoned. Although the focus of VR development should be set to address the challenges and limitations of the real world, VR should not be seen as a tool to (fully) replace processes that already work well in real life. It is advisable to utilize VR to design, test, and fine-tune solutions that would be difficult, expensive, or otherwise resource-consuming to design and evaluate in real-world settings with physically co-located people.

5. Conclusion

The richness and flexibility of VR technologies may benefit the development and deployment of intelligent transport systems. The smart application or service should cater to diverse users' needs, regardless of disability, and can be achieved in two ways (Avellan et al., 2020). Firstly, by properly designing applications accessible for a larger group of users. Secondly, the applications can be targeted toward specific user groups. From a design perspective, VR has two positive aspects: 1) *facilitating the more efficient design of digital services through real-time testing of different scenarios* and 2) *helping designers to experience the service from the end-user perspective with characteristics specific to certain user groups*. In our research, we explored these aspects and summarized our findings as guidelines on what aspects to consider when designing and adopting VR systems to enable the creation of accessible public transportation services for people with special needs.

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