Reality Anchors: Investigating the Use of Reality Cues for Socially Acceptable Immersive Technologies in Transit

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Abstract

Immersive technologies, such as virtual reality (VR) headsets, offer opportunities to transform time spent in transit by customising the user's reality with virtual content rendered anywhere around them. However, their widespread use remains limited due to the disconnect they create from the surrounding environment, reducing user's awareness and ability to respond to social cues. To address this challenge, this thesis proposes the concept of Reality Anchors, which integrate cues from the real world into virtual environments to retain immersion and alleviate concerns about using immersive technology in transit. Through a series of studies, this research investigates how Reality Anchors can address awareness needs and support the adoption of immersive technologies in transit.

Studies I and II identified barriers to adoption through surveys, confirming that immersive headset use in transit raises concerns about safety, awareness, and social acceptance. Rooted in users' lack of awareness of surroundings, other passengers, personal belongings, and journey progress, these concerns varied with journey length. Longer journeys, such as on flights, showed higher acceptance due to lower awareness needs and greater interest in entertainment, while shorter journeys, like those on buses, posed greater challenges requiring heightened awareness. These findings informed the design of initial Reality Anchors focused on addressing safety, awareness and social concerns. Building on this, Study III evaluated Reality Anchors using VR simulations of short transit journeys, identifying people and personal belongings as the most useful anchors. Study IV extended this exploration, investigating anchor usage in journey types categorised as self-managed and externally managed. Findings revealed that Reality Anchors must be flexible to accommodate changing user needs, with self-managed journeys requiring more anchor support. Finally, Studies V and VI bridge the gap between lab and real-world contexts. Study V explored asymmetric co-located passenger experiences, where passengers using different devices navigated real unexpected interactions. Study VI examined how passengers maintained awareness under changing real-world conditions. Together, these studies demonstrate the potential of Reality Anchors to reduce key safety, awareness, and social concerns. This thesis represents a first step toward enhancing immersive technology acceptance in transit environments and provides actionable recommendations for the future design of Reality Anchors.

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Declaration and Contributing Papers

The research presented in this thesis is entirely the author's own work. This thesis exploits only the parts of these papers that are directly attributed to the author:

Results of Studies I and II have been published as a poster at IEEEVR 2021: 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), pp. 432–433. https://doi.org/10.1109/VRW52623.2021.00098

Study III has been published as a CHI 2022 Late-Breaking Work: Laura Bajorunaite, Stephen Brewster, and Julie R. Williamson. 2022. Reality Anchors: Bringing Cues from Reality into VR on Public Transport to Alleviate Safety and Comfort Concerns. In 2022 CHI Conference on Human Factors in Computing Systems (CHI EA '22), Article 383, pp. 1-6. https://doi.org/10.1145/3491101.3519696

Studies III and IV have been published together at MobileHCI 2023: Laura Bajorunaite, Stephen Brewster, and Julie R. Williamson. 2023. Reality Anchors: Bringing Cues from Reality to Increase Acceptance of Immersive Technologies in Transit. In Proceedings of the ACM on Human-Computer Interaction 7, MobileHCI, Article 219 (September 2023), pp. 1-28. https://doi.org/10.1145/3604266

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1 Introduction

1.1 Motivation

The amount of travelling has been steadily increasing, driven by both work commutes and leisure journeys. The latest available data from 2022 shows that the average person in England completed 862 trips per year across both private and public modes of transport [235]. Not only are there a large number of trips, but the time spent travelling also makes this a significant part of modern routines, with the average daily commute now reaching 28 minutes [235]. As journeys get longer, spending time travelling effectively is becoming increasingly important. Research shows that time spent travelling is often seen as 'wasted' [213], and passengers frequently rely on electronic devices like mobile phones, laptops, and tablets, often connected to headphones, for productivity, entertainment [55, 56], or to mitigate the discomfort of travelling in close proximity to others [46, 119, 191].

Immersive technologies could offer a solution for making journeys more enjoyable and productive by providing control and customisation over how we experience reality, for example, in a cramped transport setting. Their key advantage over traditional devices lies in their ability to simulate unlimited screen sizes and render virtual content anywhere around the user. These capabilities enable passengers to have personal and private experiences, allowing them to escape confined spaces and immerse themselves in entirely different environments. Moreover, advancements in immersive technologies, such as the recent release of the Apple Vision Pro [236], highlight growing industry interest and the increasing feasibility of integrating these technologies into everyday life. However, while there are early signs of adoption in in-flight contexts [237, 238], which are more enclosed and controlled environments, immersive headsets have not yet been widely adopted for on-the-ground transportation. By blocking out reality, immersive headsets may limit users' awareness of their environment, including personal belongings, fellow passengers, and the surrounding space, potentially making them less socially acceptable in transit contexts.

The basis of this thesis is addressing the challenge of restoring elements from reality that people lose when using immersive headsets in transit contexts.

Current reality-awareness solutions, such as Meta's Quest's 'Guardian' and 'Space Sense', which outline spatial boundaries, can be disruptive [142]. These systems may suddenly appear in a moving environment, are not within the user's control, and are poorly suited to transit settings, as sensor data often misinterprets vehicle motion as user motion. Similarly, features like 'Passthrough', commonly used in headsets such as the Meta Quest 1 to 3 or the Apple Vision Pro, provide a video feed of the surrounding environment, but that can break the immersion in the virtual experience [85]. Research efforts to enhance reality awareness, such as visualising nearby passersby [126], employing physical world overlays [118], or creating windows and 'gates' to reality [49, 217], are primarily focused on static and controlled environments and are not suited to address the social challenges inherent in transit contexts.

Awareness needs go beyond practical concerns and pose a significant hurdle for the social acceptability of immersive headsets. Unlike traditional devices, immersive headsets create a barrier that prevents users from remaining visually aware of their surroundings or responding to social cues. This lack of awareness can lead to uncomfortable situations or breaches of social conventions [126, 218], such as accidentally entering another passenger's personal space. These challenges are amplified in transit, where social contexts shift constantly as vehicles move through different neighbourhoods and new passengers board or disembark. In such environments, passengers may need to maintain awareness of the surrounding furniture [173, 220], fellow passengers [110, 217], journey progress [99], and important announcements [99, 123, 217].

To address these challenges, this thesis investigated how showing cues from reality, referred to as 'Reality Anchors', in virtual environments can help keep users grounded in the real world while maintaining immersion. While the term *reality anchor* originates in philosophical writing by Michael Heim [66], where it refers to existential anchors such as mortality, this thesis adapts the idea to describe visual cues that represent physical objects in the real world. These may include people, furniture, or personal belongings, and are used to help ground users within their physical surroundings while using immersive technology.

This is a first step in designing reality-awareness solutions that support immersive headset use in dynamic public settings. It is worth noting that other barriers also impact the adoption of immersive headsets, such as reluctance to be immersed in virtual environments, the currently ‘bulky’ form of the devices [45, 239, 240], motion-sickness [121], gesture use [4, 72, 128] and privacy concerns [144]. However, this thesis argues that concerns affecting the device’s social acceptability are the most significant challenges to overcome. Exploring social acceptability serves as a preventative measure; addressing it early can help shape the design of these technologies to better cater to user needs and avoid rejection [32, 130, 231]. To address this, the research reported here explored what cues from reality can be used and how they can address the unique needs and challenges of passengers across various journey types, from short bus commutes to long-haul air flights, to enhance social acceptance.

The first part of this research identifies barriers to the adoption of immersive headsets, with transport mode and journey length as core factors of interest. These aspects, which have not been explored in depth in prior literature, provide a foundation for understanding key concerns and journey contexts. Building on this, the research tested the proposed concept of Reality Anchors. Reality cues such as the presence of other passengers, personal belongings, internal furniture and journey information were evaluated to determine their role in enhancing awareness, safety, and social acceptability. The research also identified two distinct categories of journeys: self-managed and externally managed. These categories were then used to further evaluate the concept’s effectiveness in meeting the varied needs of different journey types. Finally, the research examines the impact of real-world contexts on Reality Anchors, focusing on real passenger interactions and real-transit settings to uncover insights that cannot be fully captured in controlled lab studies.

1.2 Thesis Statement

Immersive technologies are not yet widely used while travelling due to awareness, safety and social concerns. This thesis argues that introducing objects from reality, referred to as Reality Anchors, represents an initial first step towards mitigating these concerns. By identifying the specific cues needed for travel contexts, such as other passengers, personal belongings, the surrounding environment, and journey information, this research demonstrates how Reality Anchors can enhance the social acceptability of immersive technologies.

Furthermore, this thesis contributes valuable knowledge about awareness needs in transit settings, providing a foundation for designing systems that address barriers to the adoption of immersive headsets in transit. The findings are based on an in-depth investigation using surveys, lab studies, and in-the-wild experiments.

1.3 Research Questions

This thesis addresses the following research questions:

Q1: *How do mode of transport and journey length affect the social acceptability of immersive technology use on public transport?*

Research Question 1, explored through Studies I and II, investigates VR usage during flights and various forms of ground public transport via two surveys, analysing users' attitudes towards VR travel experiences. The goal is to identify barriers to adoption based on factors such as transport mode, journey length, activity, and social context. This understanding is a critical step before designing solutions to address these challenges.

Q2: *Can Reality Anchors based on people, objects, environments and journey information alleviate concerns explored in RQ1, while maintaining immersion?*

Building on the findings from RQ1, Research Question 2, explored through Study III, introduces the concept of Reality Anchors and investigates key reality cues—such as other passengers, personal belongings, and internal furniture—identified as the most important awareness needs through surveys. These cues were examined during a simulated short bus journey to understand how they impact users' feelings of safety, social acceptability, awareness, presence, escapism, and immersion, all of which are significant barriers to adopting immersive technology in transit. Journey information is also incorporated into the Reality Anchors list in Study IV, further exploring its role in meeting immersive device users' awareness needs within a transit context.

Q3: *How do Reality Anchors need to adapt based on journey type and dynamic user needs during travel?*

Work conducted in Study III revealed that immersive headset users prefer to selectively choose anchors that meet their specific journey needs, with preferences varying according to the journey type. Journeys were categorised as either self-managed or externally managed. This research question, explored through study IV, investigates how passengers interact with Reality Anchors across these journey types. Understanding the ability to generalise anchor use in different contexts is crucial for shaping future immersive technology designs.

Q4: *Can Reality Anchors improve the acceptance of immersive technologies in real-world transit settings?*

Studies I-IV explored barriers to immersive headset adoption in transit, awareness needs in transit contexts, the concept of Reality Anchors, and ways to adapt them for changing user needs during travel. Research Question 4, explored through studies V and VI, focuses on understanding how reality awareness needs are influenced by real-world settings, such as interactions between passengers or the use of immersive devices in an in-the-wild transit setting. The work conducted in studies V and VI is a novel investigation into these issues in real-world transit environments, aiming to gain additional contextual insights that cannot be replicated in lab settings, ultimately providing the necessary insights for future development of reality awareness solutions such as Reality Anchors.

1.4 Overview of Studies

The following table summarises the studies conducted in this thesis and links them to the relevant chapters and research questions. A more detailed illustration of how the studies build on one another, including key methods and findings, is provided in Appendix G: Visual Mapping of the Progression of Studies in This Thesis.

RQ	Chapter	Study	Purpose
RQ1	Chapter 3	Study I & Study II	Identify barriers to adoption, focusing on core factors such as transport mode and journey length, while additionally exploring secondary factors like activity and social context.

RQ2	Chapter 4	Study III	Introduce the concept of Reality Anchors and investigate their impact on safety, social acceptability, awareness, presence, escapism, and immersion.
RQ3	Chapter 4	Study IV	Investigate how passengers interact with Reality Anchors across self-managed and externally managed journeys.
RQ4	Chapter 5	Study V & Study VI	Investigate how reality awareness needs are influenced by real-world settings, such as interactions between passengers and an in-the-wild transit setting.

Table 1.1: A summary of studies presented in this thesis.

2 Literature Review

2.1 Introduction

This chapter outlines the motivation and reviews key research areas related to the research questions explored in this thesis. Section 2.2 begins by defining the term 'immersive technology' as used in this thesis, while introducing the relevance of the virtuality-reality continuum concept and providing a brief overview of the current state-of-the-art immersive headsets, setting the necessary background. Section 2.3 outlines the key motivators for this research, highlighting how technology is currently used in transit and the benefits immersive technology offers over traditional devices. The literature review then examines related work on social acceptability and the challenges of immersive technology adoption in transit environments (Section 2.4). It further discusses how reality awareness is a key hurdle to overcome, noting that current solutions are not designed for transit contexts (Section 2.5). The chapter concludes by introducing the research and data collection methods employed throughout the thesis (Section 2.6), followed by a discussion of the open challenges addressed by this thesis (Section 2.7).

2.2 Defining Immersive Technologies

This thesis discusses work related to technologies like 'Virtual Reality' (VR) and 'Augmented Reality' (AR) that significantly alter or augment one's perception of reality. There are multiple umbrella definitions for these technologies within the

HCI community and literature, such as ‘Mixed Reality’ (MR) [182], ‘Extended Reality’ (XR) [149], and ‘Immersive Technologies’ [186]. For consistency, it is necessary to begin this literature review by setting out the terminology used throughout.

While the studies in this thesis employ Virtual Reality headsets, the term ‘Immersive Technologies’ is used throughout, as this work speculates that future devices will offer varying degrees of real and virtual content to suit user needs. Thus, the findings of this work will be applicable to a range of immersive devices that adapt to the user’s preferences in terms of the mix of real and virtual elements. This approach avoids limiting the scope of the research to current definitions or classifications of these technologies. This thesis focuses on a specific space within the virtuality-reality continuum proposed by Milgram [131, 132], where most of the user’s experience is virtual, enhanced by augmented reality cues. This concept helps position this work within the broader spectrum of immersive technologies, spanning various devices and user experiences. The continuum will be discussed further in the next section to explain where this thesis fits within existing research.

2.2.1 The Virtuality-Reality Continuum

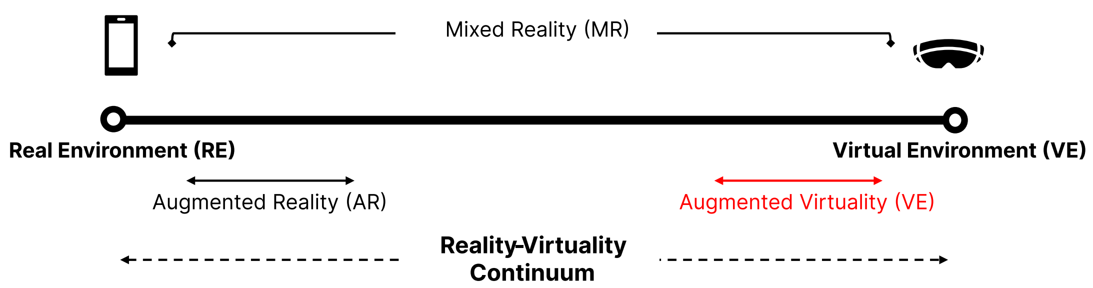


Figure 2.1: Reality-Virtuality (RV) Continuum [131, 132] **adopted for this thesis.**

The Reality-Virtuality (RV) Continuum scale proposed by Milgram [131, 132] outlines a spectrum of environments, ranging from completely real to entirely virtual. The specific placement of an environment on this continuum is determined by the amount of real-world information incorporated into the virtual world. In this thesis, a broader interpretation is adopted by including mobile phones within the AR/VR continuum, acknowledging their ability to engage users deeply in digital content without significantly altering or occluding their perception of the surrounding environment. A mobile phone user represents one end of the spectrum, where the user's awareness of reality is minimally obstructed, thus allowing them to observe their real-world environment. In contrast, a VR headset user, positioned at the opposite end, can be fully immersed with the surrounding environment entirely occluded.

It is worth highlighting that the introduction of cues from reality, a core concept proposed by this thesis, situates the user towards the more virtual end of the Reality-Virtuality Continuum, in what Milgram terms 'Augmented Virtuality'. In this state, the user is immersed in a predominantly virtual world, with elements from the real world incorporated (see Figure 2.1 for a visual representation of Milgram's RV Continuum).

2.2.2 Current State-of-the-Art

A Head-Mounted Display (HMD) is a wearable device designed to display immersive content, ranging from fully enclosed helmets to lightweight goggles [177] or see-through glasses [52]. Due to its mobility, it has great potential to be used in transit and, therefore, is used in this research. For the purpose of this thesis, HMDs are also referred to as 'headsets' or 'immersive devices', with the terms used interchangeably. VR concepts can be traced back to the late 1960s with the introduction of the first VR HMD, providing its user with an image that changed with their movement [187]. Since then, VR technology has continued to advance, with improvements in design and functionality over the years (Figure 2.2).

Over the years, VR headsets have evolved in form, becoming more compact, while also improving in processing power and functional capabilities. Early headsets were tethered devices, which required physical connections to powerful external computers via cables to deliver high-fidelity experiences. Current definitions describe the technology as a computer-generated, three-dimensional environment that is not only interactive but also capable of stimulating a feeling of presence and fully immersing the user [92, 207]. An example of a modern tethered headset is the HTC Vive [73], which provides enhanced graphics and precision but requires a cable connection and additional equipment for tracking movement [73, 241].

As VR technology advanced, the development of more mobile devices occurred alongside the continued evolution of high-performance tethered headsets. Mobile headsets offer an alternative by addressing many of the constraints associated with tethered devices, such as limited portability and dependence on external hardware. Early modern mobile headsets, such as Meta's Quest 1 [40] and Quest 2 [242], integrate processors and sensors, offering greater freedom of movement and removing the constraints of cables or external setups. For basic reality awareness, early mobile headsets include simple passthrough modes, often in black and white and lower definition, enabling users to briefly view their physical surroundings outside the virtual environment. Their portability allows them to be used anywhere, opening up opportunities for VR applications beyond constrained indoor environments.

More recently, manufacturers have been moving away from positioning their devices strictly as VR headsets, shifting the focus to mixed reality experiences that can blend virtual and real environments. For example, Meta's Quest 3 and Quest Pro use high-definition passthrough technology to present users' physical surroundings and virtual content together in a single view [243, 244]. Similarly, Apple Vision Pro features enhanced passthrough, offering an improved view of both virtual and real environments [236]. This transition towards mixed reality headsets reflects a growing emphasis on devices that enable high-quality blending of virtual and real elements, minimising the boundary between these experiences and expanding their use cases.

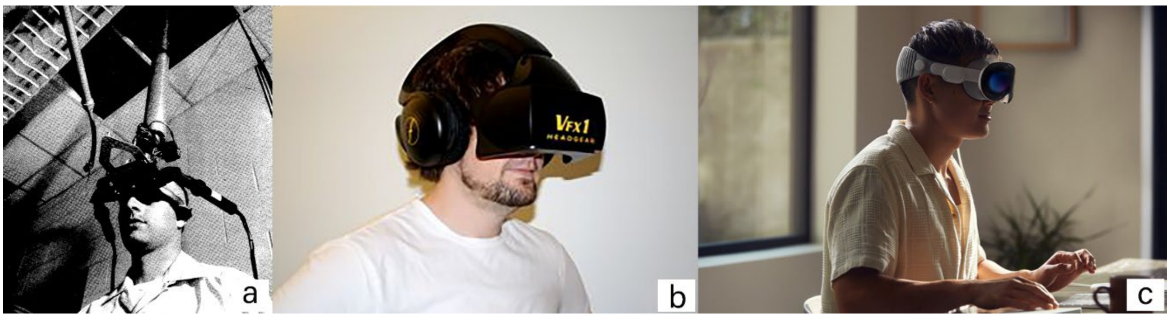


Figure 2.2: VR headset evolution. a) 'Head-Mounted Three-Dimensional Display' from the 1960s [187], **b) VFX1 'Headgear' from the mid-1990s** [245], **c) the newest 'spatial computing headset' by Apple, released in 2024** [246].

2.3 Passenger Use of Technology on Public Transport

2.3.1 Utilising Travel Time for Productivity and Leisure

People's experiences as passengers are at the very core of this thesis. Prior work has looked at passenger behaviour on public transport [147, 169, 192], revealing a range of activities that passengers engage in during their journeys, such as looking ahead or out the window, reading, talking, resting, or using technology such as headphones, mobile phones, or laptops. The increased use of technology can be linked to the development of mobile Information Communication Technologies (ICTs) [55], such as phones and laptops. Device mobility allows passengers to turn travel time from 'dead' or 'wasted' to meaningful [46, 55, 211, 213] and engage in productivity [55] or entertainment [56] tasks while travelling.

Several studies provide examples of how technology influences journey activities. In their study, Gripsrud et al. [55] observed that most commuters used some sort of device for work-related activities and felt that the train environment made a suitable space for productivity since their work tasks rely on ICTs. Similarly, Timmermans and Van der Waerden [192] further supported this finding, showing that the choice to work during the commute is not accidental. They found that the decision to travel on public transport, rather than private transport, is influenced by the opportunity to use travel time for other activities. Additionally, Ohmori and Harata [147] highlighted that both the activities passengers engage in and the devices they use vary between work and non-work-related trips, with devices often purposefully chosen to suit different activities. The authors found that passengers travelling for work used laptops more often for work tasks, while those travelling for leisure typically used mobile phones for entertainment or personal use. Building on these findings, we see a transformation in passenger experiences brought about by technology. As discussed by Lyons and Urry [107], technology can be seen as a means of empowering its users. The authors argued that equipping passengers with technology blurs the line between travel time and activity time, thereby reducing wasted time.

Reflecting this ongoing shift, more recent work by Malokin et al.[112] showed that younger commuters especially value the ability to spend travel time productively, suggesting that device usage will only increase in transit settings. This increasing reliance on devices and the desire for productive travel time creates an opportunity for immersive technologies to further transform passenger experiences, offering even more ways to utilise and enhance travel time. By combining the capabilities of multiple ICTs, immersive technologies could provide a versatile solution, enabling passengers to smoothly transition between work, entertainment, and personal activities, potentially serving as a comprehensive tool for future travel.

2.3.2 Using Technology for Privacy and Disengagement

Beyond using travel time for work or entertainment, passengers also use technology to create a sense of private space, especially in less favourable seating positions like middle seats. Evans and Wener [39] found that middle seats are particularly unpleasant and the least favourable seating option due to the increased risk of spatial intrusion and discomfort from other passengers. In addition to creating private space, devices can serve as a defence mechanism, allowing passengers to ‘shield’ themselves from unwanted interactions. This concept is reinforced by Thomas [191], who observed that reading or wearing headphones can serve as a form of ‘defence’, helping passengers reduce discomfort caused by proximity to other travellers, while maintaining a friendly atmosphere. These actions signal disinterest in social interaction, as indicated by Patel and D'Cruz [150], making passengers less likely to be approached by strangers. Zurcher [228] referred to this tactic as ‘social withdrawal’, where being engaged in an activity reduces the likelihood of social engagement with others. Patel and D’Cruz [150] also noted that immersion in an activity helps passengers feel less discomfort from the physical constraints of the cabin, enabling a form of disengagement. The immersion in an activity not only serves as a distraction but can also alter the perceived experience of the journey. Groening's work on in-flight entertainment [56] concluded that the use of screens during flights creates a private entertainment space that helps each passenger separate from others and shapes passengers' perception of time and place.

Prior work shows that changing how we experience reality can be especially beneficial in transit settings where longer periods of travel or more crowded situations might be unavoidable [191, 234]. Therefore, there is potential for immersive technologies to further customise reality in transit settings by creating private, immersive personal spaces, offering a greater escape from the surrounding environment. Privacy and disengagement are key advantages of immersive technologies, and their broader potential in transit settings is explored next.

2.3.3 Advantages of Immersive Technology Over Traditional Devices

Earlier sections demonstrated that electronic devices such as laptops, mobile phones, and headphones are already used to utilise travel time or reduce the discomfort of travelling in cramped social spaces. Immersive technologies can provide benefits beyond these traditional devices. By rendering content anywhere in their surroundings, immersive technologies allow users to shape their experience of reality, customise virtual environments to meet their needs, and occlude unpleasant realities, such as a cramped seating space on public transport—capabilities not achievable with traditional technologies.

Prior work has explored the adoption of immersive devices, from AR glasses to VR headsets, for enhancing productivity [51, 57, 86, 104, 129, 151], entertainment experiences [122], and socialising [101, 133, 141, 188] across private and shared environments, including some early explorations of transit settings [119, 120, 123, 129, 151]. Several authors have highlighted specific advantages that immersive devices can offer. For example, in their work, Mathis [115] argued that isolating humans from their real-world surroundings by, for example, diminishing real-world sources of noise, can help with concentration. Whilst, focusing on fully immersive VR experiences, Gonzalez-Franco and Colaco [51] further illustrated how immersive devices can be used to achieve higher focus and become a productivity tool. However, the authors also highlighted that accessing and integrating the real world into the virtual environment in a blended manner is a key requirement for future success, further supporting the need for work exploring how cues from reality can be used in immersive devices (more detail on awareness solutions is presented in 2.5.2). Knierim et al. [86] argued that immersive devices have the potential to create truly ‘nomadic’ workspaces that could overcome physical constraints. As for entertainment, we see the potential of immersive devices to transform media consumption by increasing immersion in the media and supporting social interactions across distances [122]. Regarding transit environments, McGill et al. [123] have identified several unique advantages of immersive technology, such as enhanced immersion, privacy, flexible and comfortable viewing, the perception of expanded personal space, and support for both entertainment and productivity applications.

Beyond offering greater immersion in virtual content than traditional devices, immersive headsets also provide a more effective way to shield users from other passengers [129]. The ability to block out unwanted interactions, along with the added privacy of a personal screen kept out of view from others, enhances the sense of personal space [123, 129, 217]. The early adoption of headsets on planes [237, 238] demonstrates the growing interest in these technologies, which will likely continue to evolve for wider use in public spaces, including ground public transport. However, while immersive technology offers the aforementioned benefits, it also occludes elements of the transit environment, raising social concerns and presenting adoption challenges, which are discussed in detail in Sections 2.4 and 2.5.

2.3.4 Summary

This section explored how passengers increasingly use technology to enhance their transit experiences, utilising devices like laptops, phones, or headphones for productivity, leisure [55, 147], or as a 'defence' [191] against awkward social situations and a distraction from uncomfortable confined spaces [46, 119]. Immersive technologies surpass traditional devices by allowing users to customise their experience of reality, rendering content anywhere around the user while providing enhanced privacy (as discussed by multiple authors, e.g. [51, 123]), and have the potential to transform passenger experiences. This has motivated the exploration of in-transit settings as a future application area for immersive technologies in this thesis. While this section highlights the advantages of immersive technologies, their adoption in transit environments faces challenges related to social acceptance and reduced awareness of surroundings, which must be addressed. These issues create a research gap for work conducted in this thesis, discussed in the following section.

2.4 Social Acceptability of Wearable Devices

2.4.1 Technology Acceptance Models

Understanding what affects users' acceptance and adoption of new technology has long been an important research area, as knowing what shapes these behaviours can guide the design of new and emerging technologies. Insight into how passengers might perceive and use technology is covered by various theories and models of technology acceptance [29, 199-201, 203]. The most applied model of technology acceptance, 'TAM', was proposed by Davis nearly forty years ago [29] and focused on perceived usefulness and ease-of-use as key attributes that influence adoption. This well-known model has since been tested for technology adoption across areas including banking [205], engineering [71], healthcare [68] education [148], and future autonomous driving systems [158]. The model has been critiqued for being unsuitable to assess the adoption of technology outside of work environments [206] and not representative of other factors, such as social influences [202].

To improve upon the original theory, several updates to the original model—'TAM 2' [200], 'UTAUT' [201] and 'TAM 3' models [199]—have been introduced. However, these extensions to the original model were also created based on organisational use and therefore not suitable to assess voluntary technology adoption [167]. In more recent years, the 'UTAUT2' model has been proposed to address this shortcoming. The model was aimed at technology acceptance for consumer products and included three additional variables of influence: hedonic motivation (such as enjoyment), price value, and habit [203]. While this and previous models included social influence as an indirect variable affecting acceptability, recent research has shifted focus to how social factors impact technology acceptance and critiqued the existing models for their limited view on social influence [197]. The models were criticised for only focusing on the positive social influence [88], whilst social acceptance accounts for both positive and negative influences [82, 88]. The shortcomings of the models provided further arguments for exploring the social context of technology use in public [80, 89, 90]. Therefore, although the study of technology acceptance has a long history, the existing models are not applicable for assessing the acceptance of immersive technology in public social settings, such as in-transit environments.

2.4.2 Social Acceptability: The Challenge of Wearable Technologies

Technology often takes time to gain widespread acceptance—mobile phones, for instance, were initially met with resistance before becoming commonplace [224]. While all technology faces challenges to its acceptance, wearable devices [82] face the added difficulty of being judged based on how they fit into the user's surroundings and the reactions of observers [81]. Worn technology can either signal conformity with accepted norms, reflecting a sense of belonging, or challenge social norms and risk being perceived as unacceptable [81, 190]. Thus, for unconventional and emerging technologies in public spaces, social acceptability presents a complex hurdle to overcome.

Social acceptability refers to how well a product's design aligns with cultural and societal norms, facilitating its broad adoption across society rather than just individual users [90]. Immersive headsets in particular, pose a significant challenge due to their reliance on gestures and voice commands and, critically, the isolation from reality they create by augmenting, extending, or blocking the user's perception of the surrounding environment. A notable example of a wearable that was widely perceived as socially unacceptable is Google Glass [32, 130], a smart-glass display worn as spectacles that allowed users to browse, record and share data on-the-go. The device was criticised for creating an uncomfortable divide between users and non-users, leading to power imbalances where users' intentions were unclear [229]. As a result, its design was perceived as 'creepy' [229, 232, 233], unnatural, and 'scary' [231], combined with a lack of clear purpose or consumer benefit, ultimately leading to its rejection. While it can be argued that social acceptability concerns may be replaced by factors like usefulness, functionality, and usability once the technology becomes more unobtrusive [87], the example of Google Glass shows that exploring social acceptability is a preventative measure. Addressing it early on can help shape the design of technologies to prevent rejection by ensuring they better cater to user needs.

While the investigation of social acceptability of immersive technologies in public spaces is a relatively new topic, there are some initial insights. The current body of work can be divided into research that has explored the general acceptability of new wearable technologies [80–83], or the use of headsets in public spaces [14, 34, 58, 87, 123, 141, 204, 210], including specific use cases, such as usage by individuals with disabilities [155]. A more recent interest in transit settings has prompted research that highlights acceptability challenges unique to these environments [45, 120, 123, 176, 217]. However, much of this research has taken a theoretical approach [45, 123, 176], identifying the need for empirical studies in real-world contexts. In particular, social challenges with immersive headset use during transit [217] have remained underexplored through studies conducted in real-world contexts, which further motivates this thesis.

The existing in-the-wild studies typically focus on public spaces [14, 34], which are not representative of dynamic environments like public transit, where conditions continuously change internally (e.g., moving passengers) and externally (e.g., driving through new neighbourhoods). This thesis does not consider autonomous vehicles, as the social challenges in those settings—such as travelling only with familiar people—differ from those in public transit. Instead, this gap raises the question of whether research conducted in real-world public transit scenarios might reveal new insights into the social acceptability challenges unique to dynamic environments.

The collection of prior work highlights that social acceptability is complex and influenced by multiple factors, including the social context or environment [176]. This encompasses the physical space (e.g., the type of public area you are in), proximity, and relationship to fellow passengers (e.g., who you are travelling with) [123, 176]. The type of journey, perceived safety [120], and the loss of awareness of surrounding passengers and real-world events [217] also influence social acceptance. Although prior work offers valuable initial insights into factors affecting the social acceptability of immersive technology in transit settings, it is limited by focusing on singular scenarios and theoretical perspectives that cannot capture the complexities of dynamic transit environments. To truly understand how immersive technology can become socially acceptable in transit, broader investigations into a variety of travel scenarios, journey factors, and real-world experiences are necessary.

2.4.3 Other Challenges to Immersive Technology Acceptance in Public Spaces

Whilst the following challenges are not in scope for this thesis, it is important to acknowledge them as related barriers to the adoption of immersive technology in transit settings. These include a reluctance to be immersed in virtual environments, the currently 'bulky' form of the devices [45, 239, 240], motion sickness [121], gesture use [4, 72, 128] and privacy concerns [144].

To begin with, the reluctance to be immersed in virtual environments is still a challenge for immersive technology [45]. A general hesitancy toward immersive devices may also contribute to this, with market penetration and perceived utility still developing. Companies such as Meta are actively working to communicate the everyday value of immersive technologies [247], and to improve the physical design of headsets, as the still-bulky form factor continues to generate user scepticism and deter adoption [239, 240]. However, it can be argued that the form factor will continue to evolve, becoming lighter and more mobile, as seen with other technologies like mobile phones. Beyond concerns about device form and general hesitancy, potential physical discomfort also poses a challenge. Motion sickness, caused by the sensory mismatch between visually and physically perceived motion [160, 227], can make a headset unusable for some users. That said, it has been extensively explored, with efforts aimed at reducing its effects when using immersive headsets in transit (see, for example, [36, 153, 157, 174]).

In addition to physical discomfort, interaction methods such as gesture input can also affect the acceptance of immersive technology in public spaces. Gestures are often required for input when engaging with immersive devices, but they can be perceived as intrusive in public settings. As a result, more subtle, less conspicuous and familiar gestures are generally considered more appropriate [4, 9, 72, 98, 128, 156, 161, 216]. Although not explored in depth here, existing research has addressed gesture-related challenges by focusing on approaches such as hand-to-face gestures [98], adapting input techniques for confined spaces, and optimising space and furniture in public transport environments for immersive device interactions [78, 173, 196, 220]. The role of observers is also important, as gesture acceptance in public spaces depends on how well the gesture is understood [198] and aligns with observers' perspectives [9, 47]. However, other studies suggest that users and observers often share similar perceptions of comfort regarding the performed gestures [128].

Finally, the capacity of immersive headsets to collect large amounts of user and environmental data [2, 43, 61, 62, 163, 212], often achieved discreetly and without notification, consent, or clarity on potential data misuse [2, 24, 61, 144, 163], raises privacy concerns. Prior research has highlighted low awareness of what data is collected, how it is used, and why [2, 30, 144], which also contributes to the reluctance to adopt immersive technology in public spaces. Although privacy and gesture concerns are not examined in detail within this thesis, they are intertwined with the broader topic and remain relevant throughout the studies.

2.4.4 Summary

This section explores the challenge of social acceptability for wearable technologies, particularly immersive devices, in public transit settings. While technology acceptance has long been a researched topic, existing models fall short when applied to wearable devices, as they do not fully account for the unique social challenges these technologies pose [82, 88, 202]. Wearable devices are judged not only by their functionality but also by how they align with social norms and the user's surroundings [81, 82]. Immersive headsets, in particular, face social rejection due to their reliance on gestures and voice commands, and more critically, the isolation from reality they create by altering or blocking the user's perception of their environment.

Investigating social acceptability as a preventative measure can help shape the design of future technologies and avoid rejection, as seen with Google Glass [32]. The dynamic nature of transit environments, where conditions change rapidly with moving passengers and external factors, remains an unexplored context for studying the social acceptability of immersive technologies. This thesis argues that a broader exploration, encompassing journey factors, real-world interactions, and dynamic transit contexts, is necessary to fully understand the social acceptability of immersive technology in public transportation settings.

2.5 Reality Awareness as a Key Factor in Social Acceptability

The disconnect that immersive technologies create between users and their surroundings poses a significant barrier to their widespread adoption. In transit settings, there are key safety and operational awareness needs, such as being mindful of surrounding furniture [173, 220], fellow passengers [110, 217], journey progress [99], and important announcements [99, 123, 217]. However, this thesis argues that awareness needs go beyond practical safety concerns and represent a significant hurdle to the social acceptability of immersive technologies. While some social aspects of awareness have been acknowledged in previous research, such as invading others' space or being uncomfortably surprised when others invade your space [110, 217], including accidentally colliding with objects and people [220], they remain underexplored in transit scenarios.

Detaching oneself from the real environment through immersive headsets can break established social norms. Unlike traditional devices, which allow users to remain visually aware of their surroundings and engage or react to fellow passengers, immersive headsets create a barrier that can prevent appropriate responses or interactions with others. This lack of awareness, such as failing to acknowledge someone nearby or react to social cues, can lead to uncomfortable situations or break social conventions [126, 218]. Proxemics theory [63], which explains how people maintain personal space based on their relationships, helps clarify why passengers sitting close together may experience discomfort [5, 6], as their intimate zones are encroached upon in cramped environments. Traditional devices, such as smartphones or tablets, allow passengers to remain aware of these boundaries and adjust their behaviour accordingly. However, when a user is immersed in virtual content, traditional physical space norms may not apply, potentially leading to clashes in social affordances when passengers sit together. Cultural variation also plays a role [248, 249], while some passengers may prefer a more social experience, others might seek to disconnect through the use of their devices. This clash in expectations is intensified when a headset user loses control over their awareness of the environment or people around them, further complicating social interactions in transit settings. These challenges raise important questions about how immersive headset users perceive and address social dynamics in such environments, motivating this thesis to explore their concerns in order to understand what these interactions entail and how immersive technologies could support users in navigating unexpected interactions and maintaining awareness of their surroundings.

2.5.1 Navigating Levels of Asymmetry

Another social aspect to consider when investigating immersive technology adoption in public transportation is the *asymmetry* in experiences that emerge when individuals engage with devices featuring different levels of immersion, environmental awareness, and interactivity. For example, co-located users might simultaneously use a mobile phone and a VR headset. While discussions around social acceptability and the disconnect created by immersive headsets often focus on users at opposite ends of the reality-virtuality continuum [131], or even all one end of the continuum [75], it is also important to account for the interactions and experiences that occur between these extremes.

Asymmetric experiences among co-located individuals can vary by user roles, locations, or devices [76]. Previous work has categorised device-based asymmetric experiences into three levels of asymmetry: low (allowing direct interaction between users' environments), medium (involving indirect interaction between users' environments), and high (no direct link between user environments, necessitating alternative modalities such as verbal communication) [10]. High-level asymmetry often leads to intricate dynamics, positioning users at opposite ends of the reality/virtuality continuum [131]. While some have explored medium asymmetry scenarios, such as collaborations between AR and VR users [54], most past work explores asymmetry in interactions between co-located individuals wearing head-mounted displays (HMD) and those without HMDs, demonstrating effects on user behaviours, including personal space and social signals [218]. Moreover, high levels of asymmetry can lead to power imbalances between unaware users and fully aware bystanders [146], a factor seen in the failure of previous immersive headsets [229]. As HMD technology evolves, the dynamics of these power imbalances may change. Additionally, it is still unclear how asymmetric experiences, which can lead to social exclusion among co-located users [76], impact interactions when users have varying levels of access to awareness.

Prior efforts to bridge this gap in user experiences with asymmetry have primarily focused on addressing the interaction breakdown from a non-HMD user perspective, particularly in collaborative scenarios [23, 38, 59, 60, 108, 109, 183, 222]. Solutions included providing a view of the HMD user's face [23, 109], to reintroduce the missing social cues, such as gaze and facial expressions, which are important for nonverbal communication [13, 16, 84], but often disrupted by immersive technologies. Other solutions focused on sharing the virtual environment to facilitate a connection between users, using wearables [23, 60, 109], portable devices [222], projections [59] table-top displays [108, 183], non-screen-based interfaces [77] or a combination of methods [223]. Research has also addressed the interaction gap bi-directionally, creating multi-environment setups that present different views for HMD and non-HMD users [74], or adapted the environment based on user roles and capabilities [100].

From the HMD user's perspective, efforts have been made to improve awareness of bystanders or passersby through visualisations or notifications [126, 219] (for further discussion on current reality awareness solutions, see Section 2.5.2). However, it remains uncertain whether asymmetric experiences pose similar or distinct social acceptability challenges in transit settings, where interactions are spontaneous and co-located passengers frequently change. Specifically, there is limited understanding of how the degree of asymmetry impacts interactions in these environments, particularly with respect to awareness needs. For example, it is unclear how unexpected interactions between passengers, such as responding to a question or navigating around others, unfold when their devices offer varying levels of immersion, environmental information, and interactive capabilities. Further research is needed to explore and better understand these dynamics.

2.5.2 Current Reality Awareness Solutions

As previously discussed, (see Section 2.4.2), new technologies are more likely to be socially acceptable when they fulfil key prerequisites, such as having a clear purpose and demonstrating usefulness, functionality, and usability [32, 87]. For immersive technologies, maintaining the illusion of privacy and immersion created by the virtual environment is crucial, but this is at risk when reality awareness solutions are introduced.

Bringing real-world awareness into immersive experiences inherently creates a tension between immersion and awareness, with these concepts reflecting opposing goals. *Immersion* refers to a virtual system's ability to consistently maintain and present a convincing virtual environment while minimising awareness of the physical world [28, 226]. Bringing reality awareness into the virtual world aims to do the opposite, by increasing the user's understanding of their physical surroundings. In transit settings, *awareness* refers to the user's ability to notice and respond to key aspects of the physical environment while using immersive technologies, including nearby people, personal belongings, and journey-related changes. This definition aligns with prior work showing that awareness of the physical environment whilst using an immersive device is needed to enhance safety [49] and support social interaction [145]. Therefore, increasing awareness can help users stay connected to their surroundings, but simultaneously reduce the level of immersion that the experience can provide. Given these competing demands, achieving a balance between immersion and awareness is particularly challenging in transit settings, where users often need to multitask, make effective use of travel time, and monitor their journey simultaneously [99]. This presents an open challenge in how to restore elements from reality that people lose when wearing an immersive headset in transit contexts, whilst maintaining immersion.

Currently, commercial headsets offer abrupt methods for displaying real-world information to immersive device users. While most commercial headsets include safety features for increased awareness, such as Meta's Quest's 'Guardian', 'Space Sense', and 'Passthrough', they are primarily designed for static indoor experiences [65], and are not currently well-suited for environments in motion, as the sensor data interprets vehicle motion as user motion. Quest's 'Guardian' and 'Space Sense' introduce visible boundaries within the virtual reality, that can be disruptive [142], as they may suddenly appear in a moving environment and are not under the user's control. 'Passthrough' found in headsets such as the Meta Quest 1 to 3 or the new Apple Vision Pro, provides a video feed of the surrounding environment but breaks the immersion of the virtual experience [85, 226]. While more commercial headsets are now incorporating 'travel modes' [250, 251], these are primarily for improving usability rather than specifically enhancing users' awareness in a transit environment.

The research community also investigated the potential ways of providing real-world information during immersive experiences. The majority of solutions focused on the awareness of nearby people [53, 94, 113, 143, 145, 219], as well as augmenting the virtual experience with an overlay of the real-world [8, 118, 219], including distractions [189], notifications [226], warnings [25], and ‘windows’ or ‘gates’ to other realities [49, 209, 217]. Some studied audio and haptic feedback [48, 50] and redirection techniques [181, 185, 195]. The choice to bring the information could be based on the proximity of the other passers-by [127], the urgency of the information [65], or user preference [42]. However, this prior work lacks a focus on transit contexts, as set public or private spaces do not pose the same challenges as a constantly changing travelling environment.

2.5.3 Summary

A key hurdle to the acceptance of immersive technologies in transit is the disconnect they create between users and their surroundings, impacting not only safety and operational awareness but also social dynamics. Immersive headsets, in particular, isolate users from their environment, reducing their ability to notice nearby passengers or respond to social cues. This detachment can lead to breaches of social norms, such as failing to acknowledge others or respect personal space, creating clashes in social affordances where traditional physical space norms no longer apply. In transit settings, these disruptions are particularly problematic, as passengers often share confined spaces where such norms are expected.

Restoring elements from reality while maintaining immersion is a challenge for immersive technology. Current commercial solutions include safety features such as Meta’s Quest’s 'Guardian' and 'Passthrough', which introduce visual boundaries or real-world video feeds. However, these features are not designed for moving environments, which can lead to disruptions [142] and break immersion when used in transit contexts [85, 226]. From the academic community, we see explorations of reality awareness through nearby people visualisations (e.g., [145]), augmented real-world elements (e.g., [118, 219]), and concepts like ‘windows’ or ‘portals’ to reality (e.g. [49, 217]). Despite these efforts, previous work lacks specific focus on transit contexts, raising questions about how well these approaches would function in dynamic, moving environments like public transportation. This gap highlights the need for further exploration of awareness needs in transit settings and how real-world awareness could be integrated, motivating the direction of this thesis.

2.6 Research Methods for Social Acceptability in This Thesis

This section outlines the research methods employed in this thesis to investigate the social acceptability of immersive technologies in transit settings. Given the emerging nature of immersive technologies and the complexity of public transit environments, the thesis adopts a mixed-method approach that combines speculative methods, in-the-wild studies, and established qualitative and quantitative data collection techniques. The following subsections describe each method in detail and explain its relevance to the specific studies conducted.

2.6.1 Creating Speculative Experiences

Speculative methods have emerged as valuable research tools in the domain of Human-Computer Interaction (HCI) and beyond (e.g. fields such as engineering [91] and industry applications [252]). These methods are particularly effective for envisioning possible futures and alternative scenarios in relation to the use of emerging technologies, such as when imagining and designing for future passenger experiences [7, 124]. Speculative methods take various forms and encompass a diverse array of techniques, including design speculations [11, 17, 31, 33, 41, 44], fiction [12, 106, 159, 162], provocations [15], ethnographic fiction [21, 67], experiential futures [79], simulations [194], and enactments [35, 69, 138, 178]. These methods often involve narratives where participants play an active role in imagining possible futures, making decisions and interacting within the speculative context, thereby enriching the scenarios being explored [125, 178].

In this thesis, speculative research methods play a crucial role in gaining early, formative insights by simulating and enacting transit experiences in controlled environments. By engaging participants in speculative future transit scenarios, we can observe social behaviours, reactions, and acceptance of immersive technologies early in their development. Furthermore, exploring future complex transport scenarios is challenging, particularly when the necessary technologies are not yet available. The difficulty increases in public spaces, where unpredictable interactions and safety concerns arise. Speculative methods enable the exploration of ideas and challenges before advancing to costly or safety-critical real-world implementations. This is especially relevant to the investigation of real-world awareness concepts, such as cues from reality, for dynamic transit contexts, which remain speculative due to existing technological limitations in addressing the challenges associated with immersive technology adoption in transit. To tackle these challenges, this thesis employs two types of speculative methods—VR simulations and Speculative Enactments—in Studies III, IV, and V. The following sections further explain these methods and why they are well-suited for the research topics explored.

2.6.1.1 VR Simulations

In the early exploration phases of a topic, it is often unclear what specific interactions or challenges might emerge, and safely testing different variations of an idea in uncontrolled public environments can be difficult. VR simulations are a common strategy in the HCI domain for studying potentially dangerous or exploratory designs [135, 175], as well as scenarios that present ethical or legal challenges [140]. VR simulations offer several key advantages. They provide a relatively easy and cost-effective way to explore variations of concepts, allowing different scenarios to be tested while gathering focused feedback with greater control over variables. This control helps minimise noise in the data, ensuring that the feedback received directly addresses the questions of interest. Additionally, VR simulations ensure participant safety [111, 116], which is crucial when investigating the adoption of emerging devices in uncontrolled public spaces where safety risks are significant.

Although VR has limitations, recent studies have shown that VR simulations can create immersive experiences that evoke participant behaviours similar to those observed in real-world settings [111, 116, 172], demonstrating that a high level of fidelity is not always necessary to convey a sense of presence [117]. VR simulations are, therefore, a suitable method for the early exploration of reality-awareness concepts, such as showing cues from reality, as later explored in this thesis. They allow for the testing of initial user reactions by simulating virtual journeys on public transport, as conducted in Studies III and IV of this thesis (more details in Chapter 4).

2.6.1.2 Speculative Enactments

Creating realistic interactions between participants in a controlled environment is challenging, particularly when the scenario being explored is a future transit scenario that is not yet common in real life. Speculative enactments are a powerful tool in contexts where traditional research approaches fall short, especially when investigating future-oriented topics [170]. Enactments offer a unique perspective by enabling individuals to engage in real social interactions within speculative contexts, where they can 'enact' and experience elements of varied future visions firsthand [35, 178]. Similar to experience prototyping in design [20], speculative enactments provide valuable contextual insights into how people might interact with new technologies and environments.

While enactments have been used to recreate a range of interactions, from personal to openly social scenarios [35], they remain underused in transit scenarios. However, enactments can provide valuable insights into the needs and dynamics that could arise between future passengers using immersive technology. They are particularly useful for capturing the complexity of uncommon passenger scenarios, such as journeys involving multiple immersive device users or those incorporating emerging technologies like fully reality-aware headsets that are on the cusp of development. By facilitating real participant interactions within future scenarios, enactments can offer critical insights into shaping the future of immersive in-transit experiences. Recognizing these benefits, speculative enactments were employed as a research method in Study V to create a future travel scenario featuring three co-located passenger personas, each using a different device—a phone, a VR headset, and an immersive headset (more details in Chapter 5). This study utilised enactments to observe authentic human responses to immersive technologies in a controlled transit setting, as well as to explore the new passenger dynamics that may arise in near-future transit scenarios.

2.6.2 In-the-wild Studies

In recent years, the term 'in-the-wild' research has been widely adopted by the HCI community to describe the trend of conducting user research in real-world, situated contexts where technology is typically used [22, 27, 164, 166]. This shift reflects the increasing integration of technology into everyday life [27]. Nielsen et al. argued that studies in the real world are “definitely worth the hassle”, as different contexts can reveal issues beyond usability that may be impossible to identify in lab settings [139], offering greater ecological validity [166]. Part of the appeal of in-the-wild studies lies in uncovering the unexpected, rather than merely confirming what is already known [166]. Rogers et al. similarly noted that in-the-wild studies often expose unforeseen, context-based issues. In their work, for example, factors such as the time of year influenced how a learning device was used, as well as the motivations and behaviours of the users [165].

Though more challenging to organise and providing researchers with less control than lab studies, in-the-wild research allows for the exploration of how users notice, approach, and interact with technology in ways that may not be apparent in controlled environments [166]. This is especially true in social or public spaces, where social perceptions become particularly significant. In the work by Marshall et al. [114], participants were often influenced to approach a tabletop interface after observing others interacting with it—something rarely seen in lab settings. Similarly, in the work by Hornecker and Nicol [70], people’s behaviours in public social settings shifted as they became more easily distracted by their environment and the presence of others.

This thesis employs an in-the-wild methodology to complement surveys and speculative lab studies, offering deeper insights into user behaviour in real-world contexts. Specifically, Study VI (for more details see Chapter 5), investigated participant experiences using a VR headset to watch a documentary during two 15-minute journeys on a local train. Conducting this study ‘in-the-wild’ ensured that the results reflected authentic user behaviours and challenges, such as strangers boarding and alighting at each stop—factors that cannot be adequately replicated in controlled settings.

2.6.3 Data Collection Methods

2.6.3.1 Survey Instruments

Online surveys provide researchers with a cost-effective way to collect data from large groups of people [136]. In the HCI domain, they can be especially useful for understanding people's habits, interactions with technology, or subjective attitudes and perceptions toward it [96, 136], especially relevant for social acceptability research [88]. It is worth noting that, often in literature, the terms survey and questionnaire are used interchangeably [96]. For the purpose of this thesis, we use the term 'survey' to refer to a study that uses a survey as its sole methodology, and 'questionnaire' to refer to individual sets of questions used as part of a mixed-method approach. Surveys used as a sole method are effective for identifying high-level insights that can be further explored through qualitative methods [136]. An example of such application can be found in the work by Lewis et al. [102] who investigated passenger perceptions of personal space in planes. On a smaller scale, questionnaires can supplement other data collection methods, such as interviews, helping quantify specific findings. An example where a questionnaire was used to research social acceptability can be found in the work by Williamson et al. [217], who used it as part of a mixed-method approach to capture initial attitudes toward the social acceptability of VR devices in flights. In a mixed-method approach, oftentimes only a Likert scale-style questionnaire [105] is used to evaluate the usability of the proposed idea. For instance, in the work by Montagud et al. [133], questionnaires were used to evaluate their proposed low-cost social VR platform, alongside semi-structured interviews.

Online surveys and questionnaires form an important part of the methods used in this thesis. Initially, online surveys were employed to investigate users' attitudes toward using a VR device in varied transit environments and to uncover factors that influence this choice (see studies I and II, Chapter 3). In study III, questionnaires were used to complement qualitative data by collecting participants' responses on feelings of safety, usefulness, social acceptability, distraction, escapism, and immersion (see Chapter 4). Although study IV primarily relied on qualitative methods, participants were also asked to complete questionnaires to validate the accuracy of the simulated journeys employed in the study. For the analysis of the surveys and questionnaires used in this research, appropriate statistical tests or qualitative analysis methods, such as open coding [26] and thematic analysis [18], were applied and are described in the relevant chapters.

2.6.3.2 Semi-structured Interviews

The interview method is open-ended, exploratory, and subjective, using a question-based approach to collect data [97]. Its strength compared to other methods lies in its ability to explore topics in greater depth, uncovering richer insights [97]. However, there are downsides to this method. Interviews typically involve fewer participants due to resource constraints, and memory recall issues can arise [97, 168]. Conducting interviews immediately after a task, often with the aid of visuals such as images, can help reduce the cognitive load on participants and aid in recalling details about the task or experience [168]. Interviews can be unstructured, where questions are not prearranged; structured, where a strict interview protocol is followed; or semi-structured, where researchers are guided by a set of questions but can probe participants' responses with follow-up questions based on interesting comments [97, 154]. Semi-structured interviews are especially effective when exploring phenomena that are not yet fully understood, as they can help uncover valuable insights to explore further [97, 230]. In social acceptability research, interviews are an effective method to collect reflections on participants' subjective experiences. A good example of an interview used in social acceptability research can be found in the work by Eghbali et al. [34].

This thesis employs semi-structured interviews as a primary method for data collection across Studies III, IV and VI. Conducting interviews immediately after the studies helped mitigate issues with recall, and Study III also incorporated visual aids to assist participants' memory during the interviews. The semi-structured format was particularly useful for exploring the social acceptability of immersive technologies and gathering feedback on the use of cues from reality, while also allowing unexpected insights to surface. For the analysis of the interviews, a qualitative open-coding approach [26] was followed by a thematic analysis [18], with further details of the methods used for each study provided in the relevant chapters.

2.6.3.3 Focus Groups

Focus groups, which involve interviews with a group of participants, are useful for gathering a range of opinions or perspectives on a topic [97]. They are particularly effective for comparing opinions across different groups of people [93, 97], allowing participants to interact, challenge opinions, and either agree or disagree with one another [19]. A key advantage of focus groups is their ability to highlight differences in perspectives between various categories of participants [93]. However, focus groups come with challenges. There is ongoing debate about the ideal number of participants for creating a good dynamic, with most focus groups ranging from a few up to twelve participants [93]. Smaller groups are often preferred for more in-depth discussions, as larger groups risk excluding certain opinions or participants [3]. Effective moderation is essential to ensure a productive discussion, where each participant has the opportunity to share their viewpoint.

Focus groups are also effective for reflecting on shared experiences, particularly in topics related to social or public spaces, where experiences are often shared with other co-located individuals. Good examples of employing focus groups for social acceptability research include Montero et al. [134] work on understanding the social acceptance of gestural interfaces and Williamson et al. [217] exploration of VR use on planes. These studies demonstrate how focus groups can facilitate effective discussions among participants on shared experiences and concerns related to technology use in public settings. In a similar approach, Sato and Salvador [171] emphasise the need to create a shared context for effective focus group discussions. In their study, they used actors to perform live scenarios that demonstrated how the product might be used, fostering a shared understanding among participants. The audience controlled certain aspects of the enactments and subsequently engaged in discussions. The authors suggest that having participants act out the scenarios themselves could further enhance engagement and involvement.

This thesis also employs a focus group approach in study V (see Chapter 5 for more details), where a shared experience of three co-located passengers using disparate devices—a phone, a VR headset, and an immersive device with tracking enabled—was explored. In this context, the focus group allowed participants, each embodying a different persona in the shared scenario, to compare their experiences and reflect on how their devices, with varying levels of immersion, environmental awareness, and interactivity, shaped their interactions and experiences. For the analysis of the focus group interviews, a qualitative open coding approach [26] was followed by a thematic analysis [18], as discussed in the relevant chapters.

2.7 Open Challenges Addressed by This Thesis

The literature discussed in this review provides the necessary background for the inquiry and direction of this thesis, supporting the work conducted and detailed in subsequent chapters (see research questions in Chapter 1). Section 2.3 presents the background on the use of technology in transit, showing that electronic devices are already used to make time more productive or to provide privacy and disengagement. Immersive technologies offer advantages over these traditional devices, allowing users to personalise their reality while travelling, such as by rendering unlimited virtual screens around them. When looking at the adoption of immersive technologies in transit, a key question arises: what is hindering the widespread adoption of immersive headsets, despite their potential to transform passenger experiences?

As highlighted in Section 2.4, their adoption is largely dependent on social acceptability. Google Glass is a good example of how an immersive headset can be rejected if deemed socially unacceptable [130, 229, 233]. Social acceptability of immersive devices is particularly hindered by the disconnect they create between the user and the real world. Detaching oneself from the real environment through immersive headsets can disrupt established social norms and create a barrier that prevents appropriate responses or interactions with others. However, prior explorations of social acceptability have predominantly focused on single transit scenarios [176], relied on theoretical approaches [45, 123, 176], or examined real-world contexts that do not fully represent the dynamic nature of transit environments [14, 34]. This creates a clear gap for research that investigates a wider range of journey factors, explores different travel scenarios, and conducts real-world context studies to better understand the social acceptability of immersive technologies in public transportation settings.

Section 2.5 discusses the challenges posed by this lack of reality awareness and presents current solutions aimed at reducing this disconnect by bringing real-world awareness into immersive headsets. However, these solutions primarily focus on static indoor environments, leaving a gap in understanding the reality awareness needs of passengers in dynamic transit settings, where both internal factors, such as strangers getting on and off or moving around, and external factors, such as travelling through different neighbourhoods, are constantly changing. Moreover, as immersive technology becomes more popular in the near future, situations involving asymmetric passenger experiences are likely to arise. These scenarios may involve individuals using devices with varying levels of immersion, environmental awareness, and interactivity, such as a mobile phone and an immersive headset. Understanding awareness needs in such contexts can support this transition period and improve the social acceptability of immersive technologies in dynamic transit environments. Together, these challenges create an opportunity for this thesis to explore immersive headset user awareness needs in transit, considering broader journey factors, asymmetric passenger experiences, and real-world contexts. They also highlight the need to investigate cues from reality as a concept for enhancing reality awareness, thereby enhancing the social acceptability of immersive technologies in transit.

3 Journey Factors Impacting Immersive Technology's Social Acceptability on Public Transport

3.1 Introduction

The literature review in Chapter 2 emphasised that for wearable technology, particularly immersive headsets, social acceptability presents a key challenge in public transit environments. Unlike traditional devices, wearables are judged not only by their functionality but also by how they align with social norms and the reactions of observers [81, 190]. Immersive headsets, in particular, can either conform to or disrupt these norms by isolating users from their surroundings. Although research into the social acceptability of immersive technology is still in its early stages, key insights have emerged. Previous studies suggest that factors such as physical space, proximity, relationship to fellow passengers [123, 176], journey type, perceived safety [120, 123], and the loss of awareness of surrounding passengers and real-world events all influence social acceptance [217]. While prior work sets initial guidance, the focus has typically been on singular scenarios or theoretical perspectives. For example, Schwid et al. [176] explored VR use in limited contexts, such as the metro or train, but only examined two modes of public transport and focused on the setting and the number of VR wearers. Similarly, McGill et al. [123] discussed the challenges and barriers to adoption from a theoretical standpoint, suggesting that factors like the mode of transport, journey duration, and travel environment could influence social acceptance. However, these factors have not been systematically investigated with real user data, nor have the reasons for these differences, alongside awareness needs and concerns, been linked to different types of journeys.

To fully explore the acceptability of immersive technologies in transit environments, a broader investigation is needed that considers diverse types of trips, including the mode of transport and journey length. Public spaces and journeys vary greatly, and what is acceptable in one context may not be in another. Understanding these broad conditions and journey factors is essential for gaining deeper insights into how immersive devices can be adopted in transit. Additionally, little research has explored the unique awareness needs, and concerns of passengers across different types of journeys, such as short commutes on public buses or long-haul flights, leaving a gap in understanding whether these needs vary based on the journey type or remain consistent, and how immersive technology could address them. To address this gap in the literature and provide a foundation for this thesis, this chapter will answer the following research question:

RQ1: How do journey length and mode of transport affect the social acceptability of immersive technology use on public transport?

To address this, two surveys were designed and distributed (N1=60, N2=108), targeting different forms of public transport to assess how various travel conditions impact the social acceptability of immersive devices. For these surveys, the focus was on VR use, as it was the most familiar and commercially available immersive technology at the time of this work. This focus also aligns with the broader aims of the thesis to explore immersive technologies more generally, using VR as a representative case to uncover insights that extend to other forms of immersive technology. The first survey focused on VR use in-flight, where the secure nature of the travel context (with all passengers screened before entry) and the absence of passenger turnover during the journey offer unique insights into VR use in stable transit environments. The second survey explored VR use in public ground transport, such as taxis, buses, trains, and subways, where journeys are typically shorter, and passengers are free to embark and disembark as they choose, adding a dynamic element to the experience.

Together, the surveys presented in this chapter compare how different travel conditions influence the social acceptability of immersive devices in transit environments. While focusing primarily on mode of transport and journey length, this chapter provides key insights into how these factors shape user concerns and acceptance of immersive technology in transit settings.

3.2 Study I: Survey on Immersive Device Use on Aeroplanes

3.2.1 Survey Design

The first survey investigated the factors contributing to the acceptability of using VR headsets on aeroplanes. It captured respondents' interest in using VR for future flights, as well as their attitudes towards VR use across different journey lengths, activities (entertainment, work, communication), and travel classes (economy or business). The survey began by collecting respondents' demographics, including information on age, gender, and country of residence.

In total, the survey consisted of 18 questions, including both closed-ended and open-ended questions, and collected data across three core categories: flying habits, familiarity with VR, and interest in VR use for specific scenarios. The first two categories, flying habits and familiarity with VR, provided demographic and contextual information about the respondents. The third category, interest in VR use for specific scenarios, formed the core focus of the survey, exploring respondents' preferences and attitudes towards VR use during flights. These categories, which form the basis of the data analysis, are described in detail below (full survey layout can be found in Appendix A: Survey Used in Study I (Chapter 3)).

3.2.1.1 Flying Habits

This section included questions about various aspects of respondents' flying habits. Core questions addressed travel frequency (ranging from 1 to 12 or more trips annually) and the class of travel respondents typically chose (such as economy or business). Respondents were also asked to indicate the proportion of their travel for leisure versus business and how often they travelled alone versus with others. To capture in-flight behaviours, respondents ranked their typical activities on a rating scale with the following options: 'None of my time', 'A little of my time', 'Some of my time', and 'A lot of my time'. These activities included watching entertainment, socialising, working, among others, with an additional option to specify activities not listed. These questions provided background context on respondents' habits and preferences during flights.

3.2.1.2 Familiarity with VR

This section explored respondents' familiarity with VR and captured their previous experience with the technology. Respondents were first presented with an image of the Meta Quest 1 headset, accompanied by the following description:

"This is the Oculus [name now changed to Meta] Quest VR headset. VR headsets like this are worn on your head and block out your view of reality, replacing it with a private virtual world of your choosing, such as a virtual cinema, an office, or an immersive game".

Figure 3.1: Meta Quest 1 headset shown in the survey. The device includes integrated tracking cameras and a black-and-white passthrough mode, enabling users to view their surrounding environment.

Respondents were then asked whether they had ever used a VR headset and, if so, to indicate which devices they had experience with. Examples of listed devices included the Oculus (Meta) Quest, Rift, Gear VR, HTC Vive, and Sony PlayStation VR, with an option to specify others. Those with prior VR experience were further asked whether they had ever used a VR headset while travelling by air, and, if so, to describe their experiences and the activities they engaged in.

3.2.1.3 Interest in VR Use for Provided Travel Scenarios

This section examined respondents' interest in using VR during flights across a range of scenarios. Core questions included assessing overall interest in VR usage for future flights and preferences for VR use on journeys of different lengths, with additional questions investigating preferences for using VR in different travel classes, activities, and social settings. To aid respondents' understanding when comparing travel classes, an image illustrating business and economy class seating was provided (Figure 3.2). Respondents were then asked to rate their interest on a 5-point Likert scale for various activities, such as entertainment, work, and communication, as well as for different journey durations, ranging from domestic to long-haul flights. Likert scale answers were in range from 'Not at all interested' to 'Very interested'. Respondents were also asked to indicate whether they would be more likely to use VR when travelling alone, with friends or family, or with work colleagues. These questions collected data on how travel contexts and circumstances influence the acceptability of immersive technology use during flights.

Figure 3.2: Business (left) and Economy (right) class seats shown in the survey.

3.2.2 Respondents

The respondents for the first online survey were recruited using mailing lists, online forums and social media channels and were offered to participate in a prize draw for a £25 Amazon voucher. Respondents had to meet the eligibility criteria of having taken at least one flight in the last year with a minimum duration of one hour.

The results are based on 60 respondents, from which 27 identified as female, 31 male, one non-binary and one preferred not to disclose their gender. The study also received geographically diverse responses from the UK, the USA, the UAE, Spain, Poland, the Philippines, New Zealand, Malaysia and Lithuania. 54.2% were based in the UK. The age of respondents ranged from 18 years old to over 60, with 53.3% reporting that they travelled by air between two to five times a year. The majority of respondents (86.7%) typically flew in economy class. Additionally, 70% of respondents reported having prior experience with VR headsets, with the most commonly used being the Oculus Rift (46.5%). However, only 9.5% of respondents reported having ever used a VR headset while travelling by air.

The recruitment included dedicated VR user groups, which resulted in a high number of respondents with VR experience. Online VR communities were targeted to ensure responses from individuals with real-life experience using VR or a strong interest in the technology, allowing them to provide more informed answers based on their familiarity with VR.

3.2.3 Survey Results

Quantitative analysis was completed using non-parametric statistical tests for ordinal data. For pairwise comparisons, p values were adjusted using Bonferroni corrections. Open-ended questions were analysed following a qualitative coding process [26]. While the study used VR imagery in the survey (Figure 3.1), and respondents frequently referred to ‘VR’ in their comments, these terms were not altered to preserve the authenticity of their input. Whilst the chapter uses the terms ‘immersive technology,’ ‘devices,’ and ‘headsets’ when describing overall goals and findings, the results section retains the term ‘VR’ for consistency with the original study context, as it was specifically applied in participants' tasks and study questions.

3.2.3.1 Interest in VR Use for Future Flights

The interest in using immersive technology for future flights was strong—when asked to rank their interest in using a VR headset on future flights, the majority of the respondents were somewhat interested (50%) or very interested in the idea (15%), as shown in Figure 3.3.

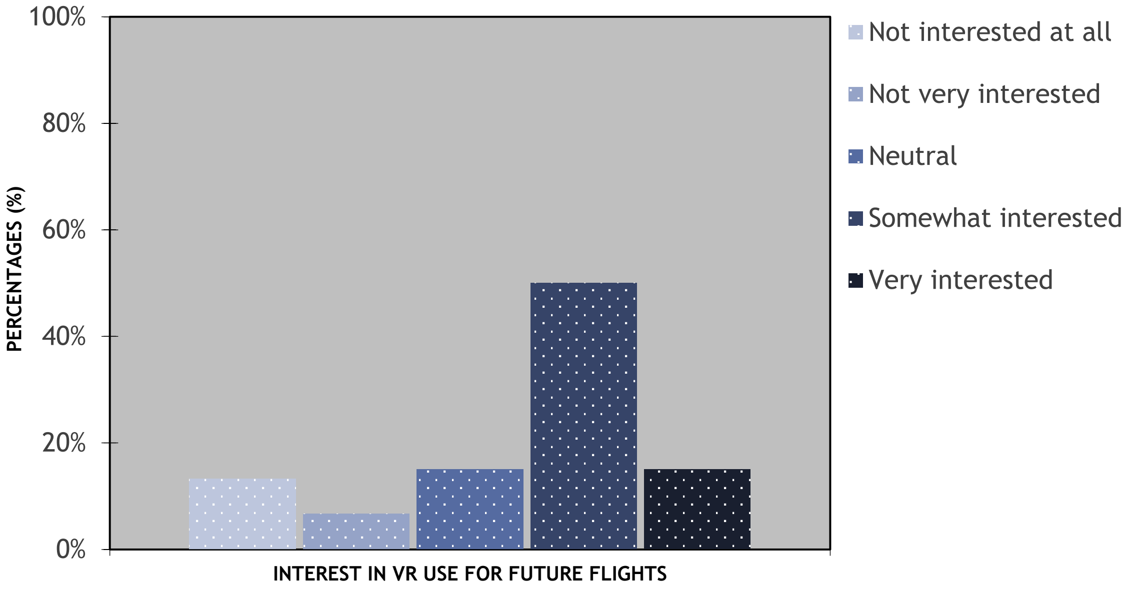


Figure 3.3: Overall respondents' interest in using a VR headset for future flights, including those with and without prior VR experience.

There was a total of 42 respondents that had prior experience with a VR headset and 18 that did not. Out of all respondents who previously used a headset, 64.3 % stated that they would be somewhat or very interested in using a headset. The respondents who had no VR experience also showed a strong interest—66.7% expressed being somewhat or very interested in trying it on future flights. However, interest in using VR for future flights was influenced by certain journey-related factors and challenges, which are discussed in the following sections.

3.2.3.2 Journey Lengths

To gain a more in-depth understanding on how journey length might affect the decision to use an immersive device, the respondents were also asked to rank their interest in using a VR headset for domestic (up to one hour), short-haul (up to three hours), medium-haul (three to six hours) and long haul (more than six hours) flights. A Friedman test (N=59) showed significant differences between journey lengths ($\chi^2(2)=108.311$, $p < 0.001$). Kendall's W showed a strong effect size of W=0.61. The scores between those who have used VR before and had no experience were also compared for journey lengths but did not show any significant difference.

Friedman pairwise comparisons were performed with Bonferroni correction for multiple comparisons to identify specific differences. Interest in VR use for different journey lengths was significantly different between long-haul and short-haul ($p < 0.001$), long-haul and domestic ($p < 0.001$), medium-haul and short-haul ($p=0.029$), medium-haul and domestic ($p < 0.001$) and short-haul and domestic ($p=0.002$), but not long-haul and medium-haul flights. Figure 3.4 shows the interest levels based on the journey length.

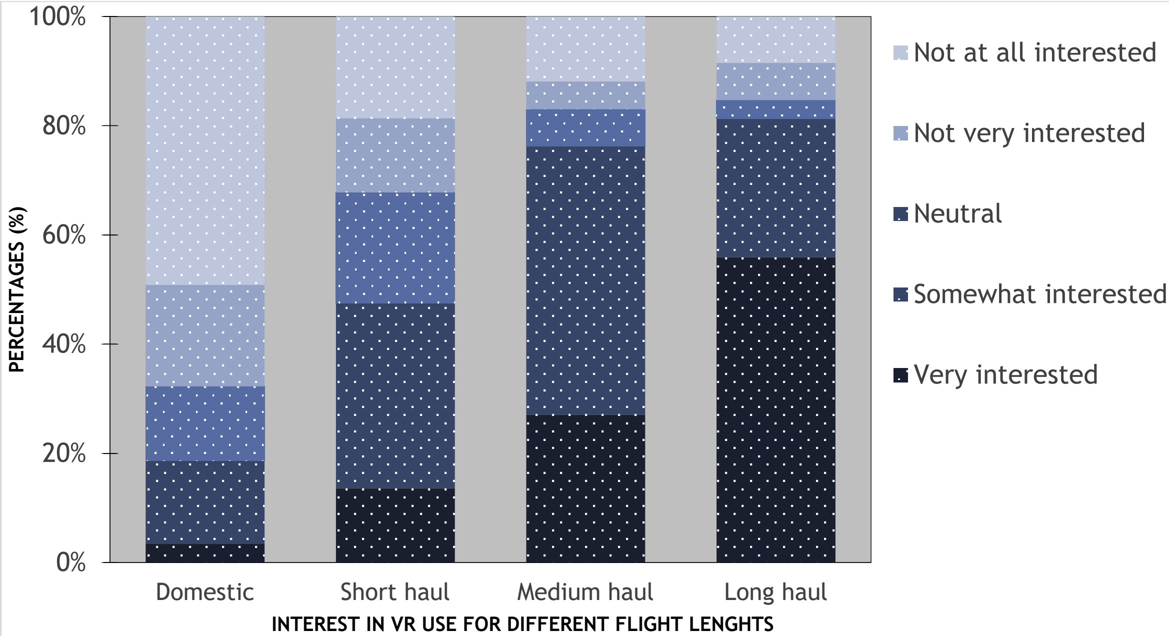


Figure 3.4: Respondents' interest in VR use on flight for different journey lengths.

Respondents expressed a strong preference for using VR on longer journeys, whilst domestic flights were of the least interest. The responses revealed that short flights "*can be tolerated*" (P10), are "*bearable*" (P2) or "*quick*" (P11), whilst the longer journeys are associated with needing a "*variety of things to keep you occupied*" (P1), or a possibility to "*run out of [traditional] entertainment*" (P4), more time to "*enjoy the experience*" (P19) and "*more interest in entertainment*" (P51). One respondent thought a short trip was "*not worth the setup*" (P18). Respondents see current devices as "*bulky*" (P23) and "*cumbersome*" (P13), which is a consideration to potential users. Future immersive headsets require a quicker set-up and lighter design to be more attractive for use when travelling.

3.2.3.3 Activities

As part of the survey, respondents were asked to rank their interest in using VR for entertainment, communication and work. A non-parametric Friedman test was run to compare the interest of using VR for different activities (N=60). To conduct the analysis, the answers ('Very interested' to 'Not at all interested' were converted to scores 1 to 5 respectively). The Friedman test showed significant differences between activities ($\chi^2(2) = 44.682$, $p < 0.001$). For effect size, Kendall's W was calculated [184, 193], which showed a moderate effect size of W=0.37. To address whether respondents' experience with VR, or lack of, had an effect on their rankings, both groups were compared but no significant difference was found.

Friedman pairwise comparisons were performed using SPSS Statistics [95] with a Bonferroni correction for multiple comparisons. The results showed that interest in VR use for different activities was significantly different between entertainment and communication ($p < 0.001$) and entertainment and work ($p < 0.001$), with a preference towards entertainment in both. No significant difference in rankings was found between communication and work. Figure 3.5 shows the interest levels based on the activity.

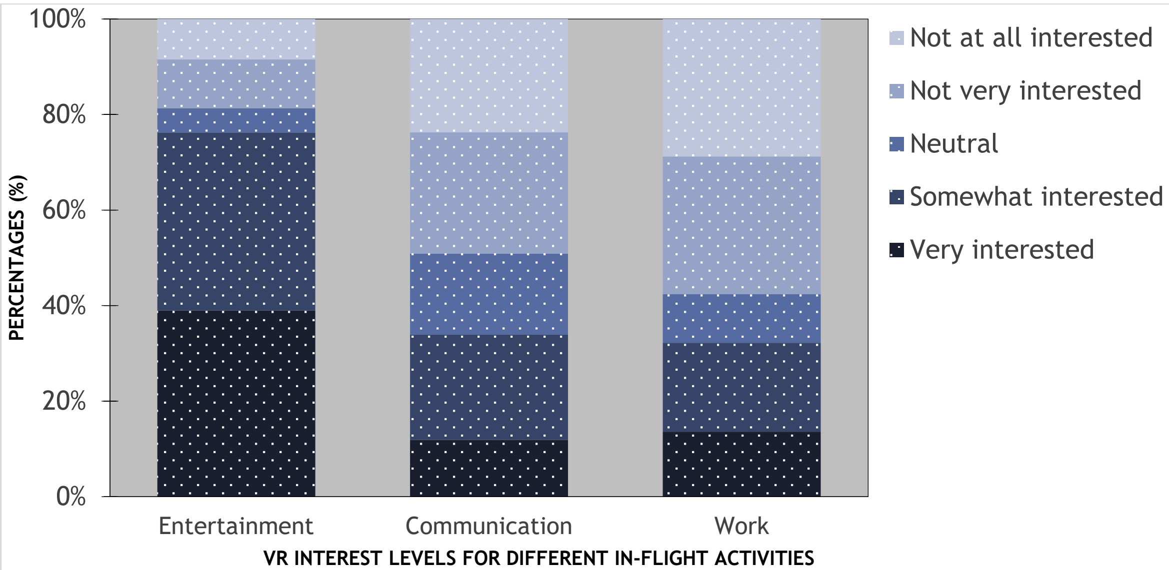


Figure 3.5: Respondents' interest in VR use on flights for different activities.

The analysis of open-ended questions provided insights into why interest in using VR for entertainment, communication and work were ranked differently. Respondents were most interested in VR for entertainment, with one of them commenting: "*anything other than entertainment in VR is more trouble than it's worth for me*" (P29). VR for communication and work were not rated as highly as respondents thought that current devices were not good enough. For example, one respondent stated, "*I think VR at the moment is solely for entertainment. For work or communication, it is too distracting and over the top for these activities*" (P23). Another respondent also supported the use of traditional devices: "*the majority of the above tasks could be better achieved with classical and not vision-distracting devices*" (P37). VR use for communication was followed by concerns of disturbance, with one respondent saying communication via VR "*will bother your fellow passengers*" (P43). VR for work was ranked the lowest. One of the respondents who previously used a VR headset expressed being unaware what benefits VR could provide in this area, saying: "*VR is no [sic] good solution to work, at least I have not seen any so far*" (P24). Respondents' answers suggest that there is a lack of awareness of benefits in other application areas for immersive headsets beyond entertainment.

In addition to the suggested activities, the analysis uncovered that flight escapism was another potential purpose for immersive devices. Some respondents felt that they just wanted to change their environment, with one saying that VR could "*distract you from being stuck in your seat for hours on end!*" (P44), and another—"*VR might help to create an illusion of space*" (P24). Other respondents have disclosed they feel uneasy during flights and that VR could "*be handy for fearful flyers to take their mind off what was going on*" (P55) and provide "*a relaxing atmosphere*" (P8). Respondents' answers confirm that an immersive virtual environment also offers the opportunity to escape the confined surroundings of the aeroplane seat.

3.2.3.4 Space, Movement and Awareness

As part of the survey, respondents were shown two pictures representing an economy and a business-class seat (Figure 3.2). The aim was to understand whether there were preconceptions about the image of a VR user and to explore whether VR use was more associated with an economy or business class traveller, as well as whether the available space affected attitudes towards the use of VR in-flight. The analysis of answers shows that the majority of respondents (56.7%) would be more likely to use the headset in business class. Analysis of the open-ended question that followed revealed that the reason for this is not the image of the business-class flier (although one respondent indicated that they would expect this to be part of the business-class service) but the space constraints in economy-class seating.

Respondents would be reluctant to use a VR headset in an economy seat due to the limited space; believing they would not have enough room to manoeuvre as required by most applications on the headset and they might accidentally injure someone. For example, one of the respondents said, "*it is uncomfortable to do anything in economy class (even to watch a video on my phone or sleep) as there is no space, so I cannot imagine wearing a headset comfortably in such an environment*" (P31). Another commented: "*much less risk of whacking someone when turning suddenly in business!*" (P34). These answers suggest that for an immersive headset to become more appealing to use in an economy seat, future applications need to support alternative input techniques that minimise movement.

Finally, another potential barrier, although less commonly mentioned, was the loss of awareness. A few respondents expressed their concern about losing awareness of what is happening around them during the use of a VR headset. One stated "*I like to be aware of my surroundings… I need to look after my two young children*" (P30), and another stated that "*[I] don't see the point of wearing a massive device on my head during flight when you should be cautious of your surroundings*" (P16).

3.2.3.5 Social Perception and Self-image

Another significant barrier to headset adoption was the self-image of the wearer and perceived judgement from others, especially in smaller economy seats. Respondents were worried about other passengers staring at them or being annoyed. One of the respondents explained their concern as "*not sure what people could think about me in economy*" (P14). Another respondent added: "*I would not feel comfortable being so close to someone in economy using a VR headset. Especially if they were not using one.*" (P40). The judgement from other passengers seemed to be less of an issue if people were familiar. For example, one respondent said: "[*I] would feel awkward looking around with strangers next to me. If I was sitting with family, this would not be an issue*" (P28). Interestingly, respondents felt they would be judged more by using a VR headset in a tighter space as the same fears did not occur for business-class seating.

3.2.3.6 Summary

The first survey revealed strong interest in immersive headset use for longer flights, as they were associated with a greater need for available entertainment and more time to enjoy the experience. There was also a preference for headset use for entertainment, as respondents felt most familiar with this use case and lacked understanding of how VR could serve other purposes. Despite this interest, concerns about self-image, unintentional interruptions to other passengers, and a lack of awareness of surroundings were identified as key barriers to immersive technology acceptance for in-flight journeys.

3.3 Study II: Survey on Immersive Device Use on Public Ground Transport

3.3.1 Survey Design

The second survey followed the model of the first survey but focused on VR use across five modes of transport: buses, coaches (long-distance bus travel), local trains/subways, long-distance trains, and taxis. It aimed to assess how the core factors of mode of transport and journey lengths influence the acceptability of VR headsets, continuing the exploration from the first survey. In addition, it examined activity preferences and explored respondents' preferences for using VR when travelling alone, with friends, or with colleagues. The survey also included a scenario-based question presenting two commuting situations, one crowded and one empty.

In total, the survey consisted of 22 questions, including both closed-ended and open-ended questions, and captured data across three core categories: travel habits, familiarity with VR, and interest in VR use for provided travelling scenarios. The first two categories, travel habits and familiarity with VR, provided demographic and contextual information about the respondents. The third category, interest in VR use for specific scenarios, formed the core focus of the survey, exploring respondents' preferences and attitudes towards VR use across different modes of transport and various travel contexts. These categories, which form the basis of the data analysis, are described in detail below (full survey layout can be found in Appendix B: Survey Used in Study II (Chapter 3)).

3.3.1.1 Travelling Habits

This section included questions about respondents' travel habits for each of the five modes of transport. Core questions addressed the frequency of travel for buses, coaches, local trains/subways, long-distance trains, and taxis, categorised as *infrequently* (1–11 trips per year), *frequently* (at least once a month), or *regularly* (at least once a week). Respondents were also asked to indicate the primary purpose of their travel for each mode (e.g., *work* or *leisure*). To capture behaviours during travel, respondents ranked their typical activities on a scale ranging from 'None of my time' to 'A lot of my time'. Activities included entertainment, socialising, working, and other in-transit behaviours, with an additional option to specify activities not listed. These questions provided background context on respondents' habits and preferences across different transport modes.

3.3.1.2 Familiarity With VR

This section explored respondents' familiarity with VR and their previous experiences with the technology. Respondents were shown an image of the Meta Quest headset, accompanied by the following description:

"This is the Oculus [name now changed to Meta] Quest VR headset. VR headsets like this are worn on your head and block out your view of reality, replacing it with a private virtual world of your choosing, such as a virtual cinema, an office, or an immersive game".

Respondents were then asked whether they had ever used a VR headset and, if so, to indicate which devices they had experience with, such as the Oculus (Meta) Quest, HTC Vive, Sony PlayStation VR, and others. Those with prior VR experience were further asked whether they had used a VR headset during travel and, if so, to describe their experiences and the activities they engaged in.

Figure 3.6: Image used in the survey showing a person wearing a VR headset.

3.3.1.3 Interest in VR Use For Provided Travel Scenarios

This section examined respondents' interest in using VR during travel across a range of scenarios. Core questions assessed the likelihood of using VR on specific modes of transport, including buses, trains, and taxis. Respondents were also asked to indicate their likelihood of using VR for different journey lengths. Additionally, they also rated their interest in VR use for various activities, such as entertainment, work, and communication, using a 5-point Likert scale ranging from 'Not at all interested' to 'Very interested', such as trips lasting up to 1 hour or more than 6 hours.

To examine social factors influencing VR use, respondents were asked two questions. The first asked whether they would be more likely to use VR when travelling alone, with friends or family, or with work colleagues. The second was a scenario-based question that presented respondents with two contrasting commuting situations: one crowded and one empty, accompanied by an illustrative image. For the image-based scenario questions, respondents were instructed: *"Please look at the following image. It shows a commute scenario. Please imagine you enter and take a seat in this situation."*

Figure 3.7: Two images were shown to the respondents, one showing an empty train carriage (left), and one a busy train carriage (right).

For each illustrated scenario, respondents rated their comfort level with using a VR headset, ranging from ‘Very uncomfortable’ to ‘Very comfortable’ (5-point scale), and provided an explanation for their responses. These questions were designed to explore how social and environmental contexts shape attitudes towards VR use during travel.

3.3.2 Respondents

The respondents for the second online survey were recruited using mailing lists and social media channels and were given the opportunity to participate in a prize draw for a £25 Amazon voucher. The results are based on 108 respondents, from which 93 declared their gender and included 56 males and 37 females. From the total of respondents, 94 declared their country of residence including respondents from the UK, Australia, Belgium, Denmark, Finland, France, Germany, India, Israel, Italy, Japan, The Netherlands, New Zealand, Portugal, Saudi Arabia, Spain, Sweden, Ukraine and the USA. The largest proportion (64.9%) were based in the UK and Northern Ireland. The respondents' ages ranged from 18 years old to 74 years old, with 86.3% of respondents reporting previous experience with VR headsets. Among these, the Oculus Quest was the most popular headset, used by 23.97% of respondents. The high percentage of respondents with VR experience was achieved by purposefully targeting VR forums and online communities to capture feedback from individuals with familiarity or interest in VR technology.

3.3.3 Survey Results

The analysis followed the same approach as the first survey, with quantitative analysis completed using non-parametric statistical tests for ordinal data. For pairwise comparisons, p values were adjusted using Bonferroni corrections. Open-ended questions were analysed following a qualitative coding process [26].

Whilst the chapter uses the terms ‘immersive technology,’ ‘devices,’ and ‘headsets’ when describing overall goals and findings, the results section retains the term ‘VR’ for consistency with the original study context, as it was specifically applied in participants' tasks, study questions, and quotes.

3.3.3.1 Acceptance Across Different Modes of Transport

To understand how immersive device acceptance varied, respondents were asked to rank their interest in using a VR headset on the five modes of transport (see Figure 3.8).

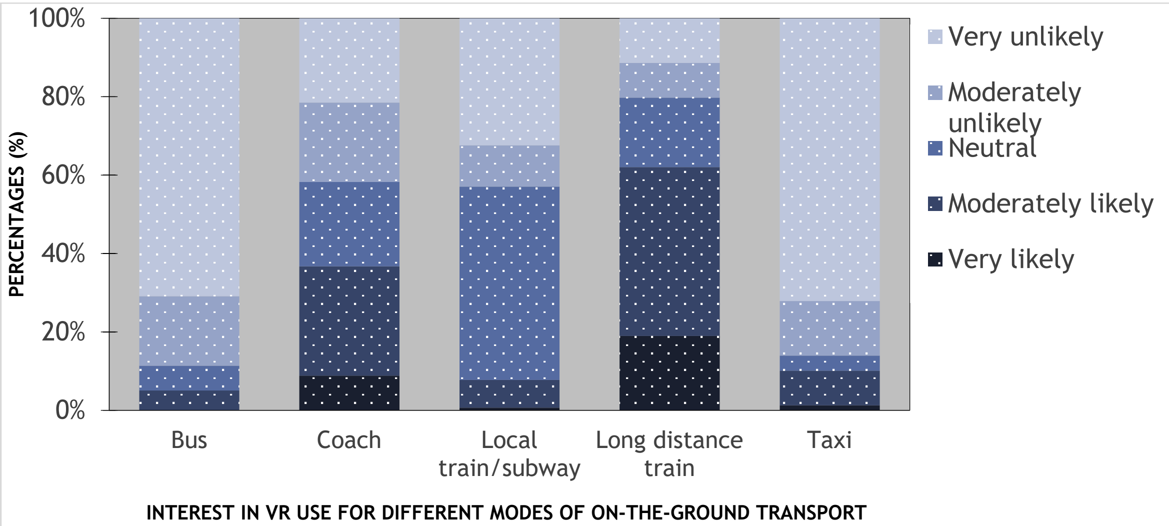


Figure 3.8: Respondents’ acceptance of VR use on different modes of on-the-ground transport.

A Friedman test was used to analyse respondents’ rankings (N=79 when incomplete responses were excluded). Results showed significant differences between the modes of transport ($\chi^2(4)=164.575$, $p < 0.001$). Kendall’s W showed a strong effect size of W=0.521. Pairwise comparisons showed that the acceptance of VR use on different modes of public transport was significantly different between long-distance train and local train/subway ($p < 0.001$), long-distance train and taxi ($p < 0.001$), long-distance train and bus ($p < 0.001$), coach and local train/subway ($p < 0.001$), coach and taxi ($p < 0.001$) and coach and bus ($p < 0.001$). Other comparisons were not significant. In order to address whether respondents' experience with VR had an effect on their rankings, both groups were compared but no significant difference was found.

The analysis showed that long-distance trains and coaches (long-distance bus travel) were the most accepted modes of transport for VR use, whilst taxis were of the least interest. The open-ended questions revealed some of the key reasons for this. Respondents associated buses, local trains/subways and taxis with short journeys which required attention to one's surroundings, with one of the respondents commenting that they want "*to have control over what is happening*" (P68) in these situations, and another that they would feel "*stupid*" (P63) if they did not pay attention to their surroundings. Coach and train journeys were more favourable for immersive headset use because they were seen as requiring less concentration in addition to immersive headsets being more socially acceptable. According to one respondent: "*long-distance train seems more socially acceptable since it is expected that passengers will find ways to entertain themselves*" (P17).

Interestingly, taxis were least favourable not just because it is typically a short journey, but also because it might be considered "*rude*" to ignore the driver, with one of the respondents explaining: "*taxi rides seem a little short and I can learn from talking to the taxi driver (plus it might be rude to ignore them)*" (P55). The open-ended questions also revealed that motion sickness and safety were other important barriers to immersive headset acceptance. Motion sickness was mentioned as mostly being felt in buses and taxis, whilst worries about safety were linked to shorter journeys, as respondents thought they require more awareness of one's belongings.

3.3.3.2 Journey lengths

As in the first survey, respondents were asked to rate their interest in using VR for various journey lengths: up to 1 hour, up to 3 hours, from 3 to 6 hours and more than 6 hours (see Figure 3.9). A Friedman test (N=78) showed a significant difference between journey lengths ($\chi^2(3)$ =92.238, $p < 0.001$). Kendall's W showed a moderate effect (W=0.394). Pairwise comparisons showed that there was a significant difference between 'more than 6 hours' and 'up to 3 hours' (p=0.035), 'more than 6 hours' and 'up to 1 hour' ($p < 0.001$), 'from 3 hours to 6 hours' and 'up to 1 hour' ($p < 0.001$) and between 'up to 3 hours' and 'up to 1 hour' ($p < 0.001$).

As part of the question, respondents were also asked to comment on their choices. Several respondents felt that shorter journeys required the passenger to have more awareness of their surroundings *and that the "fear of missing stop [sic] on shorter journeys"* (P52), "*paying attention to your luggage and surroundings*" (P12) and "*personal security*" (P55) are important considerations. Respondents said that using the device in this situation would require it to provide information about the journey. One respondent noted that this information could extend to the entire journey, including the destination, explaining: "*for me, knowing how to navigate the airport (or station) I land in, and how to get to the next destination is always on my mind. A VR world that could show me this information would be very useful (and for millions of travellers like me)"* (P55).

Amongst the barriers was the perception that VR required time to set up and fully enjoy, therefore making it more suitable for longer journeys. Conversely, several respondents also brought up the issues that might put them off from using VR on longer journeys, including eye strain, VR-induced sickness as well as battery life and discomfort caused by the bulkiness of the device.

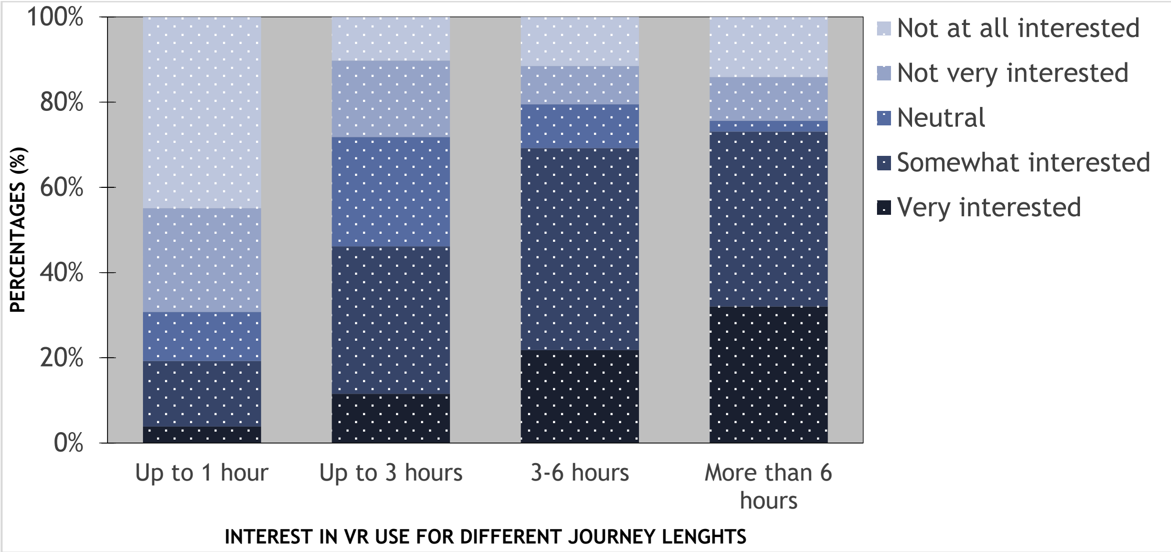


Figure 3.9: A comparison of respondents' interest in VR use for varied journey lengths.

3.3.3.3 Activities

Following the model of the first survey, respondents were also asked to rate their interest in using VR for entertainment, communication and work (N=81). A Friedman test showed a significant difference between the activities ($\chi^2(2)=43.371$, $p < 0.001$). Interest in VR was significantly different between entertainment and work ($p < 0.001$) and entertainment and communication ($p < 0.001$) but not work and communication. Kendall's W showed a small effect size (W=0.268), suggesting that the choice of VR activities for public transport has a lesser effect on acceptance than when on the aeroplane.

The qualitative analysis provides further insight into why VR for entertainment was preferred. Respondents felt that VR is for entertainment and leisure and that current devices are not good enough for other purposes, echoing the findings from the first survey. One of the respondents explained: "*I find VR in its current state not as good for productivity than traditional devices*" (P44). In addition, communication was also seen as socially unacceptable due to the risk of disturbing other passengers. For example, one respondent stated, "*I fail to see how VR would really offer much over current communications technology in a journey context and would risk disturbing other travellers*" (P85). However, several respondents also thought that they would be more likely to use VR for getting information about their destination, or instructions on how to "*navigate the station*" (P55) they will arrive in, hence making it more acceptable to use.

3.3.3.4 Purpose of Travel

To understand if the purpose of travel influenced the likelihood of using an immersive device, respondents were asked to rate their interest in using a headset when travelling for work and leisure. Results were analysed using the Wilcoxon signed-rank test (N=83) and showed a significant difference between the journey purposes (p=0.018) and that leisure journeys were more acceptable for VR use. The study has not collected information on respondents' commonly used VR applications, which could have biased their opinion towards leisure journeys. However, the result had a small effect size (d=0.26), which suggests that the influence of the purpose of travel is not as strong.

3.3.3.5 Other Passengers

To understand how other passengers influence the decision to use a headset, the respondents were asked if they would be more likely to use one when travelling alone, with friends and family, work colleagues or if they feel neutral about these situations. The majority of respondents (65.63%) said they are more likely to use a VR headset when travelling alone. Family and friends were the second option (26.04%) and work colleagues (4.17%) and feeling neutral (4.17%) were the least common answers.

To understand how unfamiliar passengers affect one's comfort of using a headset, respondents were asked how comfortable they would feel using VR in two commuting scenarios (Figure 3.7): a busy and a quiet subway carriage (in a randomised order). Only 10.98% of respondents thought they would feel 'Very comfortable' or 'Comfortable' to use VR in the busy scenario, and 26.15% in the empty subway carriage scenario. The analysis of respondents' comments showed that the risk of accidentally injuring other passengers, personal safety of oneself and one's belongings, potential lack of an empty seat, not being able to react to fellow passengers, "*drawing attention*" (P32) and "*being judged by others*" (P15) were amongst the key barriers to VR. The quiet carriage was only seen as a slightly better option. According to respondents, although there was less chance for embarrassment or hurting fellow passengers, the detachment from reality, such as not knowing which stop you were at, was still seen as an issue. Several respondents reflected on the changing nature of public transport and that new passengers could onboard at any moment, making this only a slightly more acceptable situation than a busy train. Being the only VR user was also seen as an embarrassment in empty and busy carriages. Respondents thought they might attract unwanted attention, or even be “*judged*” for wearing a headset.

3.3.3.6 Summary

The second survey revealed that on-the-ground public transport was perceived as challenging for immersive headset use, with acceptability varying based on the mode of transport. Buses, local trains/subways and taxis were seen as means for short journeys that required awareness of the surroundings and journey progression and therefore were least acceptable for VR use. Coaches (long-distance bus travel) and long-distance trains were more favourable due to longer journey durations. The lack of awareness and safety risks were amongst the more prominent barriers to VR use in on-the-ground transport in comparison to VR use on aeroplanes.

3.4 Discussion

The results of the surveys provide new insights into the factors that contribute to immersive headset adoption. The results of the surveys provide new insights into the factors that contribute to immersive headset adoption. Findings show that activity, particularly entertainment, and concerns about physical movement influence acceptance, with respondents showing a preference for situations where less movement is required. In addition, travel circumstances such as travelling alone and having more space available further increase the likelihood of immersive technology use. These preferences contribute to the early adoption scenarios explored in this thesis.

However, the systematic exploration of multiple modes of transport and journey durations is the core focus of this chapter. The chapter demonstrates that shorter journeys, such as those on a bus, pose a particularly challenging scenario due to the increased need for awareness. Consequently, the impact of journey length and mode of transport on immersive device acceptance, along with the unique concerns for in-transit contexts, are explored below and form the foundation for the subsequent work in this thesis.

3.4.1 Impact of Journey Length and Mode of Transport on Immersive Device Acceptance

Prior literature suggested that the mode of transport and journey length could influence the social acceptance of immersive devices [120, 123], but did not investigate this. The surveys presented in this chapter address this research gap by examining and comparing a wider variety of transport modes, including both aeroplanes and ground transport. The findings reveal that journey types are perceived differently depending on their length and mode of transport, both of which influence the acceptance of immersive devices. Additionally, there was a strong preference for using headsets for entertainment, particularly on longer journeys, where the need for engaging activities is greater.

For longer journeys, particularly those over three hours, there is a greater interest in using immersive headsets as passengers seek more engaging forms of entertainment to pass the time. Respondents indicated that the extended length of these trips often leads them to “*run out of [traditional] entertainment*” (P4), and that the extra time allows them to "*enjoy the experience*" (P19), with VR providing an alternative way to stay entertained. Longer journeys were most commonly associated with long-haul flights, long-distance trains, and coaches (long-distance bus travel). These trips were seen as requiring less concentration, making immersive technology more acceptable. Conversely, shorter journeys, such as those under one hour, were generally seen as less suited for immersive device use. Passengers perceive these trips as "*quick*" (P11) and "*tolerable*" (P10), making immersive devices less appealing due to the time required for setup and the perceived lack of necessity. Respondents felt that shorter journeys did not provide enough time to justify using a VR device. These shorter trips were commonly associated with buses, local trains, subways, and taxis. A key characteristic of shorter journeys was the higher perceived need to pay attention to surroundings and journey progression. Passengers also expressed a greater need to maintain “*control over what is happening*” (P68) compared to longer journeys. The surveys provide an initial framework for categorising the types of journeys people experience, warranting further investigation to refine these categories and assess their generalisability across different transit environments.

While technical challenges such as headset form factor and setup time were cited as barriers on shorter journeys, these are expected to improve as technology advances. The bigger challenge lies in addressing the demands for greater attention to the immediate environment and journey progression during shorter trips. This highlights the need for research into adapting immersive devices for shorter journeys, a crucial step that could serve as a foundation for generalising solutions to other journey types.

3.4.2 Awareness Gaps in Transit: People, Objects, Environment and Journey Information

The results of the open-ended questions revealed that immersive headset adoption in transit raises distinct concerns across three key areas: safety, awareness, and social. These concerns are rooted in a lack of awareness regarding other passengers, personal belongings, surroundings, and journey progression.

Firstly, the lack of awareness of other passengers was identified as a major safety concern, particularly due to the risk of accidentally injuring someone nearby while using a headset. Respondents viewed this risk as unacceptable, confirming the findings of Williamson et al. [217]. The surveys further emphasised that this issue is not static but a constant challenge in the dynamic environment of public transport. When asked to compare photos of a busy and an empty carriage, several respondents noted they would still be concerned about other passengers even if a journey began in an empty carriage, as more passengers could board throughout the trip. This ever-changing environment amplifies the need for passenger awareness, as unexpected movements increase the risk of unintentional collisions or discomfort. Losing track of personal belongings was another unique safety concern not widely discussed in previous literature. Respondents, particularly for shorter journeys, expressed a strong desire to remain aware of their belongings. Space constraints during the journey were also a concern. Several respondents mentioned discomfort in confined spaces, such as economy seating on flights. One respondent remarked, "*It is uncomfortable to do anything in economy class (even to watch a video on my phone or sleep) as there is no space*" (P31), further preventing them from adopting an immersive headset. Outside of safety concerns, respondents highlighted the importance of knowing their physical location during transit, particularly to avoid missing stops. This underscores the necessity of providing location-based cues and journey information to the headset user.

Finally, social concerns were another key issue raised by respondents. Many expressed worries about being "*judged*" or seen as "*stupid*" by fellow passengers for disengaging from reality while using a headset. With immersive headsets becoming smaller and more mobile, it could be expected that this should also change people's attitudes towards wearing them. Despite the look factor, devices worn on one's face bring additional challenges for social acceptance. As highlighted by the respondents, judgement from other passengers for occluding their reality acts as a strong barrier to immersive device use. However, the attitudes towards other passengers may also differ based on how long they have been observing the VR user. Work by Williamson [215], which looked at usability studies in real-world settings, showed that sustained spectatorship is more uncomfortable than interactions with passers-by. In a travel context, especially on longer journeys, this could become a more significant issue, while on shorter journeys it may be more tolerable unless enhanced awareness of other passengers could enable immersive headset users to better react and engage with those around them.

3.5 Chapter Conclusions

This chapter presented the results of two surveys focused on assessing the acceptance of immersive headsets across different modes of public transport. These surveys offer the first in-depth investigation into how the acceptance of immersive technology is influenced by a broader range of journey factors, with key elements including the mode of transport and journey length. Surveys revealed that journeys are not perceived uniformly. Longer journeys, typically associated with long-distance travel, are seen as requiring less concentration, making them more suitable for immersive technology. In contrast, shorter journeys are linked to short-distance travel, a greater need to monitor the journey and stay aware of one's surroundings. Additionally, the surveys highlight the transit-specific need for users to maintain awareness of other passengers, personal belongings, the immediate surrounding environment, and journey progression.

The results of this chapter answer RQ1 of this thesis:

How do mode of transport and journey length affect the social acceptability of immersive technology use on public transport?

Based on the results of Study I and Study II, the social acceptability of immersive technology in public transport is significantly influenced by the mode of transport and journey length. Longer journeys, such as those on long-distance trains and flights, tend to show higher acceptance because they require less constant awareness and concentration, and passengers have a greater desire for engaging entertainment. In contrast, shorter journeys, such as those on buses and local trains, present more challenges for acceptance due to the increased need for attentiveness to surroundings, other passengers, personal belongings and journey progression.

The surveys conducted in this chapter are one of the first to explore how journey factors, such as mode and length, affect the social acceptance of immersive technologies in transit environments. The findings reveal that transport environments are not perceived uniformly; instead, journeys are categorised based on factors like length, the associated mode of transport, and the corresponding level of reality awareness required. An open question remains, particularly for shorter journeys, regarding how the lost elements of reality, such as awareness of surroundings and other passengers, can be restored while still providing a meaningful immersive experience and maintaining immersion.

4 Using People, Objects, Environments and Journey Information Anchors to Alleviate Immersive Technology Acceptability Concerns

4.1 Introduction

In Chapter 3, the results of two surveys highlighted transit-specific awareness needs, including maintaining awareness of other passengers, personal belongings, the surrounding environment, and journey progression. However, an ongoing challenge remains on how to restore these elements of reality whilst maintaining an immersive experience during travel.

The literature review in Chapter 2 discussed existing reality-awareness solutions, which primarily focus on stationary, indoor private spaces (e.g., living rooms) and are therefore unsuitable for the dynamic nature of public transit. Features like the Quest's 'Guardian' and 'Space Sense' outline boundaries but are ineffective in mobile environments where constant movement and excess detail can overwhelm users. Similarly, video-based 'passthrough' solutions display the surrounding environment, but frequent use disrupts immersion [85, 226], limiting the benefits of immersive technology in transit. Academic solutions have also addressed awareness needs, such as proximity to others [126], using immersion-preserving features like real-world overlays [118, 219]. However, these solutions lack adaptation for the unique challenges of transit settings. In transit, passengers must navigate a constantly shifting environment that intensifies awareness needs, requiring a focus on avoiding collisions, managing personal space, safeguarding belongings, and staying alert. Therefore, there is a need to explore the requirements for a potential solution tailored to the transit context that can address awareness needs with the goal of sustaining immersion in the virtual experience.

This thesis proposes that using cues from reality, positioned within a virtual environment as reference points, can create experiences that retain immersion while addressing concerns associated with immersive technology use in transit. To achieve this, *Reality Anchors* are introduced: these are reality-based cues that reference other passengers, belongings, furniture, and journey information within the virtual environment. To begin exploring the potential of Reality Anchors, this chapter first addresses the following research question:

RQ2: Can Reality Anchors based on people, objects, environments and journey information alleviate concerns explored in RQ1, while maintaining immersion?

Additionally, reflecting on the findings from Chapter 2, it was highlighted that different journey types influence how users experience and prioritise awareness needs. For Reality Anchors to be generalisable across various journey types, further investigation is required into their adaptation to different journeys. Therefore, this chapter also addresses the following research question:

RQ3: How do Reality Anchors need to adapt based on journey type and dynamic user needs during travel?

To address these research questions, Studies III and IV used speculative VR simulations of public transit scenarios, including bus and subway rides, to explore and assess different anchor usage. This approach was taken to explore a possible future where immersive technology is common in real transit environments and to overcome technical limitations and safety concerns of deploying immersive technologies in an uncontrolled public setting in the early stage of exploration. Study III focused on testing initial user reactions to the concept of Reality Anchors and evaluated how they influenced attitudes toward using headsets in transit contexts. Building on these findings, Study IV examined how Reality Anchors could be adapted for different journey types and evolving user needs. Collectively, Studies III and IV explore the concept of Reality Anchors and their requirements for generalisability across various journey types and changing user needs in transit.

4.2 Study III: Exploring Reality Anchors on Public Transport Through VR Simulations

4.2.1 Reality Anchors Concept

4.2.1.1 Guiding Principles for Reality Anchors

The idea of Reality Anchors in this thesis is inspired by the philosophical work of Michael Heim. In *The Metaphysics of Virtual Reality* [66] Heim uses the term *reality anchor* to describe fundamental aspects of human experience, such as mortality, temporality, and fragility, that help users stay grounded in the real world, even during virtual experiences. The author argues that some link to reality is necessary to avoid disconnection or confusion when navigating virtual environments. Heim's work suggests that virtual worlds are more meaningful and engaging when users can contrast them with reality, rather than fully escape it. This thesis draws on Heim's metaphor of anchoring and extends it into a practical framework for immersive technology design. In this context, Reality Anchors are reconceptualised as visual cues that represent physical objects in the user's environment and are situated within the virtual space. These cues could include representations of people, furniture, or personal belongings. This adaptation builds on Heim's philosophical concept by applying it to the practical challenges of designing for immersive technologies in dynamic, real-world contexts such as transit settings.

A key challenge in applying this concept is maintaining the user's immersion while introducing real-world cues into the virtual experience. *Broken immersion*—an interruption in the sense of *presence*, or the feeling of being present in the virtual world—can significantly impact user engagement [226]. Preserving the user's sense of presence is a key requirement [118, 176, 226] for an engaging immersive experience. Exiting the virtual environment, such as through a passthrough view, disrupts the illusion and reduces engagement with the virtual world [85, 226]. Therefore, adopting an augmented virtuality solution provides a means to sustain immersion in the virtual world [118, 219], yet achieving this depends on integrating real-world elements in a balanced way. Too much of it can lead to an increase in distraction [118] and reduce immersion [226] in the virtual content, highlighting the importance of identifying how and when the anchors should be presented. In addition to maintaining immersion, Reality Anchors also need to a*nchor* or ground virtual reality within the real world, with cues presented consistently regardless of the virtual content. As noted by Heim [66], a clear contrast between the virtual and real worlds helps sustain immersion, which is crucial for a cohesive and seamless user experience across both environments. While fully diegetic representations—those matching the virtual environment—have been explored in prior work [53], this thesis assumes that a clear contrast is needed to ground users effectively. However, this assumption is subject to further exploration in the context of transit scenarios.

While the exploration of the most effective visual design is beyond the scope of this thesis, the design choices are informed by key insights from prior academic work. Most previous research has focused on awareness of bystanders [53, 94, 113, 143, 145, 219] or specific objects, such as keyboards or phones [8, 118], in relatively static environments where the surrounding context does not change significantly. While these environments differ from the dynamic nature of transit, they provide useful insights. Studies have explored how different visualisations influence immersion and awareness, comparing abstract notifications, avatars, and realistic camera overlays of passersby and objects [8, 53, 94, 113, 118, 145]. Studies suggest that increased fidelity is not always necessary to convey presence [117]. Avatar-like representations have been identified as the fastest to recognise in virtual environments [219], making them a promising choice for Reality Anchors, particularly in dynamic and unpredictable scenarios. Avatars that are visually contrasted from the rest of the virtual environment, such as through distinctive colours or outlines, have been shown to be particularly effective, as they are attention-grabbing and easy to recognise [53]. Such avatars, with at least some human-like resemblance, such as a head or nose, are especially useful for providing awareness of bystanders [94]. This approach is extended in Reality Anchors to include not only avatars but also highlighted objects, ensuring that key elements in the real world are recognisable in virtual environments. While some research has explored peripheral solutions—visuals that remain in the user's periphery [94, 118]—these are at risk of being unnoticed and were therefore not considered as a starting point for this research. Consequently, the starting point for Reality Anchors involves virtual avatars and objects that are highlighted or contrasted with the virtual environment, ensuring they are consistently recognisable and actionable (Figure 4.1).

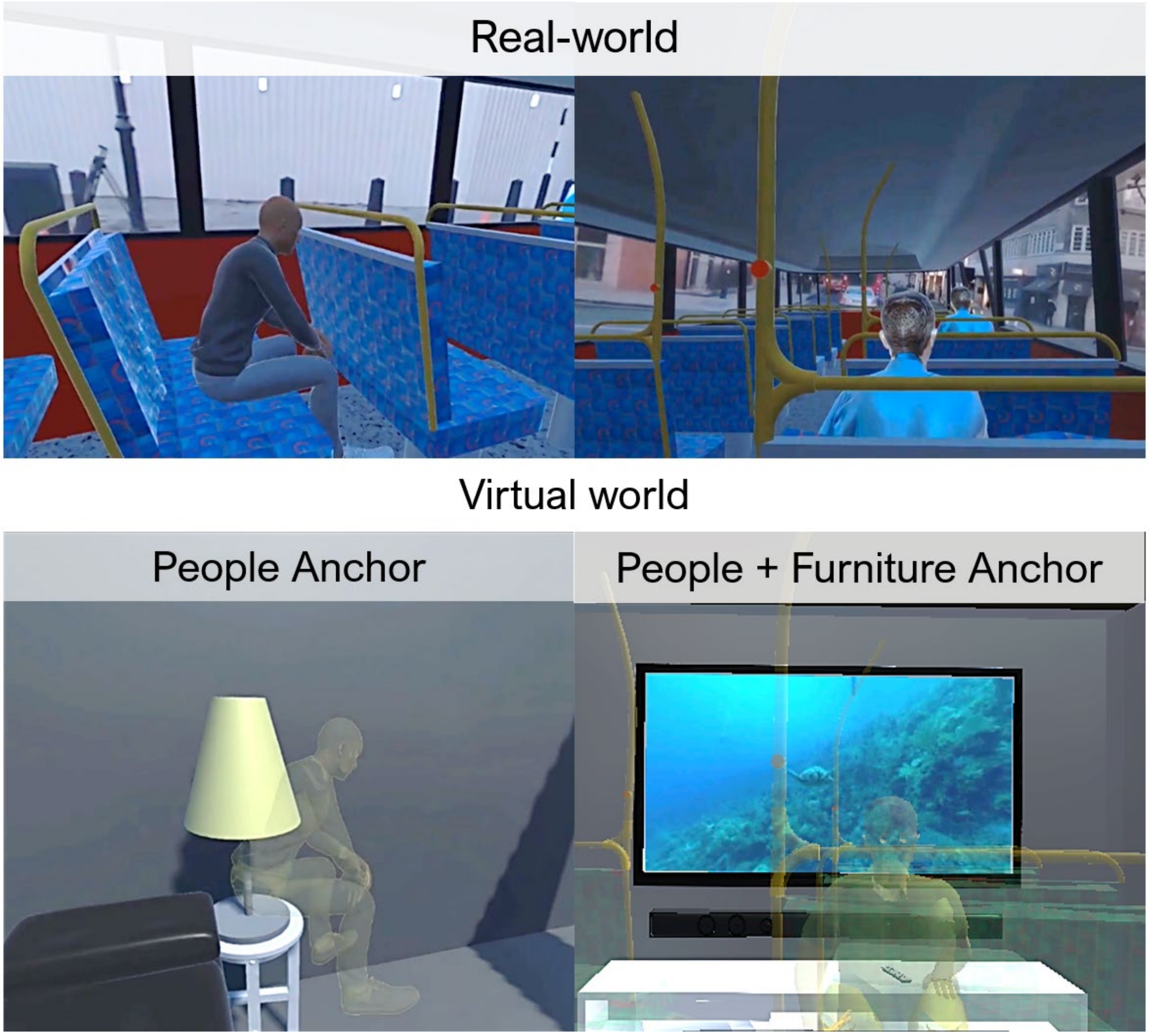


Figure 4.1: The design of Reality Anchors, featuring highlighted and transparent anchors in the virtual environment.

4.2.1.2 Future Vision of Reality Anchors

It is important to acknowledge the speculative nature of the Reality Anchors concept. While current technology does not yet fully support the visualisation and tracking of obstructed real-world cues with immersive technology headsets, recent developments in the area suggest that these limitations are likely to be overcome. Reality Anchors represent a plausible future technology, and while this thesis does not implement a fully realised solution due to current technical constraints, the speculative nature of this work is grounded in the likelihood that these limitations will soon be addressed, providing a strong foundation for exploring their potential.

Consumer headsets can already identify and convey the presence of objects and people visible within a user's ‘playspace’ (e.g. Quest’s Space Sense). Additionally, developer tools like ‘ARCore’ [253], ‘ARKit’ [254], and ‘Snaplens Studio’ [255] already offer object segmentation. Minor advances in this area could allow for the inclusion of signs and avatars within immersive headsets. However, being able to fully sense an entire cabin, which may be necessary for full awareness, could need new sensing or shared data infrastructure. Public transit already uses occupancy sensors (e.g., [256, 257]) and CCTV cameras [258] to ensure passenger safety and comfort. These approaches could be extended to include sensors such as depth cameras or RADAR to detect passengers and furniture in the environment. This information could then be broadcast anonymously to headsets in the area, which could use it to represent Reality Anchors, similar to the approach of broadcasted vehicle telemetry discussed by McGill et. al [124]. In addition, privacy-preserving sensor data collected by each headset could also be shared with other immersive technology users in the local environment to avoid occlusion problems. Leveraging distributed sensing in a shared environment has already been proposed by Meta in their plans for ‘Live Maps’, which are based on distributed AR headsets [259]. Finally, users’ own devices can be used to provide additional information about the immediate environment. The wide-angle cameras on the headsets could collect visual information about the surroundings which can be used to infer things about the movements of other passengers and objects. In addition, the non-visual cues about users’ personal items could also be incorporated and obtained using tags with Inertial Measurement Unit (IMU) sensors, considering the growing popularity of similar devices, such as the Apple air tags [260], allowing the headset to alert the users of the movement of their belongings.

4.2.2 Study Design

Study III was designed to test initial user reactions to the concept of Reality Anchors and investigate their influence on attitudes towards using headsets in transit contexts. As discussed in Chapter 3, the adoption of immersive technology in transit is shaped by concerns related to safety, awareness, and social factors, stemming from challenges such as needing to monitor other passengers, personal belongings, surroundings, and journey progression. To evaluate how Reality Anchors address these concerns while maintaining immersion, changes in participants' perceptions were assessed across six factors: safety, social acceptability, usefulness, distraction, escapism, and immersion, when exposed to variations of Reality Anchors.

The study was conducted in a lab and used a VR headset to simulate a short journey on a public bus. As discussed in the literature review, VR simulation is a valuable tool for studying immersive designs [135, 175] as it allows for greater control of variables and ensures the safety of participants. A bus scenario, where participants are travelling alone and engaging in an entertainment task, was chosen based on survey findings in Chapter 3. In the same findings, shorter journeys were associated with a greater need for awareness of surroundings and other passengers, making the bus a fitting context for this study. Participants were tasked with watching 360-degree videos and framed 2D videos within a cinema environment during the study, as the type of virtual content could influence which anchors are preferred by the users [94] and can affect the sense of escapism from reality [1]. The simulation created an augmented virtuality experience where a fully virtual bus environment represented the real-world surroundings (Figure 4.2 a). Virtual Reality Anchors were integrated within this environment as augmented elements, enabled during the video content viewing to support awareness of the bus environment. A transparent anchor approach was used, applying a semi-transparent yellow-green overlay to distinguish passengers and furniture anchors from the rest of the virtual scene. The outcome of this design can be seen in Figure 4.1.

To simulate the journey, a high-fidelity model of a London bus [261] was used in Unity [262] with a combination of 360-degree video, showing a real drive through London streets [152] visible through the bus windows (Figure 4.2 a). Several virtual avatars from the Adobe Mixamo library [263] were placed around the participant's position in the virtual environment to simulate a realistic social setting, as might be expected in a public space. The simulated avatars were kept static, in fixed positions throughout to avoid introducing additional bias. The street sounds were kept at a consistent level throughout the study, including when the participant was watching the video content.

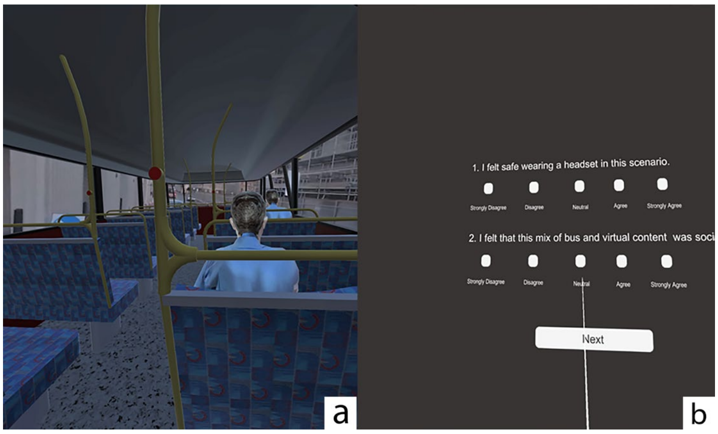


Figure 4.2: Study III set-up in Unity. a) the bus scene, shown at the start of each condition, representing the real world; b) the questionnaire screen shown after each condition.

The study employed two different simulated environments: a streamed 360-degree video of a nature documentary [208] and a cinema room, created using freely available assets [264, 265] with a 2D-fixed video of the same documentary. Both environments incorporated a variety of anchors from the bus throughout the eight conditions, as shown in Figure 4.3. These anchors consisted of semi-transparent highlighted avatars representing other passengers, bus furniture, and personal belongings. After each condition, participants were given a questionnaire to complete (Figure 4.2 b) and then taken back to the main menu for a break.

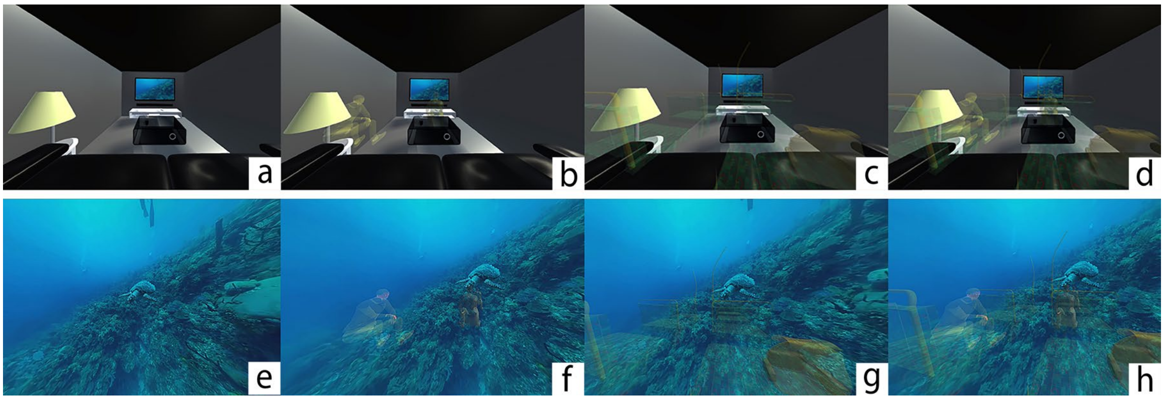


Figure 4.3: Study III conditions. a) 'No Cues' condition in the 2D-fixed video in a room; b) 'People visible' in the 2D-fixed video in a room; c) 'Furniture (incl. belongings) visible' in the 2D-fixed video in a room; d) 'People and Furniture (incl. belongings) visible' in the 2D-fixed video in a room; e) 'No Cues' condition in the 360-degree video; f) 'People visible' in the 360-degree video; g) 'Furniture (incl. belongings) visible' in the 360-degree video; h) 'People and Furniture (incl. belongings) visible' in the 360-degree video.

The study used a two-way repeated-measures design (4x2), with the two factors being: a) the Visible Reality Anchors (no cues, people visible, furniture visible or people and furniture visible), b) the Virtual Environment (360-degree video or 2D-fixed video in a room). The Visible Reality Anchors factor was presented in a way where the amount of treatment (visual cues) either increased (from no anchors to all anchors) or decreased (from all anchors to no anchors). This approach was designed to identify the point at which a sufficient number of anchors becomes visible. The direction of anchor visibility (from no anchors visible to all anchors visible) was counterbalanced. The anchors remained consistently present throughout each condition, with no fading effects applied to avoid introducing confounding variables. The virtual environment factor was also counterbalanced across all participants. The anchors were selected to cover a consistent social zone radius of 2.5 m from the passenger, measured in Blender, a distance that is appropriate for public and casual social interactions [63]. The radius was kept consistent throughout the experiment.

4.2.3 Participants

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

4.2.4 Procedure

The study ran on a Meta Quest 2 headset connected to a desktop PC via Quest Link to guarantee that the bus journey and human avatars were in maximum resolution and ran at maximum frame rate to reduce motion lag. The study was conducted in a large room where each participant sat on a non-swivel chair in front of a desk, with the researcher sitting at a desk across from them. The participant was greeted and provided with an information sheet and a consent form. They then completed a short questionnaire to collect demographic information and details about their previous experience using a VR headset and travelling on a bus.

During the study, participants were asked to imagine that they were travelling on a public bus whilst using the VR headset to watch a documentary video. Figure 4.2

a) illustrates the simulated environment they experienced, showing the interior of a London bus with surrounding passengers and a continuously moving view of London streets visible through the windows. 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 and four in a 2D-fixed video in a room. After each condition, participants were asked to fill in a questionnaire in VR. Once all conditions were over, a semi-structured interview was conducted to capture additional thoughts on the presented anchors and virtual environments.

4.2.4.1 Quantitative Data Collection

Participants responded to 5-point Likert-type questions after each condition, collecting their responses to feelings of safety, usefulness, social acceptability, distraction, escapism and immersion. Participants completed the questionnaire in VR (see Figure 4.2 b) 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*" (Usefulness), "*It was distracting to have this mix of bus and virtual content in this scenario*" (Distraction), "*I felt I could escape from the bus environment in this scenario*" (Escapism) and "*I felt immersed in the documentary in this scenario*" (Immersion). The *Distraction* metric was used as a way to measure Presence in VR as an overload of cues could disrupt the VR experience, thus breaking the feeling of *Presence*. The question for measuring *Immersion* was focused on the documentary to measure if participants were able to focus on their main goal for using the headset—to watch a documentary—instead of commenting on the overall experience of using VR. The collected data were logged in a file on the PC and later used for quantitative analysis.

4.2.4.2 Qualitative Data Collection

Following the completion of all eight conditions, a semi-structured interview was conducted with all participants. The interview followed the questionnaire themes, asking participants to comment on all six metrics (*Safety, Usefulness, Social Acceptability, Distraction, Escapism and Immersion*). The interview guide is available in Appendix C: Interview Guide for Study III (Chapter 4). In addition, printouts of all conditions were provided in the order they were experienced by each participant, to serve as a reminder. Participants were asked to discuss the six metrics, comparing their experiences in the 360-degree video environment and the 2D-fixed video in a room environment. Each participant took an average of 20 minutes to complete the interview. All interviews were audio-recorded, ensuring the anonymity of the participant, and then later transcribed for analysis.

4.2.5 Quantitative Results

To conduct quantitative analysis, the answers 'Strongly Disagree' to 'Strongly Agree' were converted to scores 1 to 5 respectively. Figure 4.4 presents the median values for participant answers to six questionnaire statements. To further prepare the data for analysis, the data were transformed using an Aligned Rank Transform (ART) approach [221] and then a two-factor repeated-measures ANOVA was performed with the Anchors and virtual environments as factors. *Post hoc contrast* analysis was conducted to compare different conditions for the factors that showed significant main effects. The results of these analyses are presented in the sections below.

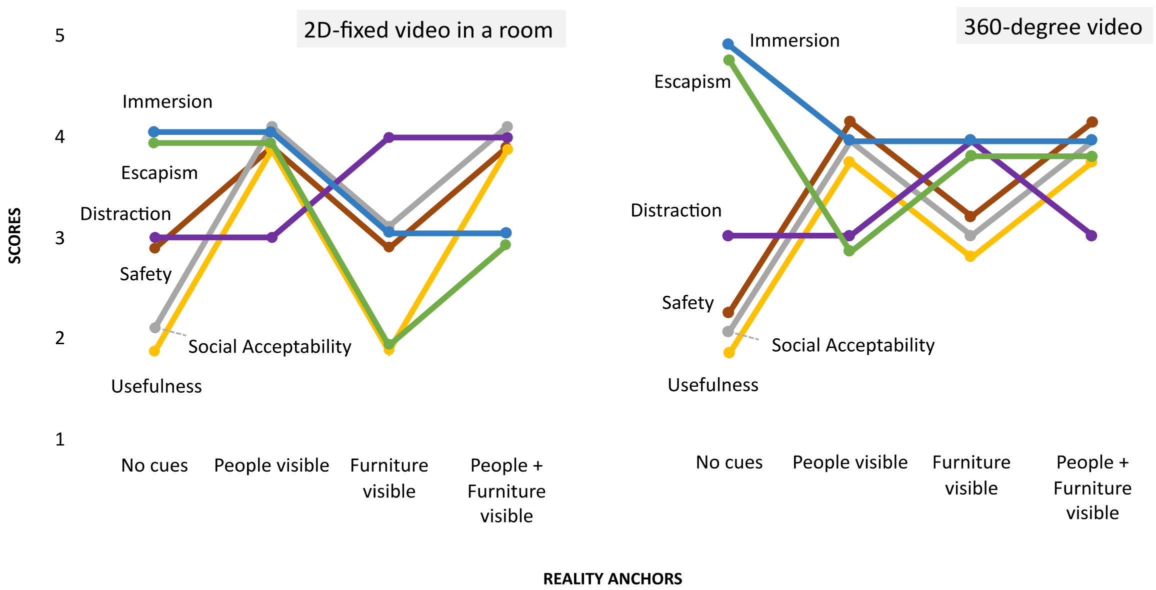


Figure 4.4: Median scores of participants' ratings to the six questionnaire statements, split by the virtual environment.

4.2.5.1 Safety

Reality Anchors showed a significant main effect on feelings of *Safety* (F(3,57)=15.40 p < 0.01). Virtual Environments did not show a significant main effect and there were no interaction effects between the factors. *Post hoc contrast* comparison (t(57)=-4.56, p < 0.01) showed that viewing People (Mdn=4, IQR=3.25-4) led to a significantly greater feeling of safety than No Cues (Mdn=2, IQR=1.25-4). Comparisons also showed users also felt safer (t(57)=-5.75, p < 0.01) when they saw People and Furniture (Mdn=4, IQR=3.25-4.75), compared to No Cues. Interestingly, seeing just People was perceived as safer (t(57)=3.63, p < 0.01) than seeing just Furniture (Mdn=3, IQR=2-3.75), but seeing People and Furniture was seen as safer (t(57)=-4.81, p < 0.01) than just seeing Furniture. The remaining pairs did not show significant differences.

4.2.5.2 Usefulness

The analysis showed that *Usefulness* was significantly affected by the Reality Anchors (F(3,57)=14.15, p < 0.01). Virtual Environments did not show a significant main effect and there were no interaction effects between the factors. Further *post hoc contrast* analysis (t(57)=-4.29, p < 0.01) showed that seeing People (Mdn=4, IQR=3-4) was more useful than having No Cues (Mdn=2, IQR=2-3).

Comparison between People and Furniture and No Cues ($t(57)=-5.97$, $p < 0.01$) showed that seeing People and Furniture (Mdn=4, IQR=3.25-5) was more useful than not seeing any cues from the bus. The People anchor was a crucial element for usefulness, as seeing People and Furniture ($t(57)=-4.29$, $p < 0.01$) was perceived as more useful than just seeing the Furniture (Mdn=2.5, IQR=2-4) on its own. The remaining pairs did not show significant differences.

4.2.5.3 Social Acceptability

Reality Anchors showed a significant main effect on *Social Acceptability* ($F(3,57)=19.10$, $p < 0.01$). Virtual Environments did not show a significant main effect and there were no interaction effects between the factors. *Post hoc contrast* comparisons ($t(57)=-5.46$, $p < 0.01$) showed that users felt that it was more socially acceptable to see People (Mdn=4, IQR=4-4) than have No Cues from reality (Mdn=2, IQR=2-4). People and Furniture (Mdn=4, IQR=4-4) were also seen as more socially acceptable ($t(57)=-6.27$, $p < 0.01$) than having no information from the bus. Seeing People ($t(57)=4.24$, $p < 0.01$) or People and Furniture ($t(57)=-5.05$, $p < 0.01$) also returned higher scores than just seeing Furniture (Mdn=3, IQR=2-4) in terms of social acceptability. The remaining pairs did not show significant differences.

4.2.5.4 Distraction

Reality Anchors showed a significant main effect for *Distraction* ($F(3,57)=2.93$, $p=0.041$). Virtual Environments did not show a significant main effect and there were no interaction effects between the factors. *Post hoc contrast* comparisons revealed that seeing just the Furniture (Mdn=4, IQR=3.25-4) was found to be more distracting ($t(57)=-2.66$, $p=0.049$) than having No Cues (Mdn=3, IQR=2-4) brought into the environment. The remaining pairs did not show significant differences.

4.2.5.5 Escapism

Both the Reality Anchors ($F(3,57)=8.15$, $p < 0.01$) and Virtual Environments ($F(1,19)=12.42$, $p < 0.01$) factors showed significant main effects for *Escapism*. Interaction effects between Reality Anchors and Virtual Environments were also significant ($F(3,57)=3.45$, $p=0.022$) but *post hoc contrasts* found no significant differences.

The participants felt that they could escape the bus environment more ($t(57)=3.33$, $p < 0.01$) when No Cues (Mdn=4.5, IQR=4-5) were present, compared to seeing People (Mdn=4, IQR=2.25-4). Comparisons ($t(57)=3.14$, $p=0.014$) also showed that People and Furniture (Mdn=4, IQR=3-4) reduced escapism more than No Cues. The final significant comparison ($t(57)=4.80$, $p < 0.01$) of Furniture (Mdn=3, IQR=2-4) versus No Cues revealed that Furniture reduced escapism the most. The remaining pairs did not show significant differences.

For Virtual 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).

4.2.5.6 Immersion

Immersion was also significantly affected by Reality Anchors ($F(3,57)=8.43$, $p < 0.01$) and Virtual Environments ($F(1,19)=21.30$, $p < 0.01$). Interaction effects between Reality Anchors and VR Environments were also significant ($F(3,57)=3.49$, $p=0.021$) but *post hoc contrasts* found no significant differences.

Immersion was strongest when No Cues (Mdn=5. IQR=4-5) were visible and showed a significant difference in comparison ($t(57)=3.01$, $p=0.020$) to seeing People (Mdn=4, IQR=3-4). Seeing People and Furniture (Mdn=4, IQR=3-4) was also less immersive ($t(57)=4.30$, $p < 0.01$) than seeing No Cues. However, seeing just the Furniture (Mdn=3.5, IQR=2-4) was the least immersive of the three, compared to No Cues ($t(57)=4.41$, $p < 0.01$). The remaining pairs did not show significant differences.

For Virtual Environments, 360-degree video (Mdn=4, IQR=4-5) also led to greater immersion than a 2D-fixed video in a room (Mdn=4, IQR=2-4).

4.2.6 Qualitative Results

Upon transcription, all interviews were coded using an open-coding process [26] where each statement was assigned an emergent code that was iterated over several cycles and used to re-code the transcripts until no new codes were needed. Following that, all codes were arranged into meaningful groups, following a thematic analysis approach [18]. A single coder performed the coding, discussing, and amending of the codes after the first and the final iteration with another researcher.

Whilst the chapter uses the terms ‘immersive technology’, ‘devices’, and ‘headsets’ when describing overall goals and findings, the results section keeps the use of ‘VR’ for consistency with the original study context, using it where it was originally applied in participants' tasks, questions, or quotes.

4.2.6.1 VR Acceptance on Public Transport

Four themes emerged as key factors influencing the acceptance of VR on public transport: 1) the ability to maintain awareness, 2) social acceptability, 3) the extent of required physical movement, and 4) concerns about motion sickness.

The ability to maintain awareness depended on remembering that you were on a bus and not becoming “*carried away by the VR content*” (P2), as this was perceived negatively. P7 highlighted this concern, stating, “*I don't want to forget where I am because I have to be alert*”. Similarly, P17 expressed that such situations could lead to constant worry: “*You're too concerned about the world outside; you don't feel very comfortable because you can’t see what's going on*”. Participants worried that losing awareness whilst in VR could result in missing the required stop, not noticing that other passengers require attention or are up to malicious actions, losing personal belongings or not realizing there was an accident on the road. These concerns align with the findings from surveys discussed in Chapter 3. While some participants felt they would prefer to remove the headset if they were worried about someone or felt they were receiving too much attention, others noted a preference for a solution that allowed them to be, as P6 stated, “*able to not have to take the headset off and you could still make safety checks*”.

Social acceptability was another factor influencing VR acceptance on public transport. Participants mostly linked social acceptability to other passengers. VR was deemed acceptable if it was “*discreet and not intrusive*” (P6), ensuring that the user avoided behaviours perceived as “*irritating*” (P21), “*weird*” (P11), or “*rude*” (P19). Such perceptions could arise from actions like “*moving [the] head really vigorously*” (P15) or “*staring at people*” (P8) while immersed in VR. These concerns underscore how acceptable interactions and motions are constrained in public transport environments. This aligns with the concerns identified in the surveys in Chapter 3. However, in this study, we observe that exposure to people as anchors can influence social acceptance. Overall, participants felt that social acceptability would increase with the visibility of people because "*when you are around people you cannot be oblivious to their presence*" (P3*)* and you can "*adjust the behaviour based on other passengers*" (P8). Only two participants mentioned that other passengers may object to having their image represented in VR, making it unacceptable in that case, and only one participant felt that they stopped worrying about other passengers once they were not visible anymore.

Linking back to the earlier finding, how much physical movement is required was also a factor influencing VR acceptance. Too much physical movement was not only seen as socially unacceptable but also physically demanding, increasing the risk of injuries, or being physically tiring. Concerns about motion sickness were the final influencing factor, only mentioned by two participants. Although motion sickness and input techniques are not within the scope of this work, these factors are noteworthy as they can further hinder the adoption of immersive technologies in transit.

4.2.6.2 Factors Influencing the Choice of Reality Anchors

Participants' reflections on Reality Anchors revealed four key considerations influencing their choice of anchors: 1) the ability to enhance the sense of safety, 2) whether the anchor(s) provide added value, 3) the ability to maintain immersion or focus on the task, and 4) whether the anchor(s) align with the requirements of their journey type.

The first consideration, the ability to increase the sense of safety, was linked to how the sense of safety was affected by the different anchors. Those anchors that increased the feeling of safety were preferred and were mostly represented by the people anchor. The majority of participants agreed that they felt safer when they could see people as that helped maintain awareness ("*seeing the people - that was good because I could be aware of my surroundings*" *(P15))*. Following that, seeing the belongings was another preferred anchor that increased a sense of safety, as noted by *P7*: "*won't feel 100% safe if I don't know where my bag is*".

However, seeing the bag was not enough for some participants, who noted that in addition to the visual, they would still want to touch their belongings ("*would use the visual representation but also touch to make sure my item is still there" (P9))*. Contrary to this, one participant felt that they would not need to see their belongings if they could at least see the people: "*if I could see the people all the time then I don't need to see my luggage*" (P16). Seeing no anchors had a strong negative effect, and the majority of participants felt that it was unsafe and uncomfortable, and they would worry about their surroundings all the time, thus disturbing their VR experience. Overall, anchors that increased the sense of safety were those that reminded them of the bus environment, especially other passengers, allowing for a quick response if their attention was needed.

Another consideration when choosing the anchors was their added value. As adding more anchors increased objects in the visual field, participants were selective and preferred only those anchors that were perceived as useful. As discussed earlier, people and personal belongings were the two most useful anchors, however, most participants considered furniture to be the most redundant visual cue. Participants thought that it "*does not move on its own*" (P1) and "*doesn't really change*" (P8) and that you already know you are "*in a chair*" (P9). However, a few participants felt that the furniture anchor added value when in combination with people as that provided a reference point to where the people were sitting. As P20 noted: "*when I could see them with chairs, I had a bit more information about them, I knew, Oh, they're kind of over here*". Despite this, most participants thought that furniture or furniture and people together resulted in a busy environment, that distracted them from their main task of watching the documentary.

Maintaining immersion and focus on the task was an important consideration when selecting the anchors. Participants often found the furniture and furniture and people anchors particularly distracting. For example, P8 observed, "*people and furniture together is too much, distracts from the task*", while P1 added, "*furniture on its own—really distracting*." In contrast, "*just [seeing] people still allow for better immersion in VR*" (P22). Interestingly, a couple of participants noted that, although they initially found the anchors distracting, they eventually got used to them. P13 explained, "*the anchors, at first it was jarring, but then I* *got used to it*”. Others mentioned learning to ignore the anchors over time, as P3 shared, “*cues are easy to ignore when you get used to them*”.

Participants also discussed the visualization of the anchors, revealing that those taking up the most visual space, particularly the furniture anchor, were found to be the most distracting. For example, P8 noted, “*furniture is disruptive because it blocks the screen and contains a lot of information*”, while P4 commented, “*furniture is everywhere and can't be easily ignored*”. Surprisingly, distraction was not only a consequence of how much space the anchors occupied but also how naturally they fit into the virtual scene. The mismatch between the anchors and the virtual environment affected how “natural” anchors seemed within the environment. Some participants thought that “*people look weird because they clash with virtual objects*” (P8), or floating in the air, as noted by P14: “*it doesn't make sense. There are people sitting on nothing*”. The clash of bus furniture and virtual objects was more profound in the 2D-fixed video in a room (“*suddenly you have like a seat with a lamp on it and it looks a bit weird*” (P11)) and it even affected participants' perception of reality (*[it] mixed with my perception of reality. Because sometimes maybe I'm not sure is this real or not?*” (P19)).

Surprisingly, some participants looked for a sense of familiarity, comparing the 2D-fixed in a room scenario to a familiar setting, as explained by P21: “*in the cinema room it felt like I was actually at home watching it*”, and many of the participants felt that seeing people in the room environment felt very natural (“*seeing other passengers in the room with a screen felt like a cinema*” (P2)). However, that only applied to seeing the people, not the furniture as “*with people, it's just like you're in your living room and sitting with other people, the furniture is like something that don't belong there*” (P20). Although less so in the 2D fixed-video condition, the people anchor clashing with objects from the virtual environment was distracting to some participants (“*the passengers' anchor clashing with the virtual furniture was distracting*” (P7)). However, one participant also noted that if people also matched the virtual objects, then the unnatural mismatch would no longer be a problem, P17 explained: “*it felt unnatural, the mismatch. But for example, if I was like in a cinema, and these people were in like seats like in the cinema, then it would be alright*”.

Contrary to this, in the 360-degree environments, none of the anchors felt natural and were easier to ignore due to the full-scale mismatch they had to the scene, which lead to higher immersion and a likelihood of completely forgetting the bus that participants disliked, as noted by P19: "*in 360 I completely forgot about the bus, but I don't think it's safe*". Some participants still found it uncomfortable to see people in the 360-degree video environment. P13 explained, "*the intention is to make you feel that you're underwater, but there's people in it, so it's kind of unrealistic*". However, this issue was discussed less frequently than the clash between people and objects from the virtual scene in the 2D fixed-video room set-up, suggesting that because the mismatch in the 360-degree video environment was more apparent, it was also perceived as less uncomfortable.

Finally, participants also considered how specific anchors might match their journey requirements, making this the final factor influencing their choice. The analysis confirmed that shorter journeys required more awareness than longer journeys, specifically when the journey does not end at the final stop. As P11 noted: "*would need to know If you are getting closer unless it is the end stop*", as that would require the user to manage their journey themselves. Not having any anchors was seen as unsuitable for shorter journeys, whilst longer journeys were a more appropriate environment for getting immersed in VR. Participants felt that longer journeys are different from shorter journeys by a lower passenger turnover, ("*on a longer trip most people just get in and then they sit there, then I might not need to know a lot going on*" (P11)), no need to manage the journey ("*If it's like overnight, you want to be completely immersed. You don't need to go anywhere. You don't need to look for the stops*" (P16)), and a journey length that implied entertainment is needed ("*long journeys are boring, not much happening outside, need less information - more suitable for VR*" (P1)). The answers also showed that longer trips are more suitable for VR with a clear final stop, as noted by P8: "*long ride with clear final stop can be more occluded. People don't tend to move about*".

4.2.6.3 Requirements for Future Reality Anchors

Participants also discussed potential improvements and requirements for the anchors. The key recurring themes were: 1) depicting changes in other passengers' movements, 2) including journey information as an anchor, and 3) enabling the selection of anchors based on the needs of the journey.

The study included static representations of other passengers, that remained in fixed positions throughout, but most participants also discussed scenarios where the passengers might be moving. The change in direction or position was considered more important than a constant feed of other passengers. As P15 explained, "*knowing where people are at that time. If they did move, I want to see where they moved to. Minimal movements on the seat wouldn't make a difference*". Constant movement, however, could even be perceived as distracting, as P16 noted, "*people, if they're moving all the time, it's more distraction than usefulness*". The change in position was especially important if the other passengers required the VR user's attention or were getting closer to them ("*if they're [people] not walking toward you then I don't care if they're moving*" (P12)), suggesting that anchors based on proxemics might be a useful feature in the future. Participants also missed having journey information in the provided scenarios, including knowing when they are approaching/or at their destination. Finally, being able to select the anchors based on journey needs was among the most common suggestions. Participants agreed that they wanted to tailor the anchors based on their journey type, or sense of safety to regain control of their journey ("*I would like to select what I want to see to be in control of the situation*" (P5)).

4.2.7 Summary

Study III demonstrated an initial attempt to explore Reality Anchors for in-transit contexts. The overall findings showed positive indications that Reality Anchors can increase the overall acceptance of immersive technologies on public transport, particularly the visibility of other passengers and one's belongings. However, that is not without an effect on immersion as with an increased number of anchors, participants' ability to focus on the video content also decreased. The study also revealed that headset users are selective when choosing which anchors suit their journey needs.

Surveys from Chapter 3 revealed that not all journeys are perceived equally. Shorter journeys often demand greater awareness, a heightened need for control, and are more tolerable before entertainment becomes necessary. The findings from this study build on these insights, highlighting that journeys can also be categorised by the need to manage progress, whether they involve a predefined final stop or require passengers to determine where they need to get off, and by the likelihood of continuous or minimal passenger turnover. Based on the findings from both the surveys (Study I and Study II) and Study III, the key differences in information needs and concerns based on the type of journey can be categorised as follows:

- **Self-managed journeys**: Typically, short trips where passengers must decide when to get off, often involving frequent passenger turnover and heightened concerns about safety and journey awareness.

- **Externally managed journeys**: Characterised by longer trips where passengers do not need to manage when to get off, minimal passenger turnover, and longer durations. These trips were often perceived as less stressful and more monotonous, making entertainment a priority.

The results suggest that passengers' anchor needs vary depending on the type of journey. For self-managed journeys, the demand for Reality Anchors is likely to increase, while for externally managed journeys entertainment may be prioritised over awareness. However, it remains unclear which specific anchors would be prioritised for each journey type and how these preferences might evolve as the journey progresses.

Generalising anchor use across self-managed and externally managed journeys would be beneficial for designing future immersive technologies. To further investigate, the next study was designed to allow participants to freely choose anchors throughout two journey scenarios representing self-managed and externally managed journeys, to better understand how anchor preferences change over time.

Additionally, two key requirements for future anchor designs emerged from the findings of Study III:

- **Inclusion of journey information:** Although not implemented in Study III, the findings strongly support the need for journey information as an anchor, which will be explored in Study IV.

- **User control over anchors:** Allowing users to freely select and adapt anchors throughout their journey was identified as essential. Participants expressed a desire for greater control over their in-transit experience, as preset anchors, while useful as a starting point, were often perceived as limiting in addressing their individual needs and adapting to changing circumstances.

These features were integrated into Study IV, which is discussed in the following section.

4.3 Study IV: Reality Anchors for Different Journey Types

4.3.1 Study Design

Study IV was designed to explore anchor usage on self-managed and externally managed journeys. This study used a VR headset to simulate two rides on a subway train and was conducted in a lab environment. The first scenario was a multi-stop ride on the London underground, which was designed based on the real route of the train and represented a self-managed journey. The ride included all 16 stops of the Victoria line and was designed to last for a maximum of 12 minutes, but the participants' target stop was the tenth stop, bringing the journey duration to approximately 8 minutes. The second scenario was a modified journey that represented an express train, where the destination is the final stop and there are no stops throughout the journey with an approximate ride time of 8 minutes to maintain consistency in both conditions. To simulate the rides, a high-fidelity subway model was used in Unity where the realistic movement of the train was depicted using Unity's physics engine. Several virtual avatars from the Adobe Mixamo library [263] were placed around the VR user to simulate a realistic social setting. Findings from Study III indicated that anchors based on an object's distance from the user could be useful. Therefore, in this study, the avatars were positioned within the user's personal zone (~1.2 m) and social zone (~3.6 m), based on Proxemics theory [63].

The simulated avatars were animated with realistic body movements (such as slight movements of hands and head) to increase the fidelity of the scenarios. The human avatars stayed in fixed positions throughout the experiment to avoid introducing additional bias caused by passengers moving around, which will be explored as a separate factor in the following chapter. The sound of the subway moving was kept at a consistent level throughout both study conditions (a self-managed and an externally managed journey) and included the sound of doors opening and closing. No audio announcements were played throughout the journeys to maintain the focus on the use of the visual cues that are represented by the anchors.

All participants experienced both rides in a counterbalanced order. For the task, participants were told to treat the virtual train environment as a real-life journey, during which they were wearing a VR headset and watching a nature documentary video [266] in an immersive 3D cinema created using freely available assets [264, 265]. Once immersed in the cinema room, participants were able to use a pop-up menu to activate or fully deactivate the following Reality Anchors (as shown in Figure 4.5): Passenger, Possession, Furniture and Signage. Participants were also able to increase the visibility radius (shown Figure 4.5 c) to cover their social zone, measured as 3.5 m in Blender, to investigate if there is a preference for the radius that the anchors should be displayed within. The anchor design followed the same approach as in Study IV. A semi-transparent overlay was used to visually distinguish the anchors from the rest of the virtual scene, as illustrated in Figures 4.5 d, Figure 4.5 e and Figure 4.5 f.

After each ride, participants were given a short task asking them to mark which anchors they selected throughout the journey and to rank seven Likert-scale statements. To maintain a controlled experimental environment and minimise potential distractions, the in-VR scenes were kept constant across all conditions, except for the manipulation of journey type, which was the primary focus.

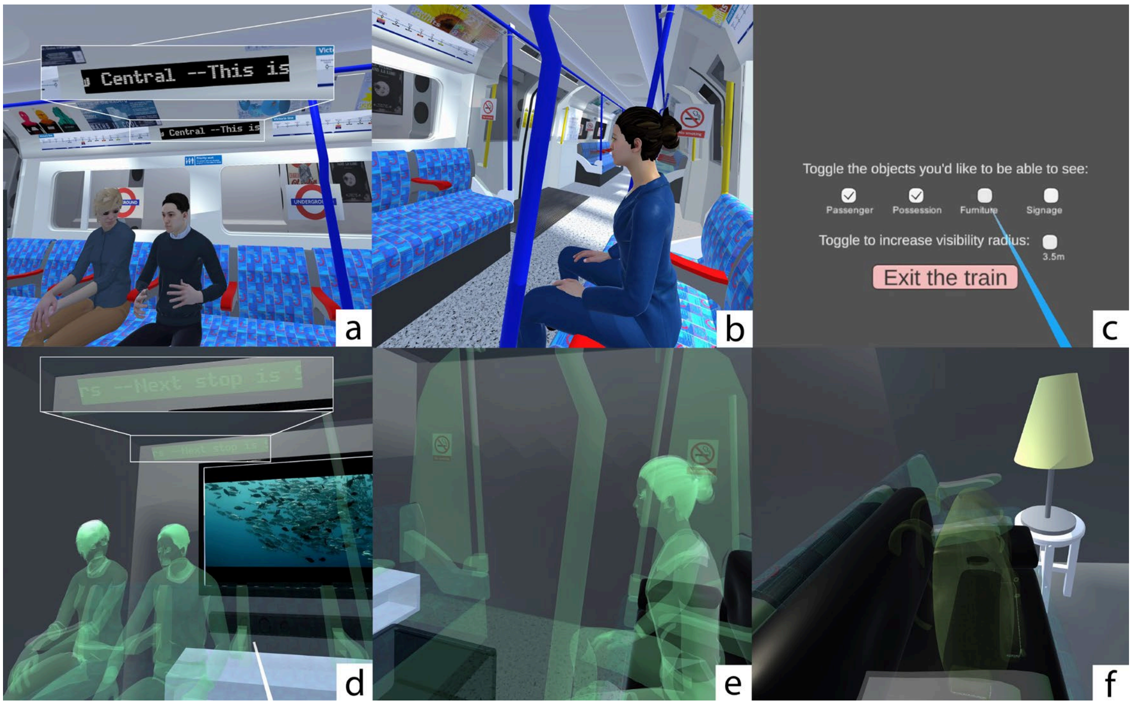


Figure 4.5: Study IV set-up in Unity. a), b) other passengers in the subway scene, d), e), f) Reality Anchors showing 'Other Passengers', 'Next station signage', and 'Furniture' visible in the increased radius mode, and c) a pop-up menu for Anchor selection.

4.3.2 Participants

In total, 19 new participants (8 females, 10 males, 1 non-binary, mean age = 27 years, SD = 6) were recruited for the study. The majority were students, 17 have used a VR headset at least once, 2 have never used one before; all participants had previous experience travelling on a subway and 2 travelled on a subway in London in the last month. The study took approximately 60 minutes to complete, and participants were compensated for their time with £10 Amazon vouchers. It was ensured that participants took a rest between the two journey simulations to minimise any possible VR-induced sickness. The study was approved by the university ethics committee.

4.3.3 Procedure

As for Study III, each participant sat on a non-swivel chair in front of a desk, with the researcher sitting at a desk across from them. The participant was greeted, presented with an information sheet, a consent form, and filled in a short questionnaire to collect demographic information and previous experience of using a VR headset and travelling on a subway. During the study, participants were asked to imagine that they were travelling on a London underground train whilst using the VR headset. Figure 4.5 a and b illustrate the virtual subway environment shown to participants at the beginning of the study, featuring the inside of a subway car and the presence of other passengers. For the self-managed condition participants were instructed to 'get off' at the tenth stop, "Oxford Circus", which they could do by selecting a button on the pop-up menu (Figure 4.5 c). For the externally managed journey, participants were told they were travelling to the end of the route, where the train would stop. Each ride started with a virtual scene on the subway, which participants were to consider as 'reality', and which then faded out through a black screen into the cinema room. Participants were asked to imagine they were putting a headset on when the fade-out appeared. Once in a cinema room (seen in Figure 4.5 d), participants were unable to return to the subway train environment but could use the pop-up menu with the anchors throughout the journey (Figure 4.5 c). Once both rides were completed, a semi-structured interview was conducted to capture participants' thoughts on the two different journeys and their use of Reality Anchors.

4.3.3.1 Quantitative Data Collection

Study IV leaned on qualitative methods for the majority of its data collection, however, participants were asked to rank seven 5-point Likert-type statements to ensure that the simulated self-managed journey and an externally managed journey were perceived differently by the participants, and that the chosen approach was suitable for the study. The results of Study III indicated that a self-managed journey might require an increase in awareness and safety concerns, whilst an externally managed journey should allow for a more immersive VR experience. Based on this, the following seven statements were formulated (answers ranging from Strongly Disagree to Strongly Agree): "*The anchors assured me that my belongings are safe*", "*The anchors increased my sense of personal safety*", "*Being able to see the anchors was useful*", "*The anchors were distracting*", "*I had to focus on my journey progress*", "*I felt I could escape from the subway environment during this journey*" and "*I felt immersed in the documentary during my journey*".

4.3.3.2 Qualitative Data Collection

The semi-structured interviews included 10 questions focused on the experience and the use of the anchors, social acceptability, and the use of anchors in different journeys (please refer to Appendix D: Interview Guide for Study IV (Chapter 4) for the full interview guide). During the interview, participants were encouraged to discuss the differences and similarities between the two journeys in relation to each interview question. If needed, participants were probed to further explain or clarify their ideas. Each participant took an average of 25 minutes to complete the interview. All interviews were audio-recorded, ensuring the anonymity of the participant, and then later transcribed for analysis.

4.3.4 Quantitative Data Results

To conduct quantitative analysis, the answers "Strongly Disagree" to "Strongly Agree" were converted to scores 1 to 5 respectively. The Wilcoxon signed-rank test was used to analyse the results and showed a significant difference between the two journeys for the following three statements: "*Being able to see the anchors was useful*." ($p=0.33$, $z=-2.126$, moderate effect size, $d=0.60$), where the usefulness of the anchors was higher for a self-managed journey; "*I had to focus on my journey progress.*" ($p < 0.001$, $z=-3.436$, large effect size, $d=2.24$), where participants had to focus on their journey progress more in a self-managed journey; "*I felt immersed in the documentary during my journey*." ($p=0.006$, $z=2.749$, large effect size, $d=0.85$), where participants felt more immersed in the documentary in the externally managed journey. There were no significant differences between the journeys for the remaining statements. These results were in line with the definitions for self-managed and externally managed journeys.

4.3.5 Qualitative Data Results

Interview analysis followed the approach of the previous study. All interviews were coded using an open-coding process [26], where statements were assigned emergent codes iteratively until no new codes were needed. These codes were grouped into meaningful themes following a thematic analysis approach [18]. A single coder conducted the coding, with discussions and amendments made in collaboration with another researcher after the first and final iterations.

Whilst the chapter uses the terms ‘immersive technology’, ‘devices’ and ‘headsets’ when describing overall goals and findings, the results section keeps the use of ‘VR’ for consistency with the original study context, using it where it was originally applied in participants' tasks, questions, or quotes.

4.3.5.1 Prioritising Reality Anchors for Self-Managed Versus Externally Managed Journeys

Interview analysis showed that participants prioritised the use of anchors differently for self-managed and externally managed journeys. They considered the following: 1) whether they needed to track the route, 2) whether passengers were expected to change throughout the journey, and 3) whether they were approaching their destination.

Tracking the route was especially important for self-managed journeys. All participants used the signage anchor in the self-managed journey, and most participants turned the anchor on as soon as the journey started, as “*there was a need for the signage from the get-go*” *(P2)*. Keeping track of the route was important as missing a stop would be difficult to rectify: *“if you pass the station you want to go to, you probably will take more time to get back*” (*P10)*. Interestingly, a few participants also noted that the time in VR felt distorted, potentially contributing to the loss of awareness if no anchors were present, (“*time moves differently in VR somehow. It moves a bit faster*” (P5)), further increasing the need to see the stop information. For externally managed journeys, tracking of the route was not as important, as highlighted by P14: “*on the express journey, because I wasn't worried about my stops, I don't need the signage*”. All the participants used the signage anchor, but almost half of the participants turned it on halfway through the journey. Participants' answers revealed that this was because the sign was used to check on the journey, but not to keep constant track of the progress: “*I knew that I did not have to get off at a certain stop, so I put the stop on just over halfway, whilst in the other one I would have put it on ages ago*” (P17).

The expectation of passengers to change was another factor influencing anchor choices for self-managed and externally managed journeys. Self-managed journeys were associated with a high passenger turnover, reinforcing the findings of Study III. Most participants had the passenger anchor on at least at some point throughout the self-managed journey. However, contrary to the use of the signage, the passenger anchor was used sporadically rather than kept constant throughout the journey. Participants used the anchor to “check-in” on the passengers in between the stops (“*the passengers were only useful in that period between its stopping and starting again because that's the only time I actually really care about passengers, who's coming on who's getting off*” (P2)). Participants also found the passengers to be more distracting from the documentary than other anchors, which also resulted in periodical checking instead of constant use of the anchor, as noted by P3: “*I realised that I didn't really look at the people. They were just annoying because I could see them and not watch the film so much*”. For externally managed journeys passenger turnover was not seen as a big concern. Participants did not display a consistent use of the passenger anchor and some did not turn it on at all. Lack of passenger turnover, however, did not affect the need to see the belongings which was the most consistently used anchor in both journeys. The majority of participants used the anchor at least at some point in both experiences and noted that upon occluding the reality it is important to check on possessions (“*first I need to ensure my bag is safe*”, P16: “*so at the beginning, I just selected my possession, because that's the important thing*” *(P7))*. Participants' reflections revealed that the need to use the furniture anchor was not influenced by tracking the journey, passenger turnover or approaching the destination. Furniture only served the purpose at the start of the journey, to paint a mental picture of the environment (“*the furniture was useful at the start because I could see the pole and it is a hazard, but after I got used to, I turned it off.*” (P17)), or as a reminder of the subway environment (“*when I wanted to remind myself that it was a subway, that's when I enabled the furniture*” (P2)), but was not prioritised differently in a self-managed or externally managed journeys. Maintaining awareness of the belongings and the journey progress also helped to focus on the task, as noted by P1: “*my possessions and the fact that I knew where I was, it increased my immersion*”. Interestingly, the option to increase the visibility was not commonly used by passengers as they thought it was “*distracting*” (P1), due to the visual space it takes in the scene. However, the option was still used by those participants who were most worried about other passengers.

The findings also showed that as the journeys progressed, the need for the anchors changed. Participants employed several methods to determine if a change in the anchor selection was needed. This was especially prominent in self-managed journeys. Participants re-evaluated the safety of their environment (*"in the middle, I just wanted to see what's happening around me, just for a second, so I just looked around and then I closed it" (P9))*, and if other passengers might be a cause of worry, as discussed by *P10: "there's one next to me, but she looks fine and the other two, they talked to each other, so I think my things are safe, so unselected the passengers in the middle of the journey"*. Lastly, as participants were getting closer to their destination, the need for the anchors increased, as P5 explained*: "I turned on the passengers and possessions and stuff to kind of prepare so I can grab my bag and if the passengers stood up, I could stand up as well"*. For externally managed journeys, participants felt that they could immerse themselves more: *"in the express, it was much easier to focus on the documentary because I didn't have to pay attention to the stuff" (P1)*, whilst, throughout the middle of the journey, the need to maintain awareness increased for some, as highlighted by *P17: "at first I turned off the signage but then I got a bit more nervous halfway through"*.

4.3.5.2 Key Characteristics of Different Journey Types

Study III indicated that different journey types affected Reality Anchor use. This study uncovered what other factors determine a journey type, including 1) whether it is a self-managed or externally managed journey, 2) the likelihood of passenger turnover, 3) seat arrangement, and 4) familiarity with the route. Journey length was not a contributing factor as long as the trip was considered "long enough" for an immersive experience. The following section will discuss seat arrangement and familiarity with the route in more detail.

As part of the discussion, participants were asked to think about VR use on different journeys. The analysis of the answers revealed that the seating configuration could contribute to how comfortable the participants would be using the headset, and which anchors they would choose. Seating that blocked other people ("*in a bus, you can have people sat next to you, so if someone wants to get up it is a lot more difficult*" (P17)), or was opposite to other passengers ("*because on the subway the person is directly opposite you, so he can actually* *stare at you*" (P5)), was linked to more uncomfortable experience where the participant would need to endure an awkward social situation. Contrary to this, spaces that allow for easy get around ("*the space is huge [on a train]. The most important is the passengers next to you don't need my help if they want to access the train*" (P7)), or where people were not expected to move ("*on a plane, once you sit in your seats, you know who is sitting next to you and that's it*" (P6)), were seen as more appropriate for an immersive experience. The seating arrangement also influenced the need for anchors. For example, P17 noted, "*On a plane, I think maybe the passengers' anchor is less necessary; you sit in one seat for a long time*". In contrast, P5 observed, "*On the bus, you're more likely to keep your possessions right next to you. If someone wants to sit there and you have to move your possessions, I'm more likely to use anchors there*".

Participants also reflected on the familiarity of the journey, with the answers showing that despite the journey length, they felt that an unfamiliar journey would not be acceptable for an immersive experience ("*in an unfamiliar journey I will prefer not to use it because everything is unfamiliar. I need to take care, but on a familiar journey I will probably use it.*" (P10)), whilst a familiar route is less unpredictable ("*I would feel more relaxed to use it because I know what to expect every day*" (P3)). Finally, one participant also noted that the perception of the environment would be an important factor as well for the overall choice to use a headset: "*if the place is too noisy, then I will not use it because I feel that is a little bit dangerous*" (P10), suggesting that a sense of safety might override environment expectations based on familiarity.

4.3.6 Summary

The analysis of Study IV revealed distinct differences in how participants prioritised Reality Anchors based on journey type. Self-managed journeys heightened the use of anchors such as signage and passengers, while externally managed journeys required fewer anchors, allowing participants to focus more on immersive content. Belongings were consistently prioritised across both journey types, while furniture anchors were mainly used at the start to familiarise with the environment. As journeys progressed, participants adjusted their anchor preferences based on changing needs, such as wanting an increased awareness near their destination or re-evaluating safety during the trip. Participants also demonstrated a "check-in" behaviour, periodically enabling anchors like passengers to assess their surroundings before returning to their immersive content.

The study also revealed additional factors that shape journey types and influence the use of Reality Anchors, including seating configurations, passenger turnover, and familiarity with the route. Participants highlighted that seating arrangements affecting ease of movement or proximity to others shaped comfort and the perceived need for anchors. For example, seating that allowed for unobstructed movement, such as on a train, was seen as more conducive to immersive experiences, while seating opposite others, as on a subway, heightened social discomfort. Familiarity with the journey also played a critical role; participants found immersive technology less suitable for unfamiliar routes due to increased awareness and safety concerns, whereas familiar journeys were perceived as more predictable and acceptable for immersive headset use.

4.4 Discussion

Study III explored how Reality Anchors could reduce concerns associated with immersive technology use on public transport. It provided an initial exploration of the anchors concept, aiming to understand which anchors would be most useful and why in transit contexts. The subsequent study examined Reality Anchors in the context of two different journey types, seeking to define the characteristics of these journey types and understand how they influence the use of the anchors. Overall, the work presented in this chapter demonstrates that Reality Anchors have the potential to enhance the acceptance of immersive technology in transit settings, although further challenges remain. The key findings and future challenges are discussed below.

4.4.1 Maintaining Awareness on Public Transport

Previous work that looked at immersive technology use in travelling contexts [34, 45, 176, 214, 217], highlighted the importance of maintaining awareness of the surrounding environment to increase immersive technology acceptance. Chapter 3 demonstrated that other passengers, personal belongings, the surrounding environment, and journey progression are key elements to be represented as anchors. The work presented in this chapter further reveals that not all Reality Anchors are regarded as equally important; their prioritisation depends on their ability to enhance the sense of safety, provide added value, minimise distraction and align with the journey type. The most important anchor was found to be other passengers, which reduced awareness, safety, and social concerns. Passengers were seen as the most dangerous element in the travel environment due to their dynamic nature, compared to furniture that remained static and added the least value to maintaining awareness. However, the work also showed that increasing awareness of reality leads to reduced immersion, especially when the anchors block the view of the virtual content. However, Study IV extended this further, showing that not all anchors were used continuously throughout the journey to preserve immersion. Four Anchors were used in Study IV: passengers, personal belongings, signage and furniture. Participants demonstrated that the anchors were either used continuously or to “check-in”. For those anchors that were more distracting, which included people or furniture, participants would periodically turn them on and off to maintain awareness. Furniture anchors, in particular, were often used to familiarise oneself with the space or to reference one's location in the world. In contrast, anchors that were less distracting or required continuous observation, such as signage and belongings, were kept on constantly or for longer durations.

Self-managed and externally managed journeys showed the need for different anchors. The need was determined by the necessity to track the trip, passenger turnover, and getting close to the destination. For self-managed journeys participants found it to be important to maintain continuous awareness of the subway environment and their journey. They relied heavily on the signage anchor, using it continuously, while periodically activating passenger and furniture anchors to maintain awareness of the environment. Conversely, in externally managed journeys, continuous awareness of the environment was less critical, and participants often did not activate the signage anchor until at least halfway through the journey.

Passenger turnover was another key factor defining anchor use. For self-managed journeys, the expectation for turnover was high, therefore the participants used the passenger anchor more consistently throughout the journey compared to an externally managed journey where other passengers were not expected to move or change as much. Finally, as the journey progressed participants re-evaluated the safety of the environment and the need for the anchors. If the environment was deemed to be safe, then some anchors could be removed. In addition, if the journey was coming to an end, the need for the anchors increased for both journey types. Participants used the anchors as a way to prepare to leave the train.

4.4.2 Reality Anchors That Match Journey Needs

The work discussed in this chapter shows that the need and the choice of the anchors were influenced by the type of journey. Previous work tended to classify the journeys by the mode of transport [46, 176, 217] but this thesis argues that these following classifiers define a journey more effectively: self-managed or externally managed journey, likelihood for passenger turnover, seat arrangement, and familiarity with the route. This thesis introduces the idea of self-managed and externally managed journeys as a new way to describe a travelling experience. A self-managed journey is often associated with a short duration, has constant passenger turnover, and requires the passenger to decide when to get off, resulting in increased worries about safety and journey awareness. An externally managed journey is described as one that has a clear endpoint to the trip that a passenger does not need to track, is less likely to have much passenger turnover, can be longer in duration, and is often perceived as boring, making entertainment an acceptable way to pass time.

The likelihood of changing passengers can result in increased worries about safety influencing the use of an immersive headset. Seat arrangement was another way that our participants used to describe different journey types. While exploring the impact of different seating arrangements on immersive experiences is beyond the scope of this work, initial interest in the topic has been noted [173], and warrants further exploration. The work in this chapter showed that being able to avoid uncomfortable social interactions is key to an acceptable experience. Further exploration is needed to understand how Reality Anchors can support users in navigating unavoidable awkward interactions. Finally, the last uncovered descriptor was familiarity with the route. Unfamiliar routes were perceived as more dangerous and unpredictable, making them less acceptable for immersive experiences. Familiar routes, on the other hand, were perceived as more predictable or even boring, making immersive experiences more appealing. The findings indicate that the unpredictability of a journey poses a barrier to the adoption of immersive technology. Reality Anchors, however, have the potential to support users in navigating unfamiliar or unpredictable journeys. Yet, further understanding is required to explore how anchors could be used in real-world unpredictable environments.

4.4.3 The Mismatch Between Virtuality and Reality

While the exploration of the most effective visualisations for Reality Anchors is beyond the scope of this thesis, work in this chapter uncovered notable findings about how the mismatch between virtual and real objects influenced anchor choice. Study III showed that a virtual scene could significantly shape how “natural” the anchors felt within the environment. A 2D-fixed video in a room appeared closer to the bus environment, where people and furniture were more expected. In this case, the people anchor tended to be perceived as more fitting. However, clashes, such as virtual furniture conflicting with bus furniture, were felt more strongly, leading to a reluctance to use these anchors. By contrast, the 360-degree environment depicting underwater scenes, which was more disconnected from the bus and where neither people nor furniture were expected, did not evoke the same level of discomfort, even if the anchors seemed more random.

This aligns with prior work by Slater [179] that discussed the concept of *plausibility illusion*—the feeling that the scenario being depicted is real. This concept helps explain why virtual scenes that felt more “natural” to the anchors enhanced the plausibility of the experience but also amplified frustration when disrupted by elements such as a furniture anchor clashing with virtual furniture. McGill et al.[118] explored how such clashes could be resolved, suggesting that modifying the appearance of real-world elements to better match virtual content could help strengthen the user’s sense of presence in the virtual environment.

Unlike prior research, however, the findings in this work highlight the risks associated with a close blend of real and virtual elements. When virtual scenes closely resembled real-world environments (e.g., an anchor showing people sitting in a 2D virtual cinema room with a couch) or when clashing objects made it difficult to discern which were real and which were virtual (e.g., a furniture anchor shown in a 2D-fixed video of a cinema room where furniture is expected), the distinction between real and virtual objects became harder to maintain. In transit contexts, this uncertainty about which reality one is experiencing could pose safety risks, as it could lead to a loss of awareness, which was found to be essential. Although this lies beyond the scope of this thesis, future research could explore visualisations that achieve a logical fit between anchors and the environment while maintaining sufficient contrast to preserve both immersion and awareness.

4.5 Chapter Conclusions

This chapter presented the results of two studies that investigated the use of Reality Anchors, cues from reality that help anchor a user in immersive applications for in-transit contexts. The findings showed that Reality Anchors could significantly improve user acceptance of immersive technologies on public transport.

Study III captured initial reactions to the concept and demonstrated that the visibility of other passengers and one’s belongings can increase the acceptance of immersive technologies by alleviating safety, awareness, and social concerns. Study IV expanded on the role of journey type by simulating two rides on a subway train: one representing a self-managed journey with multiple stops, and the other an externally managed journey with a clear end and no stops in between. The findings revealed that self-managed journeys require more anchors than externally managed ones and that the need for anchors evolves as the journey progresses.

The results in this chapter address the following research questions:

RQ2: Can Reality Anchors based on people, objects, environments and journey information alleviate concerns explored in RQ1, while maintaining immersion?

The findings suggest that Reality Anchors have the potential to alleviate safety, awareness, and social concerns. People and belongings emerged as the most valuable anchors, while environmental objects, such as furniture, were found to be less critical. However, maintaining immersion was shown to depend on allowing users to control the anchors, enabling them to turn anchors on or off as needed to adapt to changing journey contexts. The work underscores that the constant display of anchors can disrupt immersion, highlighting that flexible, user-controlled anchor deployment is essential to balancing awareness and immersion.

RQ3: How do Reality Anchors need to adapt based on journey type and dynamic user needs during travel?

The studies reveal that journey type significantly influences the prioritisation and use of Reality Anchors. In self-managed journeys, where passengers must track their route and navigate higher passenger turnover, anchors like signage and passengers play a crucial role. Conversely, externally managed journeys, with fewer interruptions and no need to track when to get off, demand fewer anchors, allowing users to focus more on immersive content. Additionally, anchor usage shifts dynamically as journeys progress, with participants relying more heavily on certain anchors near their destination or during moments requiring heightened awareness, such as monitoring passenger changes or reassessing their environment.

The findings underscore the importance of tailoring Reality Anchors to the distinct needs of self-managed and externally managed journeys. Beyond journey type, flexibility is critical; anchors must support dynamic user needs, allowing adjustments as their requirements evolve throughout the journey.

The studies conducted in this chapter provide an initial exploration of the Reality Anchors concept, specifically tailored for in-transit contexts. The findings demonstrate the potential of Reality Anchors to alleviate concerns associated with immersive headset use in transit. However, an open challenge remains in understanding how reality awareness needs are influenced by unpredictable real-world settings, such as passenger interactions or the use of immersive devices in live transit environments. Investigating these issues in real-world contexts will provide additional insights that cannot be replicated in lab settings, forming a crucial foundation for the future development of reality awareness solutions like Reality Anchors.

5 Impact of Reality Anchors in Real-World Public Settings

5.1 Introduction

Chapter 4 was the first step in exploring the Reality Anchors concept and examining how the anchors might need to adapt to different journey types. Conducted in a controlled lab environment, this phase of research allowed for greater control over variables and ensured participant safety. However, moving beyond the lab environment is essential to uncover how awareness needs are influenced by real-world transit settings, such as interactions with other passengers or the unpredictability of live transit conditions. Lab studies, while valuable for informing the design and initial exploration of reality-awareness systems, cannot fully capture the dynamic and evolving nature of real-world environments [27, 164, 165].

Real-world transit settings introduce unique challenges due to the presence of people and the constantly changing internal and external environments. Internally, other passengers create a dynamic social environment where unexpected interactions can occur at any moment. For example, someone may ask a question, sit nearby, or move through the space. These interactions can raise concerns related to safety or social acceptability, particularly when using immersive devices. The environment itself also changes, both internally and externally. A train may suddenly become busy, arrive at a station, or pass through different neighbourhoods. These changes can increase or decrease a passenger's need to track the progress of their trip or remain aware of their surroundings. Therefore, the key factors that make reality-awareness solutions like Reality Anchors necessary, such as personal safety, journey management, and unpredictable social interactions, are difficult to evaluate without accounting for these constantly changing conditions. This chapter builds on previous findings to address the challenges posed by real-world transit contexts, including unexpected interactions with passengers and the dynamic nature of live transit environments.

This chapter explores these challenges of real-world settings through two studies. These studies examine unexpected interactions, the dynamic nature of transit environments, and their implications for the use of Reality Anchors. Study V explores the concept of *asymmetric* co-located experiences, where passengers using different immersive devices in close proximity must navigate unexpected interactions. As discussed in Chapter 2, asymmetric experiences occur when co-located passengers use devices with varying levels of immersion, environmental information, and interactive capabilities. For example, one passenger may be fully immersed in a virtual reality headset, while another interacts with content on a mobile phone. These interactions, while not collaborative, often require sudden shifts between virtuality and reality, such as responding to a question or navigating around other passengers. Study V investigates these social interaction challenges using an enactment method to simulate future asymmetric passenger scenarios in transit settings. This study focused on real, unexpected interactions but was conducted in an indoor setup where the environment remained static.

To address this, Study VI built on the investigation of real-world transit scenarios by examining awareness needs during live train journeys. Conducting the study in-the-wild ensures the results capture genuine user behaviours and challenges, such as strangers boarding or alighting at stops, which are difficult to replicate in controlled environments. This in-the-wild study investigates how passengers remain connected to their surroundings using passthrough-style portals, configurable windows that overlay portions of the real world onto the VR scene, as a simplified version of Reality Anchors. Capturing participants' use of headsets in authentic transit settings provides deeper insights into how reality-awareness systems like portals address awareness needs in everyday transit scenarios.

This chapter addresses the following research question:

RQ4: Can Reality Anchors improve the acceptance of immersive technologies in real-world transit settings?

This chapter examines the critical challenges of real-world transit contexts that affect the acceptance of immersive technologies. Study V explores asymmetric co-located passenger experiences, where passengers using different devices must navigate unexpected interactions. Study VI examines how passengers maintain awareness of their surroundings in real-world transit environments as internal and external conditions change. Together, these studies provide insights into how reality awareness needs are shaped by real-life conditions and how tools like

Reality Anchors can support the acceptance of immersive technologies in transit environments. By investigating both unexpected interactions and the need to remain aware of changing real-world environments, these studies directly address the core research problem and demonstrate how reality-awareness systems perform under unpredictable, real-world conditions.

5.2 Study V: Enacting Unexpected Passenger Interactions in Transit

5.2.1 Study Design

Study V was designed to explore unexpected interactions among passengers immersed in asymmetric experiences during transit, such as navigating around others or engaging in verbal exchanges. To simulate a transit scenario, lab-based enactments were conducted with three co-located passengers using three different devices: a mobile phone user, a VR user with fully occluded vision, and a VR user with occluded vision augmented by cues from reality. For the purpose of the study, the ‘Passthrough’ feature was disabled on both headsets. This setup allowed participants to experience and interact with one another in a simulated environment, mirroring real-world transit conditions and engaging in asymmetric experiences.

While immersive technologies such as VR or AR significantly alter or augment one’s perception of reality, this study included mobile phones as part of the reality/virtuality continuum [131], recognising their ability to engage users in digital content while minimally obstructing their awareness of the surrounding environment. Mobile phone users represented one end of this continuum, where awareness of reality is preserved. In contrast, VR users occupied the opposite end, being fully immersed in virtual content with no visibility of their surroundings. The VR user with cues from reality represented an intermediary point, blending elements of virtuality and reality. Users of different devices across this continuum thus represented a likely near-future scenario in transit settings, where a mix of more immersive and less immersive devices would coexist and shape shared interactions. These augmented cues from reality served as a representation of the Reality Anchors concept introduced in Chapter 4.

Study V employed enactments where participants were tasked to imagine that they were travelling on a train and watching a documentary to pass the time. As discussed in the literature review (Chapter 2), enactments are a powerful technique for exploring and speculating about contexts that do not yet exist [170], such as the asymmetric passenger experiences examined in this study. The enactment approach facilitates the observation of natural human responses to new technologies in a controlled setting, providing valuable insights into societal impacts and behaviours in potential future environments [35]. To create realistic scenarios and simulate unexpected interactions between participants, timed individual prompts were introduced, directing specific actions such as moving seats or asking a question of another traveller. The following sections provide a further detailed breakdown of the study design, including the design of personas, passenger interaction prompts, and the enactment setup.

5.2.1.1 Personas

In each session, three participants adopted traveller personas, each using individual devices to watch a documentary while in transit. Personas were individually and randomly assigned, with participants aware only of their own. Recognising the speculative nature of the study, a defined range of behaviours and device interactions was explored rather than attempting to catalogue every possible personality and device combination. Participants were given specific instructions related to their device usage and task, but not on how to embody the personality traits of their personas, to encourage genuine reactions to prompts.

- 'Mobile Phone User' Persona

The mobile user persona is inspired by a traveller who wants a more active experience during their journey. Their device does not limit their movements or awareness, allowing them to move around freely and engage with other passengers. Prior to the start of the experience, they received the following instruction: "*You are travelling on a train that goes to Edinburgh. To pass the time, you are using your phone to watch a documentary*" at the start of the study. The persona's scripted actions, delivered as real-time prompts (Appendix E: Interview Guide for Study V (Chapter 5)) on their device, included: sitting in front of the VR headset with Reality Anchors user, standing up and doing some stretches, changing seats, sitting next to the VR headset with Reality Anchors user, dropping a set of pens.

- 'VR Headset User' Persona

The VR user persona is inspired by a traveller who may prefer to disengage from the transit environment but may still desire to interact with other passengers during their journey. This persona represents an intriguing tension between engagement and disengagement, as it reflects the idea that in various contexts, people may choose to engage or disengage with other passengers [191]. The VR user persona was given the following instruction: "*You are travelling to Edinburgh by train to see a show at the theatre. To occupy your time, you are taking a VR headset with you and plan to watch a documentary*" at the start of the study. The persona's scripted actions, delivered as real-time prompts (Appendix E: Interview Guide for Study V (Chapter 5)) on their device, included: sitting next to the VR headset with Reality Anchors user, asking a quick question, changing seats, sitting in front of the VR headset with Reality Anchors user.

- 'VR Headset with Reality Anchors User' Persona

This user persona is inspired by a traveller who is an early adopter of immersive technologies. They prefer to stay settled in their seat until they reach their destination, utilising technology to facilitate awareness and interaction as they desire. However, they are likely to engage with other passengers. They were given the following instruction: "*You are travelling on a train to Edinburgh. To pass the time you are using an immersive technology headset to watch a documentary*" at the start of the study. The persona's scripted actions, delivered as real-time prompts (Appendix E: Interview Guide for Study V (Chapter 5)) on their device, included: initiating a quick question and initiating a question that requires more involved conversation.

5.2.1.2 Passenger Interaction Prompts During Enactment

Participants used one of three devices: a commercially available VR headset, a commercially available VR headset with Reality Anchors enabled, or a mobile device, to represent a range of user experiences. The decision to offer three distinct experiences enabled participants to gain unique insights shaped by the specific roles of their assigned personas.

To emulate an authentic in-transit environment and create real unexpected interaction scenarios, individual persona actions were intentionally not disclosed in advance; instead, they were delivered as prompts (for the full list of prompts see Appendix E: Interview Guide for Study V (Chapter 5)) on participants' devices in real-time (Figure 5.3). Each persona was designed to represent divergent ways that people deal with a travel experience. For example, someone may be more active or involved when travelling, changing seats and engaging in conversations with fellow passengers. In contrast, another passenger may prefer a more passive experience, choosing to disengage from the transit environment. While the selected interactions were scripted, they incorporated an element of unpredictability for all personas. For instance, even a VR persona, typically associated with disengagement, was provided with a question to ask another passenger. The scripted actions were active interactions that involved other passengers, as well as passive interactions, performed in a self-contained manner, and included:

- sitting in front of another passenger (entering/leaving another passenger's field of view), *active*;
- sitting next to another passenger (entering/leaving another passenger's intimate zone), *active*;
- initiating a quick question, *active*;
- initiating a question that requires more involved conversation, *active*;
- changing seats, *passive*;
- moving vigorously, *passive*;
- dropping items, *passive*.

Actions involving other passengers were inspired by related literature to explore realistic challenges that may arise in unexpected interactions among passengers using different devices. For instance, entering another person's field of view could lead to complex interactions between users with headsets and those without, occasionally resulting in perceptions of staring [129], generating unique interaction dynamics. Drawing from proxemics theory [63], the decision to seat passengers next to one another replicated the discomfort that can arise when individuals are in close proximity within their intimate zone. However, when a user is immersed in virtual content, traditional physical space norms may not apply, potentially leading to clashes in social affordances when passengers in different states of asymmetric experiences (e.g., using an immersive device or a mobile phone) sit together. Previous research on passenger behaviours on public transport has shown that passengers often engage in non-visual activities, such as listening to music, to disengage from conversations with fellow passengers while maintaining a friendly atmosphere [191]. Nevertheless, it remains unclear how verbal interactions would be perceived when all passengers are engaged in asymmetric experiences, with some encountering visual occlusion, influencing the choice to include verbal interactions. Conversely, passive actions consisted of a set of behaviours that were not reliant on direct engagement with other passengers and were instead observed by them.

5.2.1.3 Enactment Setup

This section will describe the physical lab environment where the enactments were staged, the hardware used by participants, the software for the nature documentary application that delivered timed prompts, and the visualisation choices for Reality Anchors.

- Physical Lab Environment

The study was conducted in a lab environment, where a typical transit seating arrangement was recreated. Recognising that public transport systems offer a variety of seating configurations, from individual to communal arrangements [128], a face-to-face setup was selected for its potential to foster passenger interactions. This setup involved arranging two rows of AirAsia aeroplane seats (as depicted in Figure 5.1 b), a configuration commonly found in trains or subways, where passengers are facing each other and sitting next to each other, often intruding into other passengers' personal space. The seats were positioned 77 centimetres apart, facing one another. Each seat had dimensions of 64 centimetres in length, 148 centimetres in width, and 120 centimetres in height.

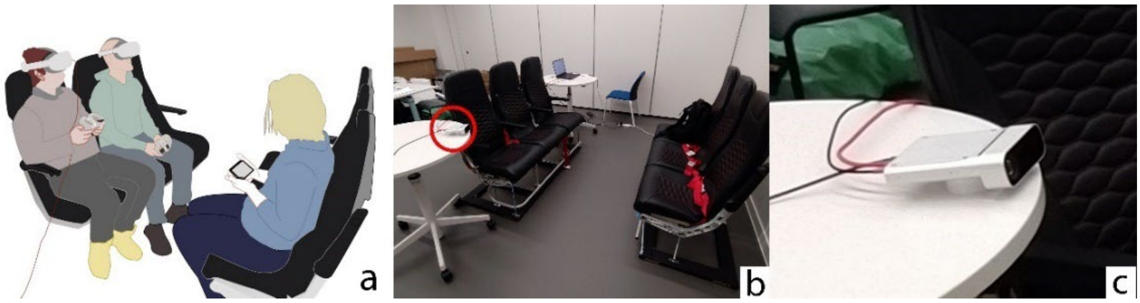


Figure 5.1: a) three co-located users enacting a transit scenario; b) seats used in the scenario; c) A Kinect camera for body tracking.

- Hardware

The devices used for the personas included a Google Pixel 7 mobile phone and two Meta Quest 2 VR headsets. To enable the VR headset with Reality Anchors, an Azure Kinect camera was paired with the Quest 2 to provide real-time tracking of other participants. These participants were represented as Reality Anchors, displayed in the form of stick skeletons depicting their upper bodies. For the Anchor that represented the seating furniture, 3D scans of the seats (Figure 5.2) were used. While the immersive tracking setup was deliberately visible, it was not explicitly disclosed. Participants were intentionally kept unaware of each other's setups and available information, creating real interactions among them. For VR headset users, the documentary audio was played through the headset speakers, while for mobile users, it was played through the phone speakers.

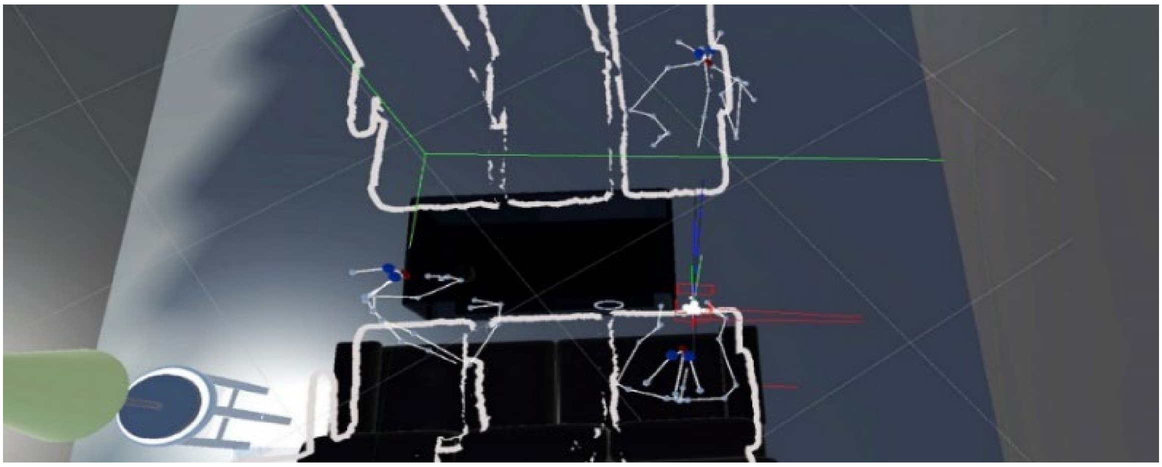


Figure 5.2: 'Train seats' and three co-located 'Passengers' as Reality Anchors.

- Software

All three personas watched the same nature documentary content on their respective devices to prevent the introduction of confounding variables. To simulate unexpected interactions, participants' applications were designed with a timed prompt that would appear as a pop-up on their device (Figure 5.3), directing them to perform a specific action. The documentary was paused automatically when the pop-up appeared to ensure participants could focus on the prompt. All device content was created and delivered using Unity. For the users wearing VR headsets, the documentary was shown within a virtual cinema setup (Figure 5.4), while mobile users viewed the same content through a custom-made video player application. One VR headset was augmented with passenger and seat anchors to support in-transit interactions.

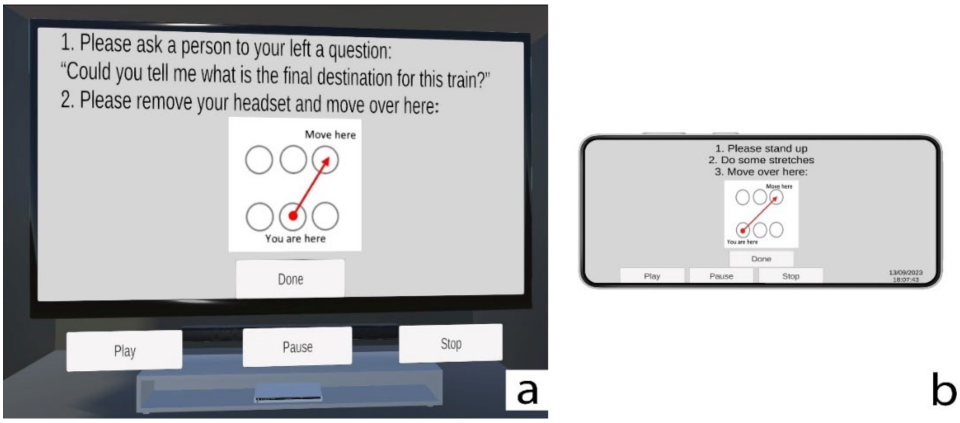


Figure 5.3: a) sample instruction prompt on 'VR' and 'VR with Reality Anchors' personas' devices; b) sample instruction prompt on 'Mobile Phone' persona's device.

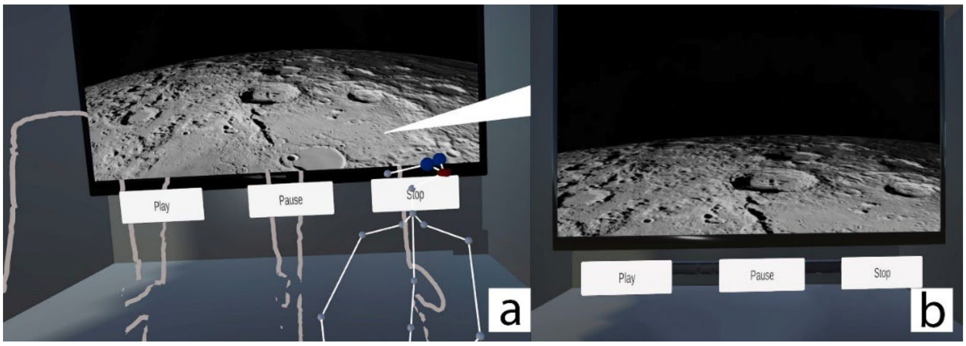


Figure 5.4: Virtual cinema experience as seen by a) VR user with 'Reality Anchors' enabled, b) VR user's perspective.

- Reality Anchors

Chapter 4 introduced the concept of Reality Anchors, cues from reality designed to enhance the use of immersive headsets in transit settings. The initial exploration emphasised the importance of passenger anchors (Reality Anchors visualising other passengers) for immersive headsets in transit. While furniture anchors (visualising seats, walls, handles, etc.) were found to be potentially distracting, the chapter also highlighted their necessity for grounding the passenger in the scene. Without these anchors, references to real objects could become distorted, which is considered unacceptable in a transit scenario. Therefore, both passenger and furniture anchors were maintained in this study. However, the belongings anchor was not included to allow for movement and interactions.

Findings from Chapter 4 demonstrated that fully detailed representations of anchors could increase distraction. To address this, the depth of the furniture anchors was adjusted in this study to ensure they did not obstruct the cinema screen. A minimal viable visual representation was selected for the Reality Anchors, consisting of outlines and skeletons of the other two passengers (Figure 5.5). This approach was chosen to maximise immersion in the documentary and avoid confounding factors associated with realistic avatars, particularly concerns around anonymity [137] and distraction, an effect observed in Chapter 4. As also noted in Chapter 4, photorealistic representations are not necessary to convey presence.

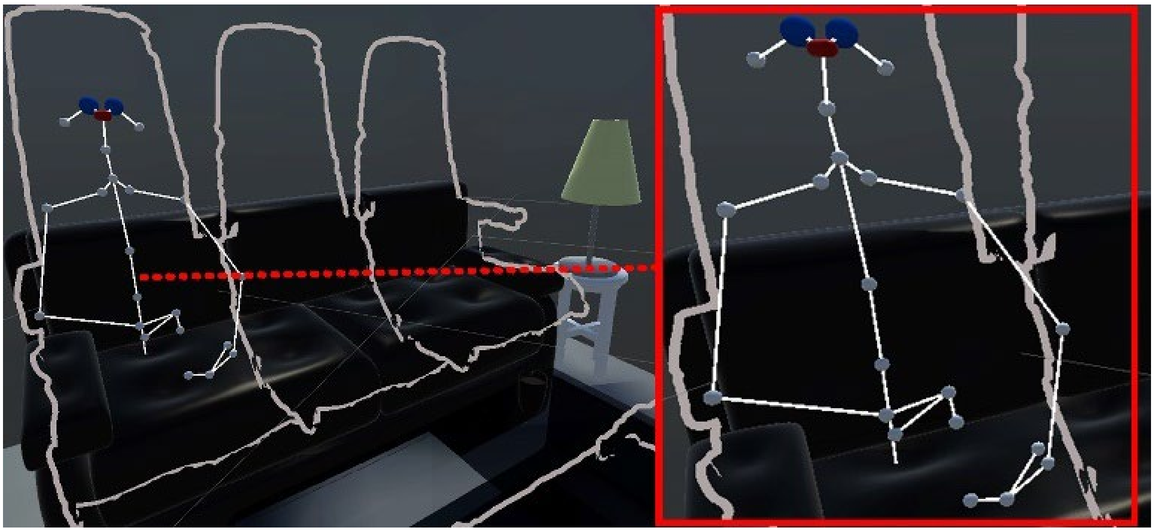


Figure 5.5: Example of an upper body skeleton used to represent other passengers' anchors.

To further reduce visual complexity, only the upper body of the skeletons was displayed, rather than the full body. Previous studies have demonstrated the effectiveness of this approach in social situations where the focus is on the upper body or when space is limited [225]. This choice suited a travel scenario where passengers often remained seated, and minimising distractions from the video screen was essential. Skeleton joints and head angles were updated in real-time, accurately portraying the movements of other passengers' bodies, but only for the immersive headset with the Reality Anchors persona. Minimal visualisations were intentionally designed to stand out from the rest of the scene, ensuring a clear distinction between virtual objects and Reality Anchors, in alignment with one of the guiding principles for their design.

5.2.2 Procedure

Before the study started, each participant was given an information sheet and a consent form to read through and sign. They were then assigned a persona (as described in Section 5.2.1.1) at random. The VR user and the VR user with Reality Anchors were given a tutorial lasting roughly five minutes that showed how to use the application on the headset and the controllers.

To prepare participants for the enactment experience, the study started with an ice-breaker from improvisational theatre [267]. All three participants were asked to imagine that they were standing next to a park bench, which was represented by the row of seats used in the study. In the ice-breaker, one participant needs to sit on the “bench” and pretend to be engaged in an activity, such as reading the newspaper, watching the birds, etc., but they must always remain seated. Another participant joins the ice-breaker and pretends to be a pedestrian. Their job is to copy the activity of the “bench” occupant and get them to laugh or leave the seat in under one minute. No physical contact is allowed. If the “bench” occupant laughs or leaves their seat the “pedestrian” takes their place. The game was repeated until all participants played the “bench occupant” and the “pedestrian” roles, taking around five minutes. The ice-breaker played a crucial role in helping participants become comfortable with assuming roles, ensuring they could fully engage in the enactment experience.

Following the ice-breaker, the study would begin. The immersive headset user started the study on the seats to calibrate the depth cameras used in this study (refer to 5.2.1.3) based on their position, followed by the mobile and VR users entering the scene and taking their places on the seats (Figure 5.6). All participants started their applications simultaneously to formally begin the enactment. This started the documentary playback and the beginning of their travelling experience. The enactment ran for ten minutes, during which the application instructed the participants to initiate unexpected interactions. Ten minutes within VR allows for a rich experience, in line with previous research in HCI employing HMDs [34, 118, 126], while minimising fatigue and VR-induced sickness. After the enactment, the mobile and VR headset users were given a preview of the Reality Anchors experience as part of the debrief. At this point, all participants were debriefed on each other’s personas and devices used.

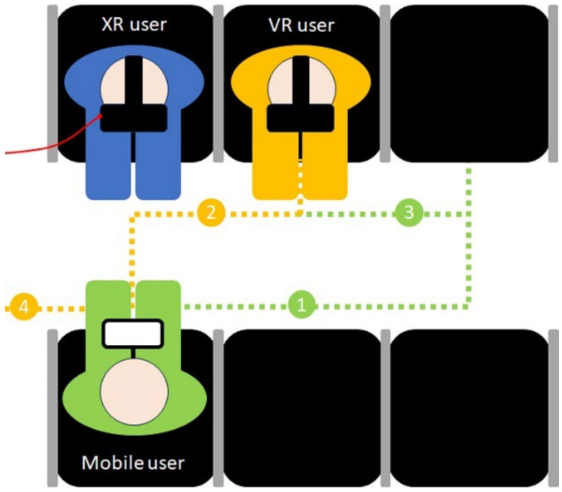


Figure 5.6: Start seating positions and movements of the three co-located personas (XR user refers to the VR user with Reality Anchors enabled).

5.2.3 Data Collection

After participants were debriefed, a focus group interview was conducted to discuss their experiences. First, the interview explored participants' perceptions of the interactions they experienced and initiated during the enactment. The interview then addressed the social acceptability of their actions and those of other passengers. Furthermore, the interview reviewed the use of immersive technology in various transit settings and gathered reflections on Reality Anchors. For the complete interview guide, please see Appendix E: Chapter 5, Study V. During the interview, participants were probed with follow-up questions (e.g., "*why do you think that*", and "*can you tell me more about X*") when necessary (e.g., to further investigate the comments made, clarify ideas, or if one or several participants were especially quiet). Interviews took approximately 30 minutes and were audio recorded, anonymised and later transcribed for analysis.

5.2.4 Participants

In total 21 participants (8 females, 13 males, mean age = 32 years, SD = 9), split into 7 groups of 3, took part. These groups included both strangers and participants who were friends or knew each other. The majority were students, 16 had used a VR headset at least once, and 5 had never used one before. The mix of experience levels reflects a diverse range of device familiarity that users might encounter in a transit setting. The study took approximately 60 minutes and participants were compensated for their time with £10 Amazon vouchers. The study was approved by the university ethics committee.

5.2.5 Qualitative Results

Once transcribed, participant statements from interview transcripts were manually coded using open-coding [26], adhering to an inductive approach. Open codes were used to annotate the interview transcripts with short phrases identifying concepts in the data. Each statement was assigned an emergent code, which was iterated over several cycles and used to re-code the transcripts until no new codes were needed. Subsequently, a thematic analysis [18] approach was adopted by examining the initial codes and searching for candidate themes and sub-themes. Themes that could not be fully supported by participants' quotes were excluded. A single researcher performed the coding with discussion and iteration of the codes with another researcher. For the purpose of detailing the results, each participant was assigned a code composed of a group number (1-7), participant number (1-21), and the device used (M: mobile phone, VR: virtual reality headset, XR: virtual reality with Reality Anchors enabled headset).

5.2.5.1 Passive Versus Active Participation in Passenger Interactions

During the interview, participants discussed different actions they were asked to perform and other interactions they would imagine engaging in whilst travelling. Interactions that do not require the active initiation by, or involvement of, headset wearers were seen as mostly acceptable. This included verbal interactions between other passengers ("*when you hear some kind of mumbling or like people are whispering around you, so you get the notion this person doesn't seem like they're actually interacting with me*" (G1, P1, VR)), 'quick queries' ("*if somebody asks me the time, I would be fine with them not taking their headset off […]it's too much work just to take off the headset, just to ask for the time*" (G4, P12, M)), or verbal interactions initiated by other passengers ("*if I am using the headset and somebody asks me a question, it doesn't really bother me to give the answer*" (G4, P10, VR)). Passive non-verbal interactions were also seen as acceptable, including moving around and sitting next to/ in front of headset wearers, and were perceived as "normal" and "to be expected" in public transport.

However, interactions that were worrisome or required active participation were perceived as less acceptable when VR or immersive headset users were involved. Most problematic activities were back-and-forth conversations, with one participant noting: "*maybe it was okay to ask for the time it's a quick question, quick answer […] but to start a conversation? […] it felt strange*" (G6, P17, XR). For non-verbal interactions, concerns arise when interactions might require a reaction and include disturbances or risk to safety, as noted by G3, P8, XR: "*like the pen dropping or whatever. It's the kind of thing that I probably would have wanted to see what was going on, to make sure everything was okay, if somebody needed help*". Such interactions were most uncomfortable for VR users ("*I just heard some sounds, but then I was I wasn't sure what it was. So, I was just sitting there confused. Like, what? Did something break?*" (G3, P7, VR)), whilst immersive headset wearers were reassured by the ability to monitor the environment ("*because I could see people around me, I was pretty aware that things around me seem to be progressing relatively normally*" (G3, P8, XR)).

Overall, participants' answers showed that verbal interactions require more involvement and create more complex dynamics between passengers engaged in asymmetric experiences, which are further discussed in 5.2.5.2 and 5.2.5.3.

5.2.5.2 Assessing Receptivity and Initiating a Verbal Interaction

Prior to initiating a verbal interaction, participants expressed the need to assess if their fellow passengers would be receptive. One participant noted that knowing that "*this is the right person to ask*" and "*look friendly*" (G1, P2, XR) are key indicators. Most participants felt that fundamental social norms for assessing the other passenger and initiating contact were challenging when the action was initiated by the immersive and VR headset users. Participants relied on non-verbal cues, such as facial expressions ("*we do not really know the facial expressions…I cannot really capture the whole thing that reflects the person next to me*" (G4, P10, VR)) to make the decision. Eye contact was a key missing cue that most participants felt they would resolve by removing their headset, as highlighted by G5, P13, VR: "*I think I wouldn't ask a question with the headset on I would move it up, have an eye contact first and then have the interaction*". Participants felt that not doing this would come across as rude ("*In a real-life situation, I'd find that a bit rude. Like if someone talks to you and like, isn't looking at you*" (G3, P9, M)), or selfish ("*seems like I was ignoring the person around me and then when I need something I just approach the person*" (G4, P10, VR)).

They emphasised the importance of alternative protocols to grab attention, especially if direct eye contact is not possible. For instance, gestures such as waving ("*let's say I'm watching and the skeleton was doing like that, like waving, I would stop and remove the headset and then interact*" (G5, P13, VR)), or verbally announcing the intention to talk ("*when [...] they just ask me it's impolite. You can say, sorry, excuse me*" (G1, P3, M)) were suggested. However, as in Section 5.2.5.1, removing the headset was not seen by some as a necessity when replying to another passenger, as noted by G1, P1, VR): "*if I'm wearing the headset, someone asks me a question, I'm not going to take off the headset. I'm focusing*". The rules for verbal interactions would also be less strictly followed when the other party was familiar, such as "*friends*" (G4, P11, XR) or "*family*" (G1, P3, M).

5.2.5.3 Responding to Verbal Interactions in Transit

Participants found that responding to interactions involving headset wearers was confusing. It was unclear if the interaction was taking place in the virtual or the real environment ("*did he really talk to me or talked to someone on his VR device?*" (G2, P6, M)), or who was the intended respondent to the verbal interaction ("*he's in VR world and I wasn't sure if he was addressing me or not*" (G5, P15, M)), especially when there were multiple people in close proximity ("*if there were three people or two people around them, I wouldn't know who [sic] they were asking it to*" (G3, P8, XR)). Confusion was also experienced by the headset wearers trying to determine if they were the intended recipient of interaction from other passengers, as questioned by G1, P2, XR: "*maybe I would just take it off to make sure that they're asking me […] how would I know that actually they're asking me or they're asking someone else*? No participants indicated their intentions verbally or through touch, yet a few attempted to communicate with body language. One participant shared "*when I asked a question, I tried to signal that I was asking him by leaning in... And he just completely blanked me.*" (G3, P8, XR). As noticing eye contact or reading body language was not possible, some expected non-visual cues to indicate they are the intended respondents for the interaction ("*If it was for me, then someone would tap me or, I don't know, like, nudge my leg*" (G7, P19, VR)), but this was not acceptable for all ("*if you want to catch the attention of a person or a passenger with your headset, poking them, I don't think it's a good option*" (G5, P13, VR)).

5.2.5.4 Disembodiment and Disconnection from the Transit Environment

During the focus groups, those who used VR headsets consistently reported a distinct sense of disembodiment and disconnection from the real environment, as explained by G3, P7, VR: "*I was just fully immersed in it […] it felt like I was in a totally different world*". Participants mentioned a noticeable lack of presence from other passengers, leading some to forget where they were and making it challenging to shift focus from virtual content to engaging fellow passengers, as G7, P19, VR described: "*I had to go out of my virtual reality into this real world, see where everything was, and then ask, and then do what I need to do, and then get back*". This became more difficult during asymmetric experiences ("*If one of us is not using the technology, but both of them are using the technology, maybe* *it's not really acceptable*" (G6, P17, XR)), and even more so for interactions between a user in the virtual environment another in the real world ("*to do an icebreaker or spark a conversation in VR with a non-VR user, that feels like it's a hard barrier*" (G7, P21, M)). Interestingly, for some VR users, disengagement from the real environment helped them feel less awkward about the situation, as noted by G2, P4, VR: "*if you're wearing the headset, you can't really see people's expressions or faces. Can't really see what they're thinking of you anyway. So, I guess it matters less*". In contrast, some participants using immersive headsets reported maintaining a connection to the external environment, allowing them greater awareness of their surroundings ("*when I immerse in my own world, I could see what happened in my surroundings. So […] it feels like [I Am] still connected with the world*" (G4, P11, XR)), with one participant noting a sense of social presence: "*I definitely felt inside a virtual social space*" (G3, P8, XR). However, fellow passengers felt a sense of disconnect ("*it's like a bit strange seeing people with the headsets on because they're here in front of me, but they're somewhere else completely*" (G4, P12, M)), with some feeling that headset wearers are "untouchable" ("*it is […] making them untouchable because if I want to talk to them, say something, or make the conversation, it's quite impossible because they are with their device*" (G2, P6, M)).

5.2.5.5 Breach of Trust by Immersive Tracking and Altered Behaviours

The sense of disconnect also influenced the behaviour of other passengers in the transit scenario. At the start of the study, participants remained unaware that one of the headset wearers had an enhanced view of reality. This led to behaviours that emphasised this sense of detachment. As noted by G2, P6, M: "*I thought at first that they can't see me, so maybe I can just do something and they are not going to notice. Like, maybe I would do something weird in their face, and then they will not…[know]*" and G4, P12, M: "*with the stretching I was like fine because I just assumed they did not know I was in front of them, so I thought it was fine to do*". Others sought a sense of anonymity, with one individual sharing: "*I thought I was a bit incognito*" (G4, P12, M). This exhibited this desire for discretion by keeping a distance ("*I did feel weird about going to sit next to someone where I knew they can't see me and probably would be surprised by my presence*" (G3, P9, M)) with participants keen to avoid engaging unless necessary: ("*it would have to be an absolute emergency to actually interrupt someone from this to ask a* *question*" (G6, P17, XR)). However, passenger behaviours were perceived differently upon learning about immersive tracking. Most felt uncomfortable not having known they were being tracked, as shared by G3, P9, M: "*when I realised, he could see me the entire time, it felt almost like a betrayal. If I see someone wearing a sleeping mask, I don't assume that they know what I'm doing*". This also altered the perceived actions passengers could take near headset wearers, limiting their movements ("*I wouldn't move around because I don't want to disturb people*" (G7, P19, VR)), or avoiding sitting directly in front of other passengers ("*I would probably move so they're not right in front of the screen*" (G7, P19, VR)). Immersive headset users also reacted negatively to discovering that other users were not aware they were being observed, a reaction shared by G3, P8, XR: "*now that I know that everyone else didn't have the same view, I felt like I was quite rude*". Most participants expressed concerns about their privacy and being recorded ("*maybe the headset can record what he is seeing around him...So what if he's recording what's around him? So that includes me. So that's a cause of concern*" (G1, P1, VR)), with a desire to be warned about real-time tracking ("*there wasn't anything, no context, cue or clue to show me that MR user is seeing the things around him. I think it might be a good thing with such devices if they have an indicator saying he can see, he's seeing things around him*" (G1, P1, VR)).

5.2.5.6 Reality Anchors for Supporting Passive Awareness

The investigation also explored how Reality Anchors can support unexpected interactions with immersive technology users and effectively alleviate physical safety concerns by reassuring users about passenger body movements. Further anchor detail is still needed to support passenger interactions that require a reaction or active participation, e.g. a conversation. Immersive headset users appreciated the increased level of awareness anchors provided and felt that it allowed them to focus on the task with more ease, G2, P6, M noted: "*you can still focus on what you're doing. But then you are aware there's someone else besides you, or behind you or in front of you*". Anchors allowed them to monitor their environment for safety concerns ("*but nothing was really concerning because I could infer from seeing people that nothing was wrong, particularly*" (G3, P8, XR)), described as a "*presence indicator*" (G3, P8, XR) that requires little cognitive effort to monitor the environment ("*I was very aware of any pretty much as soon as anything happened around me. I was instantly aware, although I didn't have to* *focus on it*" (G3, P8, XR)). This also made the experience feel less isolating, as G3, P8, XR highlighted: "*I felt mostly more normal than I would be in most VR setups, where you're completely in a different situation when you're really boxed in*". However, the anchors could also be distracting ("*the little skeleton guys to be, like, kind of distracting, not super distracting. I could still like, tune in and watch the video, but I was definitely drawn to it whenever there was action happening around me*" (G3, P8, XR)), but some felt this was an acceptable compromise for increased awareness ("*at some points, I feel like it's distracting because the person in front of me was moving his head, his hand... but at the same time it is comfortable seeing that rather than not knowing what the people are doing*" (G1, P2, XR)). The feelings were also shared by some observers, who, upon debriefing, felt that the anchors were useful for physical safety. G2, P4, VR shared: "*I would have actually preferred that as well. Because it makes it more personal, where you are more aware of your surroundings*".

5.2.5.7 Missing Social Cues for Comprehensive Passenger Interactions

Finally, the visual representation of the other passengers received mixed opinions. Some participants felt that the minimal visual representation was appropriate, as discussed by G3, P8, XR: "*it made asking them ambiguous and awkward, but it also meant that I didn't really feel like I was, like, spying*". However, others felt the lack of detail fostered ambiguity and impeded engagement with others, which was noted by G3, P9, M: "*I kind of know what they are doing but also, I don't really know what we're doing and can't really judge these people*". Linking to the earlier findings, participants wanted to know more about the receptivity of the other passengers, including if they were wearing a headset themselves ("*I can't tell if the skeleton is wearing a VR headset, or is not which is quite an important distinction*" (G3, P8, XR)), as well as the state they were in: ("*knowing people were there was good information, but it was kind of ambiguous as to how they were, what state they were in, and if they will, would be receptive*" (G3, P8, XR)), and desired an option for eye contact. G6, P16, VR shared: "*you need something else, like, some sort of way that people in the front that could tell you, like, where your visual attention is, so you can tell if you're being talked to*". Even though skeletons had eyes, assessing the necessary gaze direction in VR was still complicated ("*The skeleton does not give enough information on whether* *they are looking at me or not… or maybe there were some eyes?*" (G1, P2, XR)), without further indication that an interaction is being initiated.

5.2.6 Summary

Study V explored asymmetric co-located passenger experiences to examine how passengers using different devices navigate unexpected interactions and how these interactions impact Reality Anchors and the acceptance of immersive technologies. The findings from the study revealed that the acceptability of immersive headsets in transit settings depends on how well they accommodate unexpected interactions, which vary by level of engagement (passive, active, or reactive) and nature (verbal or non-verbal). Non-verbal interactions that required only passive presence from headset wearers were perceived as the most comfortable, whereas verbal interactions often disrupted established social norms and communication practices due to the absence of non-verbal social cues such as facial expressions, gestures, and eye contact. This challenge was particularly evident during interactions between passengers at opposite ends of the reality spectrum, such as VR and smartphone users. Immersed headset users were seen as unapproachable, creating barriers to interaction and contributing to discomfort for both headset wearers and bystanders. These findings highlight the importance of designing immersive technologies that accommodate varying levels of passenger engagement, support social cues, and foster connectivity to improve user comfort and social acceptability.

The study also revealed how asymmetric user experiences influence behaviours and social dynamics during transit. Participants exhibited behaviours such as avoiding headset users or adjusting seating to reduce distractions and hesitated to engage in interactions with headset users. Additionally, upon learning that headset users with Reality Anchors could track their movements, bystanders expressed discomfort about the lack of notifications or warnings regarding tracking activities, further exacerbating skewed power dynamics. While Reality Anchors provided users with reassurance about passenger body movements, helping to alleviate physical safety concerns, their current level of detail (e.g., absence of facial expressions or eye contact) limited their ability to fully support effective social interactions.

Study V provided critical insights into how real unexpected interactions between passengers using different devices impact reality awareness needs. Conducting the study in a controlled environment was necessary to evaluate these interactions without the distractions of a changing setting. Building on this, Study VI shifts focus to explore how a real changing transit setting influences awareness needs and their impact on reality awareness systems, addressing the broader research question.

5.3 Study VI: Using Immersive Technologies In-the-wild

5.3.1 Study Design

Study VI was designed to explore the use of immersive headsets in transit, focusing on collecting participants' firsthand accounts of their experiences. Building on the findings of Study V, which highlighted the impact of social dynamics on reality awareness systems, Study VI shifts focus to examine how a real, changing transit setting influences the use and acceptance of immersive technologies. The study aimed to identify the unique challenges and user behaviours that emerge from immersive experiences outside controlled environments. Additionally, it explored how headsets that incorporate views of the real world could influence the acceptance of immersive technology in transit and enhance these experiences. In the study, participants used a VR headset to watch documentary video content during two 15-minute journeys on an inner-city local train. The virtual environment provided access to passthrough-style portals (Figure 5.7), designed as a simplified version of Reality Anchors, intended to help users stay connected to their immediate train environment while immersed in virtual content. Insights from participants' real-world experiences are crucial for refining reality-awareness systems to better suit public transit spaces, thus opening the opportunity for their wider adoption. This study is one of the first to explore VR headset adoption on real train journeys, offering authentic insights beyond controlled research.

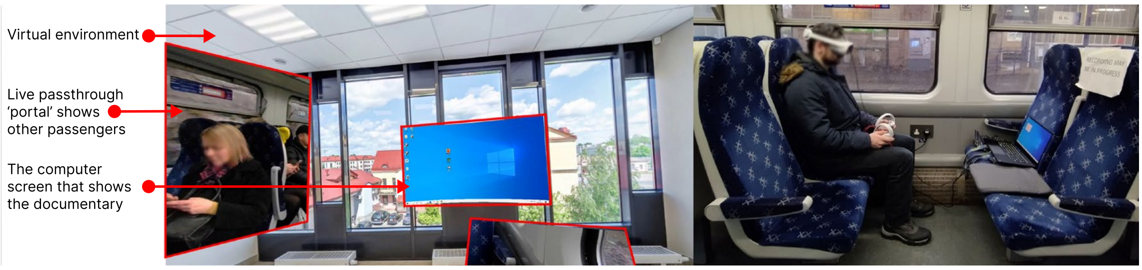


Figure 5.7: Left, virtual environment with 'portals' to reality; right, a participant uses a VR headset on a train.

The study was conducted on local trains, during the non-peak hours of train operations to ensure seating availability for both the researcher and participants. This generally involved taking trains after 10 AM and before 3 PM. Several train routes were tested to find one that caused minimal drift during the experience. Routes with significant drift caused by sharp turns, high speeds, or closely spaced stops were excluded. The final chosen route had a total of six stops, excluding the destination stop.

While the number of passengers was not recorded, there were no instances of completely empty train rides during the study. The setup utilised any available seats on the train, ensuring the researcher and the participant sat together, facing forward to minimise motion sickness, with the participant by the window for their physical safety. On the outbound journey, participants chose their seats, while on the return, the researcher selected seats that were two next to each other, opposite a row of two other seats. During both journeys, participants were shown a nature documentary, that included two staged advertisements (see 5.3.1.1), through the 'Immersed app' [268], which enables a VR headset to connect to a computer and display its contents on multiple resizable virtual screens. The study employed a single front-facing screen for the video. The app's passthrough feature was used as 'portals into the train environment', allowing participants to easily explore where, and what, they would choose to attend to in reality by creating and altering the portal size and position. On the outbound journey, participants could self-select and activate up to five portals using the in-app menu and handheld controllers, while on the return journey, the researcher pre-set three portals (more details in 5.3.1.2). Two documentary clips were shown, one per leg of the journey, each lasting around 10 minutes. The documentary was set against a distinct 360-degree virtual backdrop—one depicting a realistic office space, and the other an imaginative moonscape (Figure 5.8). Both static environments occluded the train without adding additional distractions like animations or moving virtual elements. The documentary and the virtual environment together made up each experience and were presented in a counterbalanced order.

Figure 5.8: Comparison of 360-degree images featured in the Immersed app's virtual environment. The left image presents a moon surface setting, offering an otherworldly experience, while the right image depicts a realistic office space, creating a more familiar and professional atmosphere.

5.3.1.1 Advertisement Design

During the 10-minute documentary, participants were shown two short, staged advertisements, one during each leg of the journey. Each advertisement lasted approximately between 30 seconds and a minute.

The purpose of the advertisements was to expose participants to speculative near-future travel scenarios that demonstrated the concepts of asymmetric co-located passenger experiences and reality-aware headsets. Although the 'in-the-wild' methodology itself is not inherently speculative, the use of advertisements in this way aligns with the speculative narrative developed throughout this thesis. By presenting scenarios that closely resembled their ongoing experiences, the advertisements strengthened the study's context. To ensure participants authentically engaged with the speculative scenario, they were not explicitly informed that the advertisements were staged.

The first advertisement promoted public transport as a better alternative to car travel during the winter months. It depicted a happy group of people using multiple devices, including a phone, an AR headset, and a VR headset, establishing a link to Study V by showcasing asymmetric experiences among passengers. The advertisement featured the following text: "*Are you tired of endless traffic jams, especially during the winter months? Say goodbye to the stress of commuting.*

This winter, make the smart choice—opt for public transport. Discover a faster, more reliable, and productive way to get around. Make the switch today!"

Figure 5.9: A screenshot from the advertisement depicting three individuals using different devices: a phone, an AR headset, and a VR headset.

The second advertisement promoted a commercial VR headset featuring Reality Anchors technology, designed to enhance safety during transit. The advertisement introduced a solution comparable to what participants experienced during the train journey, showcasing the potential of reality awareness. The advertisement text read: "*Tired of the daily grind? Commuting doesn't have to be a chore. Introducing the Reality Anchors VR headset – your passport to a whole new world on your daily journey! Immerse yourself in a world of entertainment, productivity, and relaxation, right from the comfort of your commute. And we get it, safety is a top priority. That's why we've developed the Reality Anchors technology. Choose which elements from the real world you want in view, such as other passengers, ensuring you stay aware of your surroundings. Stay connected with your environment while enjoying your personal virtual oasis. Try Reality Anchors VR headset today*!"

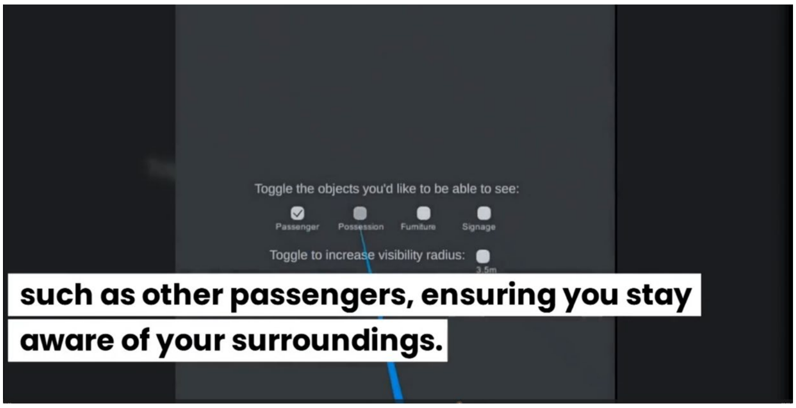


Figure 5.10: A screenshot from the advertisement showing a headset user selecting different elements from reality to display as anchors.

5.3.1.2 Portal Design

The study utilised 'passthrough' windows that displayed a real-time feed of the surrounding environment embedded within the virtual space, a feature adopted to maintain awareness without exiting the virtual content. Passthrough portals were chosen because they offer a simplified version of Reality Anchors, that needed to work effectively in a real-world environment and remain stable to maintain a seamless user experience.

On the outbound journey, participants had the freedom to create and place portals within the virtual environment (for example, see Figure 5.12), with the only requirement being that at least one portal had to be activated. The study was designed to first capture participants' uninfluenced choices by allowing them to create their own portals, ensuring that the use of pre-set portals later would not influence their initial decisions. Participants used the ‘Immersed’ app to enable and configure these portals. They brought up a menu, selected the number of portals, and the app created square portals showing the passthrough camera feed at that spatial location. Participants could create and manage up to five portals, which they could move and resize (square, rectangle, or sphere) using a controller, and close by clicking a cross icon. Portals could also be positioned next to each other, allowing participants to connect them into custom-shaped configurations.

On the return journey, however, portals were pre-positioned to specifically highlight personal belongings in front, a passenger to the side, and the view through the window (Figure 5.11). The researcher reset the 'Immersed' app during the break between train rides to draw these three portals, with the latter two positioned peripherally. These objects were chosen based on previous studies discussed in Chapter 4, indicating that personal belongings, nearby passengers, and travel information (conveyed via the window view) are key concerns of immersive technology adoption in transit. This design aimed to investigate the impact of participant-controlled versus pre-defined portal placements on the immersive experience and interaction with the virtual content.

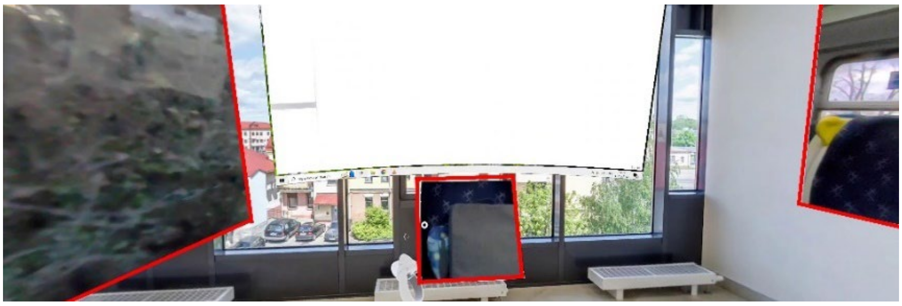


Figure 5.11: Pre-set portals displaying the portal drawn around the train window to the left (showing shrubbery outside), the passenger's bag in front, and a view of the aisle to the right, aimed at the passenger next to the participant (not visible in the image).

5.3.2 Participants

In total, 14 participants (7 females, 7 males, mean age = 26 years, SD = 7) were recruited for the study. The majority were students, 11 had used a VR headset at least once, and 3 had never used one before. Participants were compensated for their time with £25 Amazon vouchers. The study was approved by the university ethics committee, and permission was obtained from the railway carrier to conduct the research on local trains.

5.3.3 Procedure

The study procedure was carried out in two main parts: the experiential phase, which included the training and journey, lasting approximately 1.5 hours, followed by a concluding interview session, lasting about 30 minutes. The process unfolded through several stages, as detailed below.

Initially, participants underwent a briefing and training session, where they were introduced to the study's objectives and provided with an information sheet and consent form. This 25-minute period included a detailed demonstration of how to use the Pico 4 VR headset and interact with the ‘Immersed’ application.

Following the training, participants and the researcher travelled to the train station, marking the beginning of the journey. The same train route was used for all sessions of the study. Before boarding the train, participants were instructed to choose their seats, ensuring they were forward-facing and that there were two seats next to each other. The train ride lasted around 15 minutes each way, with 10 minutes dedicated to using the VR headset. The first few minutes of the journey were used to set up the headset and the laptop, which was connected to the VR headset via a cable for a more stable connection.

During each ride, participants viewed the VR documentary video content. They were instructed to watch the documentary and interact with the portals; on the outbound journey, these portals were self-drawn, while on the return journey, they were pre-determined. To ensure safety and comfort, participants were asked to wear the VR headset only while seated. Throughout the journey, the researcher handled interactions with the ticket inspector and managed any unforeseen events.

At the station, a break between trains allowed participants to reflect on their experiences and share initial impressions with the researcher. The journey concluded with a return train ride, after which participants were invited to a 30-minute interview which, to minimise fatigue, could be arranged within 24 hours of the experimental phase. This session aimed to capture their detailed feedback, perceptions of immersive devices in transit settings, and their experiences and interactions with the VR headset and portals.

5.3.4 Data Collection

The primary data collected in this study consisted of semi-structured interviews (see Appendix F: Interview Guide for Study VI (Chapter 5) for a full list of questions) that explored participants' reactions to using an immersive headset during a real train journey. During the interviews, participants were encouraged to elaborate on their responses with follow-up questions, such as “*Why do you think that?*” and “*Can you tell me more about X?*” when necessary. The interview portion of the study took approximately 30 minutes. All interviews were audio recorded, ensuring the anonymity of participants, and later transcribed for analysis. Participants' in-headset views were video recorded (with permissions) to capture their interactions within the virtual environment. While the primary data were derived from the semi-structured interviews, video stills from these recordings are used to illustrate some of the arrangements and configurations made by participants.

5.3.5 Qualitative Results

Once transcribed, participant statements from interview transcripts were coded using an open coding process [26]. The transcripts were annotated with brief phrases that identified key concepts in the data, and these open codes were iterated over multiple cycles, re-coding the transcripts until no new codes emerged. Subsequently, the codes were organised into meaningful groups using a thematic approach [18], following the approach used in Chapter 4. Initial coding was performed independently, with the codes reviewed and refined after the first and final iterations in collaboration with another researcher.

The most interesting results are as follows: portals reduced safety, awareness and social concerns (see Section 5.3.5.1) but led to difficulty in simultaneously navigating real and virtual realities (see Section 5.3.5.2). Participants wanted to passively monitor their surroundings rather than actively check the portals (see Section 5.3.5.3). They were surprised by 'information wormholes' that allowed real-world changes to slip through unnoticed, raising trust concerns (see Section 5.3.5.5).

Whilst the chapter uses the terms ‘immersive technology’, ‘devices’ and ‘headsets’ when describing overall goals and findings, the results section keeps the use of ‘VR’ for consistency with the original study context, using it where it was originally applied in participants' tasks, questions, or quotes.

5.3.5.1 Portals for Reducing Concerns and Maintaining Immersion

While portals have been applied in various contexts [49, 217], this study adapts them for public transit to enhance awareness. Participants' interview responses confirmed that the portals reduced safety, awareness and social concerns.

All participants positively perceived the portal feature, reflecting on its effectiveness in reducing concerns associated with safety, awareness, and social fears. Some participants expressed how their concerns for the journey changed as soon as they started using the portals, with one noting: "*as soon as the journey began, I could see all those things. So I didn't need to…[worry]…those concerns were unfounded*" (P5). Participants found the portals to be "*helpful*" (P1), a "*good idea"* (P3, P4), a "*nice surprise*" (P8), making the journey "*more enjoyable*" (P5), "*relieving discomfort*" (P6) and "*the only way*" to make VR work in a public space (P14). All participants reflected on the portals' ability to increase awareness of the train environment and create a sense of safety, changing their initial expectations. For example, one participant noted: "*I think the mixed reality [portals] made me a lot more comfortable than I was expecting to be*" (P6). Some noted that having the portals helped them "*focus*" (P1, P2), and reduce "*anxiety*" (P6) and "*worry*" (P1). Although several participants found setting up the portals initially "*distractin*g" (P4) and that it required practice (P2, P3, P4, P5, P8), they deemed it a worthwhile compromise: "*having portals in traffic areas would distract somewhat from the content but that doesn't mean it's not important to still do. I think safety takes precedent*" (P4).

Interestingly, many participants were conscious of other passengers' perceptions, with a few noting others "*staring*" at them (P1, P7), or feeling worried about looking unusual: "*I was kind of thinking, we do look very strange right now*" (P14). However, several participants reported that their concerns ceased once they were immersed in VR and became aware of their surroundings through the portals. As P6 noted: "*once I got into it, it was just like, yeah, don't really care [about other passengers]*", while P7 highlighted feeling less concerned about external opinions: "*others don't need to worry about it if they don't like it*" (P7), a sentiment shared by P3 and P4. P8 also noted that being immersed in the virtual environment helped them forget about other passengers: "*nobody actually wants to talk to each other unless you know each other, or something happens that sparks conversation. And honestly, the VR just made it super easy to forget about them [people]*" (P8).

Although the study utilised two distinct 360-degree backdrops, a realistic office and an imaginative moonscape, for the virtual experience, participants did not comment on their influence on the overall experience.

5.3.5.2 Challenges of Simultaneously Navigating Reality and Virtual Reality

Navigating between real and virtual environments presents significant challenges for users, as reflected in their experiences with VR portals. Viewing reality and virtual reality simultaneously can create a disorienting sense of being neither here nor there, or "somewhere in-between" (P9). This underscores the difficulty of blending reality and virtuality in public spaces. In line with the initial challenges of navigating dual realities observed in Chapter 4, this study demonstrates that these issues become far more pronounced in real-world contexts.

Although the experience included portals to the real train environment, some participants felt more "*immersed in the virtual environment*" (P5), describing it as "*more of a virtual experience*" (P7) and noting they *"didn't really feel"* like they were on a train (P8). A few compared the portals to "*CCTV*" (P8) or "*moving pictures*" (P4), which were "*not like seeing reality*" (P4), where "*you are not there*" (P9). Some even forgot that they were on a train (P8) or wearing a headset (P5). However, other participants made a conscious effort to stay aware of both environments (P1, P3, P5, P6), noting it was important to "*focus on what is happening, surrounding"* (P1) and felt the portals served as a "*reminder*" of being on a train (P5, P8), helping them connect to "*the real world*" (P8).

Staying aware of both realities proved to be challenging. Participants often encountered difficulties in multitasking and managing their attention between two co-existing realities, describing being only "*half"* present in each environment (P1). Similarly, P2 found that viewing both real and virtual content simultaneously disrupted their immersion. Echoing this sentiment, P4 highlighted the challenge, noting "*too much going on*" as the video and the portals made it hard to pay attention to both realities at the same time. P10 commented on the difficulties of navigating between two complex worlds, describing it as "*distracting having the two complex worlds mixed together*". This blending of realities also led P11 to feel detached from the primary content of the VR experience, noting, "*it did sort of deter me away from what the documentary was... and then I had to force myself to focus*". Overall, participants found the experience busy and noted that it took time to adapt to the "*dual demands*" (P4) of the environments.

5.3.5.3 Resizing the Portals for Immersion and Passive Monitoring of the Environment

Participants engaged more deeply in discussions about choosing and modifying portals based on their needs, revealing a strong preference for the ability to freely customise their portals. This customisation allowed them to tailor their experiences to specific changes in the environment, enhancing their immersion or awareness as needed. The following reflections explore what influenced their choices and how pre-set portals differed in meeting their expectations.

During the journey, participants adjusted the size of the portals according to their preferred level of immersion. In particular, participants adjusted the sizes of self-chosen portals to increase or decrease their awareness of the train environment. Larger portals were seen to "*increase presence in reality*" (P3), while smaller portals kept attention more on the virtual environment being displayed: "*if it's about focusing on the actual VR video playing, having the smaller boxes was slightly better, keeping my attention more on that*" (P12) and "*helped focus more on the video*" (P14). P11 indicated that maintaining an equal view of both realities would involve choosing portals and virtual environments of similar sizes, giving an "*equal…view into reality and virtuality*" (P11). On the whole, participants expressed a need to resize the portals based on certain events, such as wanting to quickly check what was happening around them, especially if people were nearby: "*I would just move my portal face to those people. Enlarge the size of the portal, so I can know what they are doing there*" (P1). Particularly when a new passenger entered the nearby space, adjustments were made: "*I was aware of the gentleman seated in front of me… So I had moved one of the portals slightly more towards the window and resized it, made it larger to… see the gentleman's leg, just so I knew that I wasn't encroaching on his space*" (P5). All participants appreciated the control over customising their reality, particularly through customising the portal shapes. Some used multiple portals to create shapes that "*fit around the virtual environment*" (P6) to maintain focus on the content, cover specific areas like the "*aisle space*" (P8), or form "*curved panoramas*" (P13) for passive awareness. While customisation was preferred, some participants found value in starting with a pre-set configuration, as choosing the right setup from the beginning could be challenging. As one participant reflected, "*In hindsight, [I] didn't maybe align the portals to where I would have them if I was using it* *regularly…I noticed that on the way back with the pre-designated portals that perhaps I hadn't used that functionality to its full capacity*” (P5). Another participant noted that setting up the portals themselves “*took away a bit from my concentration on the video itself*” (P4). This suggests that while the ability to customise is valuable, having pre-set portals that highlight key objects of interest could provide a useful starting point, which users could then further customise as needed.

Overall, larger portals not only increased the awareness of the train environment but were also seen as a way to passively monitor the real world rather than actively checking the portals, and were the preferred choice by participants. Participants discussed wanting to have fewer but larger portals in “*strategic places*” (P4) to get: “*an easy overall impression of what's happening*” (P8) and felt that smaller portals were “*more distracting*” (P12), because they require active monitoring: “*when they were small, I had to focus more on what was in them and look more carefully*” (P8). Several participants noted that having to turn their heads to actively look at portals was tiring and expressed a preference for portals in the periphery, where they “*don't have to totally turn my head…like how in real life…you still have your peripheral*” (P9). While two pre-set portals were positioned in the periphery, their smaller, more focused sizes necessitated more active checking, which participants found less ideal. Despite this, small portals were still valued for specific tasks, such as checking something particular. As one participant noted, “*there was a point where I was able to check my phone in the real world through that. That was quite cool…And it was quite convenient*” (P8).

Figure 5.12: a-c) Participants' use of portals, marked in red for clarity: a) custom shapes (P6), b) “curved panoramas” (P13), and c) smaller portals for focused attention, e.g., glancing at a phone (P8).

5.3.5.4 Most Important Elements of the Train Environment

Interviews with participants revealed a strong preference for portal placement facing moving passengers, staff members and those in close proximity. This is in line with the findings from lab studies presented in Chapter 4. Participants prioritised predicting changes in passengers, particularly when the train was getting busy, over maintaining a constant visual, emphasising that "*safety and anticipation go hand in hand with each other*" (P9) and that it is crucial not to have "*your space invaded without being able to be prepared*" (P5). Less importance was placed on "*non-moving*" passengers further away (P1), with most portals positioned on the aisle side. One participant described this as the "*social side*" (P7) of the train, providing a most useful view. Conversely, portals focusing on personal belongings were consistently highlighted as vital for safeguarding possessions. P6 stressed the importance of "*keeping an eye*" on them, especially in a moving environment. Yet, some participants felt they could monitor their belongings without visual aid by keeping items "*super close*" (P9), as "*you're more likely to feel if somebody does anything*" (P11). Portals aimed at windows were generally seen as less useful, except for specific purposes such as estimating the distance "*from reaching my destination*" (P2), monitoring the "*journey progress*" (P5), assisting in "*reducing motion sickness*" (P5), or simply for a "*change of scenery*" (P8). Interestingly, participants' reflections align closely with the objects selected by the pre-set portals, which focused on the passenger on the aisle side, personal belongings, and the window, though, as noted by participants, the window was only useful to some for specific purposes.

5.3.5.5 Information 'Wormholes' and Trust in the Headset

The concept of 'information wormholes' emerged as a notable phenomenon during the study. It highlights instances where changes in the dynamic real-world environment slip past the portals of the VR headset, presenting an unexpected challenge and raising concerns about trusting the headset.

A clear example occurred when P8 did not realize a passenger had sat down directly in front of them, leading to unexpected discomfort. P8 reflected on the experience, stating: "*would have liked to know he moved into the space*" after the passenger had "*snuck through a gap*" in the portals. Having auditory information but no visual to match it also added to the confusion, with P9 questioning when a passenger sat in front: "*should I try and move the thing so I could see his face?*" and P10 finding it disorienting: "*knowing that when you're sitting there, there is more to see, but all you can see is this like one person or this one small segment is quite disorienting*". This demanded mental effort to "*trying to like fill in the small gaps in between*" (P12). Similarly, P10 expressed frustration over having to "*deduce from what you can hear and a smaller snippet*" instead of recognizing events as they occurred. Knowing that there was a change in the surrounding environment evoked a sense of unease: "*I didn't expect someone to sit in front of me… I couldn't see the guy's face while I was watching the stuff, which was okay… but also a little bit like, weird*" (P9).

Such experiences underscored trust concerns with the VR device, as participants expressed doubts about its ability to reliably represent the real world. P3 particularly noted a preference for real life visuals over those offered by VR, saying, *"I would obviously prefer seeing it in real life rather than, you know, in a virtual context"*. P4 echoed this sentiment, remarking that portals are not "*like seeing reality*". Participants felt the responsibility to detect environmental changes themselves, as P11 stated, "*I trusted myself to be able to tell if something happened in the cameras*" or expected to be notified by other passengers: "*I kind of trust them to, I don't know, be looking out for me*" (P14) rather than the headset.

5.3.5.6 VR Advantages Over Traditional Devices

Participants' interviews confirmed that VR headsets are seen to offer advantages over traditional devices, providing benefits to using one on a journey.

Participants reflected on using various devices such as phones, laptops, or headphones during their typical journeys (P3, P4, P5, P6, P7, P9, P10, P12, P13, P14), to stay entertained or feel productive: "*I can catch up on my games or movies so… I feel like I'm doing something productive with the time rather than just sitting and … wasting it*" (P3). VR headsets were perceived to offer advantages over traditional devices, primarily due to being more "*engaging*" (P6), the "*privacy*" they provide (P5), and their flexibility—for example, they can be used even "*without a tray table*" (P6). Their unlimited screen size could make work easier compared to using a phone (P2, P6), making it a suitable "*workspace*" (P2), with one participant noting, "*the phone's going to make it difficult because you might have to correct those typos that you make…the screen is really small*" (P2). Additionally, a few participants observed that the experience resembled that of traditional devices during journeys, as both primarily draw the user's attention: "*just the way that people interact with tablets and mobile phones in public…is a completely immersive experience*" (P5) and consequently limit their awareness of the surrounding environment: "*sometimes I'll sit on my laptop and…be very tunnel-visioned on the laptop, so it felt like that kind of thing*" (P6).

5.3.5.7 Expectations of Social Interaction on Public Transport

Participants' interviews revealed an overall positive experience with using a VR headset on a train, attributing this to the limited interaction expected when travelling alone. However, VR is still perceived as a hindrance to communication when communication is expected, such as when travelling with friends or family.

Whilst participants viewed public transportation as a shared space, the majority noted that only minimal interaction with others is expected and viewed other passengers as "*strangers*" (P1, P2, P3, P4). However, opinions on disconnecting from the environment delivered mixed results. Some considered it normal not to feel socially "*connected*" to other passengers (P2, P3, P4, P9), and had no expectations of being approached by others (P2, P3, P5, P6, P8), or of approaching others themselves: *"I don't owe anybody any social interactions"* (P5) unless it was a brief interaction: "*maximum maybe one minute of interacting*" (P2). However, a few felt that wearing a VR headset might lead them to miss out on spontaneous social interactions: "*I do quite like just the random interactions that you get with strangers on public transport. It's one of the reasons why I like to take it*" (P14) or the sense of being part of a communal setting: *"I think it's nice to go and have an awareness of your surroundings, of the people around you... just having the ability to connect to others through kind of awareness of the communal space that you're sharing"* (P12). This sentiment was echoed by P10, who saw the value in simply acknowledging other passengers even if no immediate interaction takes place: "*nice to have that sort of acknowledgement of each other and like if the need arises, being able to ask a question*" (P10).

Interaction issues between the VR user and other passengers become more pronounced when effective communication with companions is expected or desired. Participants noted that VR headsets could prevent "*normal conversations*" (P1) and "*reduce*" the ability to communicate (P1), creating a substantial "*barrier to socialising*" (P3). This barrier manifests as an extra layer of separation between the user and other passengers, complicating interactions that could easily occur with traditional devices (P4). Communicating effectively while using VR was overall seen as more challenging (P4), as VR headsets make it difficult to divide attention between real and virtual (P4) and result in the loss of social cues, crucial for effective communication (P6). Whilst interaction is not a prerequisite when travelling alone, this changes when the user is accompanied by friends or family.

Participants' answers showed that when travelling with friends or family, communication is expected. The dynamic changes significantly when the interaction involves familiar passengers as the VR acceptability hinges on collective participation. Participants noted that wearing VR headsets is not as acceptable when travelling with someone unless the whole party can share the experience (P2, P6), whilst collaborating (P2, P6), watching content, or playing together (P4, P6). However, it would be considered rude to wear a headset if it isolates the user from friends or family who are not participating (P3, P5, P11, P12, P13), and expect real-world interaction with the user: " *if you'd gone with friends on a train and one of them just pulled out a VR headset and disappeared into that, you'd feel a bit like, huh?, that's not really what I was expecting*!" (P10). Generally, participants expressed that they would remove headphones or put away phones to engage more directly when travelling with someone they know (P4), underscoring the expectation to interact more personally in such contexts, including instances when a VR headset is being used.

5.3.5.8 Seating Choices for VR Use on Public Transport

As part of the outward journey, participants were asked to choose their seats. They predominantly selected seats further away from other passengers, in quieter parts of the train.

Interviews revealed several reasons for participants' seating choices. Sitting near a window was preferred because it provided more room: “*sitting by the window is my first choice because I can have more space to use the VR*” (P1), or felt less exposed: “*aisle… felt a bit more on the outside*” (P11). Participants also sought to distance themselves from other passengers: “*was looking for a place that was further away from other people*” (P10) or to minimise interaction: “*[sitting further away] so I don't have to interact with people*” (P4). Choosing a quieter spot was also seen as a way to avoid bothering others. P3 chose a place “*where I wouldn't disturb people*”, while P12 preferred picking a spot where they “*don't feel like [they're] intruding into someone else's space*”. This not only minimised disruptions but also allowed for better concentration on the virtual content, as P3 noted, choosing “*somewhere that wouldn't be too loud so I can concentrate on the documentary*”. Additionally, sitting further from the aisle was seen as a way to have more time to react to changes in the environment: “*further away from the aisle because … this way…if somebody came to talk to us, I could, like, see them move over*” (P8).

5.3.6 Summary

Study VI expanded the investigation of how real-world contexts impact reality awareness systems by examining their application in a real, dynamic transit environment and their effects on passenger safety, awareness, and social concerns. The findings demonstrated that portals, used as a simplified version of reality anchors, effectively mitigated safety, awareness, and social concerns for immersive technology use in transit, especially for solo journeys. Whilst participants viewed public transportation as a shared space, most noted that minimal interaction with others is expected, often regarding fellow passengers as “strangers”. Custom portals were preferred over pre-set portals because they allowed participants to tailor their experiences to changes in the environment, enhancing immersion or awareness as needed. However, some participants noted that setting up custom portals took time and suggested that pre-set portals could provide a useful starting point.

Navigating dual realities proved challenging, often creating a sense of being "neither here nor there". Some participants consciously resisted full immersion to stay aware of their surroundings, while others struggled with the effort required to manage both spaces. Participants showed a preference for passive monitoring of the real environment through the portals due to its reduced mental demand. However, this method sometimes led to 'information wormholes', where significant environmental changes went unnoticed, such as another passenger sitting in a location not visible through the user's chosen portal placement, or discrepancies between auditory and visual information, raising trust concerns.

These findings highlight the potential of Reality Anchors to support immersive technology use in transit by reducing the need for manual monitoring for awareness and the cognitive load of managing dual realities. In contrast to portals, which require users to actively set up and manage their views, Reality Anchors offer the advantage of providing predefined, essential elements such as passengers, personal belongings, and journey information. This approach could serve as a good starting point for setup, ultimately improving the acceptance and adoption of immersive technologies in real-world settings.

5.4 Discussion

5.4.1 Effectiveness of Reality Anchors in Addressing Concerns in Real-World Transit Settings

The findings in this chapter address the problem of how reality-awareness systems can support passenger safety, awareness, and social needs in the dynamic and unpredictable context of real-world transit environments. The findings in this chapter reinforce the importance of reality-awareness systems in transit environments, as highlighted in the studies conducted. In Study V, Reality Anchors effectively alleviated physical safety concerns by providing reassurance about the body movements of fellow passengers. Participants valued the increased level of awareness the anchors provided, allowing them to focus on their tasks with more ease while staying connected to their surroundings. In Study VI, portals, adopted as a simplified version of Reality Anchors, also effectively reduced participants' concerns related to safety, awareness, and social fears. Participants identified key elements from reality they preferred to track, such as moving passengers, those in close proximity, and personal belongings, with some also expressing a desire to monitor journey progress. These findings align with earlier results from controlled environments discussed in Chapter 4, confirming that passengers and belongings are critical components of reality awareness needs in transit.

However, this chapter expands on these findings by showing that perceptions of the transit environment are not uniform. Transit spaces can be divided into areas of greater social activity, where heightened awareness is necessary, and more secluded areas, such as seats next to a window, which require less attention. These findings identify archetypal spaces within transit environments: social, secluded, and hybrid. These archetypes, which vary in relevance, can extend across different modes of transport. Seating preferences also aligned with prior research [128], indicating that aisle seats were perceived as more exposed and increased the likelihood of encroaching on other passengers' space.

In contrast to immersive headset awareness needs in controlled indoor environments, such as homes and offices, transit settings present distinct challenges. Harley and MacArthur [64] noted that changes within indoor environments, such as furniture rearrangements or the presence of pets, are typically more predictable. Concerns in these settings often focus on maintaining access to specific elements of reality, such as workplace essentials or personal items [86, 145]. While prior research by Eghbali et al. [34] indicates that broader public spaces lead to similar concerns about physical obstacles, the safety of personal belongings, and avoiding collisions with passersby, the work in this chapter shows how real transit environments intensify these challenges. Passengers must remain aware of those entering their immediate space and broader environmental shifts, such as passengers boarding or alighting. This requirement encompasses tracking the journey to help passengers alight at the intended stop. These findings suggest that future anchor-like solutions must provide consistent communication about changes in the transit environment to effectively support evolving user needs.

This chapter also reaffirms that control is a fundamental component of reality-awareness systems in transit, as suggested in Chapter 4. The dynamic nature of transit environments means that awareness needs can fluctuate, sometimes requiring more or less engagement depending on the situation, such as when a train becomes busier. In Study VI, participants responded positively to being able to adjust portal coverage, including creating custom shapes. This flexibility provided greater control over their interaction with the real world. However, some participants appreciated having a useful starting point provided by pre-set portals, noting that setting up portals took time and skill. This suggests that initial anchor setups could focus on the most important elements of the environment, such as passengers and belongings.

While Reality Anchors addressed many safety and awareness concerns, they did not fully support extended passenger interactions requiring nuanced social cues. This limitation is explored in the next section, focusing on the challenges of missing social cues, such as gaze and facial expressions, in transit environments.

5.4.2 Addressing the Gaze Gap in Future Reality Awareness Systems

While Reality Anchors were effective in alleviating safety, awareness, and social concerns, their current level of detail, such as the absence of facial expressions or eye contact, limited their ability to fully support effective social interactions. Non-verbal cues, including body language, facial expressions, and gaze, are essential for facilitating human interactions [13, 16]. Gaze, in particular, serves to evaluate interaction receptivity and indicate intended respondents. The absence of gaze has long been a challenge for immersive technologies, prompting both academic and industry efforts to find solutions. These have included simulating gaze on headsets [37], as well as incorporating additional elements such as representations of the user's full face [109]. Recent commercial innovations, such as the Apple Vision Pro headset [236], have introduced simulated eye gaze through a front-mounted screen, which displays a digital version of the user's eyes. This simulation adjusts based on the user's level of engagement to signal receptiveness to others [269]. However, some initial reactions describe it as 'creepy' [270], raising questions about the suitability of this approach.

Even with advancements in gaze simulation, the requirements for effective gaze representation pose significant challenges, particularly in transit scenarios. Communication often occurs simultaneously in both real and virtual spaces, creating opportunities for 'social collision', where virtual content interferes with real-world interactions [129]. For example, a headset user may attempt to engage with someone in their virtual environment while confusing or missing cues from bystanders in the physical space. Moreover, gaze in transit environments must serve a bi-directional purpose, enabling immersive and non-immersive users to signal their intentions for interaction or confirm communication. These dynamics become even more complex when multiple passengers seek to interact, each with differing levels of access to non-verbal cues.

While Reality Anchors do not currently support the nuanced social interactions required in such scenarios, they represent an important first step in addressing key safety, awareness, and social concerns. Moving forward, anchor-like systems must evolve to incorporate richer non-verbal cues, enabling them to progress beyond alleviating basic concerns and toward facilitating effective and meaningful interactions in public transit settings. This progression remains an open challenge, requiring further advancements to seamlessly integrate social cues into these systems.

5.4.3 Balancing Dual Worlds and 'Information Wormholes'

Navigating dual realities, both virtual and real, presents a complex challenge for immersive technology users, particularly in dynamic transit environments. Prior research has highlighted the disorientation associated with transitioning between virtual and real worlds, often leaving users uncertain about their presence in either reality [85, 180]. Study VI builds on this by revealing that simultaneous engagement with both realities can create divided attention and feelings of being "in-between" realities. Some participants were fully immersed in the virtual environment, while others divided their focus between the two worlds, highlighting the difficulty of balancing competing realities. In both studies, passive monitoring of the real world emerged as a preferred strategy, allowing participants to maintain awareness without actively shifting their attention. However, Study VI showed that relying on portals for this purpose introduced additional challenges. Portals required manual adjustments, which often led to 'information wormholes', instances where critical real-world changes, such as someone entering the user's space, went unnoticed, and these lapses in awareness raised trust concerns. In contrast, Reality Anchors demonstrated the potential to mitigate these challenges by offering an integrated and consistent solution. Unlike portals, which require constant user adjustments, Reality Anchors aim to provide passive monitoring that reduces cognitive effort while maintaining awareness.

5.5 Chapter Conclusions

This chapter presented the results of two studies investigating the use of Reality Anchors to improve the acceptance of immersive technologies in real-world transit settings, characterised by unexpected interactions between passengers and changes in the transit environment. The findings revealed that Reality Anchors have significant potential to alleviate safety, awareness, and social concerns.

Study V explored asymmetric passenger experiences by examining interactions between users with varying levels of immersion and environmental awareness. The findings demonstrated that Reality Anchors effectively reduced physical safety concerns by providing reassurance about passenger body movements. However, verbal interactions, particularly those requiring non-verbal social cues like gaze or facial expressions, remained challenging. This was especially evident for interactions between users at opposite ends of the reality/virtuality continuum [131], such as VR and smartphone users. The study emphasised the need for Reality Anchors to evolve in order to support complex social interactions and foster connectivity in public transit environments.

Study VI extended the investigation to real-world transit scenarios using passthrough-style portals, a simplified version of Reality Anchors. The study showed that portals reduced safety, awareness, and social concerns, enabling users to monitor their surroundings passively. However, the reliance on manual adjustments for portals introduced ‘information wormholes’, where significant real-world changes went unnoticed, leading to trust concerns. The study underscored the importance of Reality Anchors providing continuous monitoring of the environment, thereby reducing the cognitive effort required to track changes in the real world.

The results in this chapter address the following research question:

RQ4: Can Reality Anchors improve the acceptance of immersive technologies in real-world transit settings?

The findings suggest that Reality Anchors are an effective first step toward improving the acceptance of immersive technologies in transit environments. They address key concerns by providing users with enhanced safety and awareness while reducing social concerns. However, to fully support the complex and dynamic needs of transit passengers, Reality Anchors must evolve further. Future iterations should prioritise continuous environmental monitoring and the incorporation of non-verbal cues to facilitate meaningful social interactions. As immersive devices become more sophisticated, Reality Anchors have the potential to lay the foundation for socially integrated and context-aware immersive experiences, thereby advancing the adoption of immersive technologies in real-world transit settings.

6 Discussion

6.1 Introduction

This thesis made the following statement in its introduction:

Immersive technologies are not yet widely used while travelling due to awareness, safety and social concerns. This thesis argues that introducing objects from reality, referred to as Reality Anchors, represents an initial first step towards mitigating these concerns. By identifying the specific cues needed for travel contexts, such as other passengers, personal belongings, the surrounding environment, and journey information, this research demonstrates how Reality Anchors can enhance the social acceptability of immersive technologies. Furthermore, this thesis contributes valuable knowledge about awareness needs in transit settings, providing a foundation for designing systems that address barriers to the adoption of immersive headsets in transit. The findings are based on an in-depth investigation using surveys, lab studies, and in-the-wild experiments.

The chapters that followed presented research that supports this statement by investigating the thesis research questions. Chapter 3 presented two surveys that explored factors influencing the acceptance of immersive technologies in transit, focusing on the mode of transport and journey length. The findings revealed that journeys are not perceived uniformly, with shorter journeys posing greater challenges due to the increased need for awareness of surroundings, other passengers, personal belongings, and journey information.

Building on this work, Chapter 4 introduced the concept of Reality Anchors and investigated the key reality cues, such as other passengers, personal belongings, internal furniture, and journey information, identified through surveys as the most important awareness needs. Insights from this study revealed that journeys can be categorised into two groups: self-managed and externally managed, informing further exploration of how passengers interact with Reality Anchors across these journey types. While passengers and personal belongings were particularly important, the use of all anchors depended on their ability to enhance safety, add value, maintain immersion, and align with the journey type, with self-managed journeys resulting in the most anchor usage. Key requirements for effective anchors also became apparent, including the need for anchors to contrast with the virtual environment, be customisable to journey needs, and remain under user control.

Finally, Chapter 5 extended beyond lab-based insights to investigate how reality awareness needs are influenced by real-world settings, focusing on two core elements: real-world passenger interactions and real-world transit environments, and their impact on Reality Anchors. The findings showed that Reality Anchors effectively alleviated safety, awareness, and social concerns by providing reassurance about the movements of fellow passengers. However, verbal interactions requiring non-verbal social cues, such as gaze or facial expressions, remained challenging. The chapter also highlighted real-world implications for awareness systems, including the challenges of relying on users to detect environmental changes. Contrary to the lab studies, this reliance on user control often resulted in the loss of critical information, such as failing to notice someone moving nearby, and difficulty in simultaneously monitoring two realities.

This chapter summarises the findings of this research, revisits each of the research questions to discuss how they were addressed and summarises their answers. It also highlights the main contributions of this work and outlines areas for future research.

6.2 Research Question 1

How do mode of transport and journey length affect the social acceptability of immersive technology use on public transport?

To answer this research question, the work shows that the social acceptability of immersive technology in public transport is significantly shaped by the mode of transport and journey length. Chapter 3 presented two surveys that explored how these factors influence the social acceptance of immersive technologies in transit environments.

The findings revealed that transport environments are not perceived uniformly. Longer journeys, such as those on long-distance trains and flights, are associated with higher acceptance due to a reduced need for constant awareness and a greater desire for engaging entertainment. In contrast, shorter journeys, such as those on buses and local trains, pose greater challenges for acceptance because they require increased awareness of surroundings, other passengers, personal belongings, and journey information. These findings underline the importance of addressing the unique challenges posed by shorter journeys and demonstrate that the needs of different journey types are not uniform, necessitating further categorisation to better understand and resolve the varied challenges of immersive technology adoption. To explore these issues further, the thesis introduces a framework for categorising journeys, discussed in Section 6.6.2.

6.3 Research Question 2

Can Reality Anchors based on people, objects, environments and journey information alleviate concerns explored in RQ1, while maintaining immersion?

To answer this research question, the findings in Chapter 4 suggest that Reality Anchors have the potential to alleviate safety, awareness, and social concerns identified in RQ1. Findings showed that anchors are evaluated based on their ability to enhance safety, add value, maintain immersion, and align with the journey type. Among the tested anchors, people and personal belongings emerged as the most valuable in addressing these concerns, while people and furniture were also found to be the most distracting. Journey information and furniture anchors were more context-dependent, with their relevance varying based on the type of journey and specific travel conditions, which are explored further in RQ3.

Maintaining immersion was shown to rely on allowing users to control the anchors, enabling them to activate or deactivate anchors as needed to adapt to changing journey contexts. The work highlights that constantly displaying anchors can disrupt immersion, emphasising the importance of flexible, user-controlled anchor deployment to balance awareness and immersion effectively. Key awareness needs critical to the social acceptability of immersive technologies are discussed in more detail in Section 6.6.1, providing deeper insight into which elements in transit environments require prioritisation.

6.4 Research Question 3

How do Reality Anchors need to adapt based on journey type and dynamic user needs during travel?

To answer this research question, Reality Anchors require flexibility to respond to both journey type and dynamic user needs throughout travel. Chapter 4 findings reveal that during both self-managed and externally managed journeys, anchors are prioritised based on factors such as trip tracking, passenger turnover, and proximity to the journey's endpoint. In self-managed journeys, where passengers must actively track their route and navigate higher passenger turnover, anchors like signage and passengers play a critical role. By contrast, in externally managed journeys, with fewer interruptions and a clear endpoint, users required less continuous awareness, often activating signage anchors only midway through the journey and using passenger anchors less frequently. Regardless of journey type, personal belongings remained a consistently used anchor.

Furniture anchors, however, were not influenced by these journey factors and primarily served a purpose at the start of the journey, helping users form a mental picture of their environment. Moreover, the work shows that as journeys progress, the need for anchors changes, with greater reliance on certain anchors near the destination to support tasks such as preparing to disembark or reassessing the surrounding environment. The concepts of self-managed and externally managed journeys, alongside key journey classifiers that influence the use of Reality Anchors, are discussed in greater detail in Section 6.6.2.

6.5 Research Question 4

Can Reality Anchors improve the acceptance of immersive technologies in real-world transit settings?

To answer this research question, the findings in Chapter 5 show that Reality Anchors represent an effective first step toward improving the acceptance of immersive technologies in real transit environments. They address key concerns such as safety, awareness, and social acceptability by providing reassurance about the movements of others and enhancing awareness of the surroundings. Findings also highlight the key implications of real-world contexts on reality-awareness systems. Unlike controlled lab environments, real-world scenarios demonstrated challenges in relying on users to detect environmental changes themselves. This reliance often resulted in critical information being missed, such as failing to notice someone moving nearby or difficulties in simultaneously monitoring two realities. Continuous monitoring of the environment by anchors is therefore an essential requirement for similar systems in the future. A limitation in verbal interactions was also observed. Interactions that relied on non-verbal social cues, such as gaze or facial expressions, proved challenging. To move beyond simply alleviating concerns, Reality Anchors must incorporate non-verbal social cues to enable more meaningful interactions between users. The real-world implications of deploying systems like Reality Anchors, including the challenges of navigating social interactions and balancing dual realities, are explored further in Section 6.6.3.

6.6 Contributions

This thesis makes novel contributions to inform the design of future reality-awareness systems for transit contexts. Its main contributions are as follows:

1. A study of core passenger awareness needs in transit settings that influence the social acceptability of immersive headsets.

2. An exploration of the dynamics of different journey types (e.g., self-managed and externally managed), offering insights into how these vary and their implications for the generalisability of Reality Anchors.

3. An analysis of real-world challenges for Reality Anchors, identifying practical implications and unexpected difficulties that arise when deploying these systems in real-world, uncontrolled transit environments.

4. The design and real-world evaluation of the Reality Anchors concept, which provides crucial cues in immersive environments to address concerns associated with the adoption of immersive technologies in transit.

6.6.1 Focusing on What Matters: Core Passenger Awareness Needs in Transit Settings

This thesis identifies key awareness needs in transit settings that are critical to the social acceptability of immersive technologies. Across the chapters (Chapters 3, 4, 5), passengers, personal belongings, journey information, and furniture emerged as the most relevant anchors, with passengers and personal belongings recognised as the most crucial (specifically highlighted in Chapter 4, Study III). These anchors were evaluated based on their ability to enhance safety, address social concerns, maintain awareness, support immersion, and align with the requirements of the journey type.

Passenger anchors were prioritised for their role in ensuring safety, as their dynamic and potentially hazardous nature required awareness of significant movements, such as someone passing nearby. They also addressed social concerns by helping to prevent inappropriate interactions or encroachment on others' personal space. Personal belongings were similarly critical, primarily for safety, with visual anchors providing consistent security in busy environments, though alternatives like touching a bag were also seen as viable for maintaining awareness. Journey information anchors were particularly valuable for supporting awareness of route progression, especially in self-managed journeys where preparing to disembark required heightened attention (journey types explored in detail in Chapter 4, Study IV). Furniture anchors, in contrast, were seen as offering limited value beyond providing grounding in the environment or referencing passengers' sitting positions. While they helped orient users to the environment, they were often perceived as visually cluttered and unnecessary for maintaining safety or awareness during travel (highlighted in Chapter 4). Maintaining immersion was another key factor influencing the prioritisation of anchors. Passenger and furniture anchors were often found to be the most distracting, disrupting immersion. To manage this, a 'check-in' approach was adopted, with anchors briefly enabled to reconnect with the surroundings before resuming the immersive experience (highlighted in Chapter 4, Study IV).

Awareness needs were also shaped by the dynamics of different journey types and the social characteristics of transit spaces. In Chapter 5, transit spaces are shown to fall into three archetypal categories: social, secluded, and hybrid, each requiring different levels of spatial awareness. Social spaces, such as aisles or standing areas, demanded heightened awareness of other passengers, while secluded spaces, such as window seats, required less attentiveness. Hybrid spaces balanced these characteristics, with selective awareness depending on surrounding activity.

This contribution is significant because it establishes that not all elements in transit environments require equal attention, and that reality-awareness needs are shaped by unpredictable internal and external changes in the environment. This contrasts with earlier work on immersive headset use in more stable environments such as homes or offices (e.g. [64]), where surroundings remain relatively consistent. While previous studies have explored awareness needs in public spaces and raised concerns about physical obstacles, belongings, and collisions (see Eghbali et al. [34]), the studies in this thesis show that these challenges are intensified in transit. Providing too many cues risks overwhelming users, while insufficient cues can compromise safety, awareness, and social acceptability. By identifying which elements to prioritise and highlighting that these priorities must adapt to changing conditions, this research provides a foundation for designing reality-awareness systems, such as Reality Anchors, that effectively support immersive technologies in shared transit environments.

6.6.2 Journey Types and Their Implications for Immersive Technology Adoption

Early in this thesis, it was identified that journeys are perceived differently, with shorter journeys posing greater challenges for immersive technology adoption (Chapter 3). Shorter journeys are associated with increased concerns about awareness of surroundings, other passengers, personal belongings, and journey information, highlighting a greater need for users to stay connected to their immediate environment. Longer journeys, such as those on flights or trains, were seen as less demanding in terms of awareness needs and more focused on entertainment, making immersive technology use more acceptable. The differing perceptions of journey types in relation to immersive technology acceptance highlight that findings from one type of journey may not necessarily be transferable to another, underscoring the need to generalise journeys to better address barriers to adoption. To address this, this thesis introduces self-managed and externally managed journeys as a new way to describe travel experiences, alongside key classifiers that further define transit journeys: likelihood of passenger turnover, seat arrangement, and familiarity with the route (highlighted in Chapter 4, Study IV). Contrary to previous work, which tended to classify journeys primarily by mode of transport [46, 176, 217], this thesis argues that these classifiers offer a more effective and generalisable way to describe journeys. Together, these concepts provide a framework to describe journeys in a generalisable way, offering a foundation for designing immersive technologies and reality-awareness systems that can adapt to diverse transit settings.

Self-managed journeys require individuals to actively manage their travel, including tracking their route and determining when to disembark. These journeys are typically shorter in duration and characterised by frequent passenger turnover, increasing concerns about safety and the need for heightened awareness. These factors make the use of immersive headsets more challenging in self-managed contexts. Externally managed journeys, by contrast, are often longer in duration, with a clear journey endpoint and minimal passenger turnover. These characteristics reduce the need for active monitoring, allowing passengers to use immersive technologies more comfortably, particularly as a way to alleviate boredom during extended trips.

The classifiers further describe journeys and their characteristics. A high likelihood of passenger turnover can result in increased worries about safety, influencing the use of an immersive headset. Seat arrangement, linked to the earlier described archetypes (see 6.6.1), also influences the experience. Aisle and window seats, for example, are associated with varying levels of comfort, exposure, and social dynamics, with aisle seats requiring more awareness of reality. Familiarity with the route is another key factor. Unfamiliar routes are perceived as more unpredictable and potentially unsafe, demanding greater attention to surroundings. In contrast, familiar routes are seen as predictable or boring, making immersive headsets more acceptable in these contexts.

This contribution is significant because it establishes a framework for generalising journeys in transit settings. By identifying journey types and classifiers, this research supports the development of immersive technologies and reality-awareness systems that can effectively address the unique challenges and requirements of different transit contexts.

6.6.3 Real-World Implications: Navigating Social Interactions and Balancing Dual Realities

This thesis examines the real-world implications of deploying reality-awareness systems, uncovering the complexities of social interactions and the challenges of balancing dual realities in transit environments. The findings highlight both the strengths and opportunities for systems like Reality Anchors to evolve and meet the demands of dynamic, real-world contexts.

Social interactions in transit often rely on non-verbal cues, such as gaze and facial expressions, which are essential for effective communication. Reality Anchors effectively alleviate key safety, awareness, and social concerns by offering reassurance about passenger movements and positions. However, to move beyond simply alleviating these concerns, Reality Anchors must evolve to incorporate richer non-verbal cues (highlighted in Chapter 5, Study V). Features such as gaze tracking and facial expression representation could help bridge the gap, enabling immersive headset users and users with less immersive or no devices to engage more effectively in both virtual and physical environments, and fostering deeper social connections in shared transit spaces. While some recent work has begun exploring gaze integration in immersive systems, a natural and socially acceptable implementation has not yet been achieved [16, 271], making this an open challenge.

The work also underscores the challenges of balancing dual realities in real-world transit settings. The concept of ‘information wormholes’ was identified, describing instances where critical real-world changes, such as someone entering a user's personal space, went unnoticed (highlighted in Chapter 5, Study VI). These lapses in awareness exposed the limitations of manual adjustment systems such as portals that use camera feeds (a common approach in passthrough-based solutions [272, 273]), which require users to actively switch attention between realities. While previous work has noted that transitions between virtual and physical environments can be disorienting [85], the findings from this thesis show that trying to monitor both realities simultaneously can also create a sense of being in between, leading to increased cognitive load and fragmented awareness. By contrast, the findings show that a solution such as Reality Anchors could offer continuous passive monitoring to reduce cognitive effort and maintain consistent awareness in real-world settings.

This contribution is significant because it used a novel approach to explore awareness needs directly within real-world transit contexts, where immersive headsets would be used. By uncovering unexpected challenges unique to dynamic transit environments that cannot be fully replicated in controlled settings, this research provides valuable insights for designing reality-awareness systems that are better equipped to support the demands of unexpected interactions and continuous awareness needs in real-world applications.

6.6.4 The Reality Anchors Concept: Design and Future Guidelines

The findings in this thesis provide baseline guidelines for the design of reality-awareness systems, such as Reality Anchors, offering a foundation for creating solutions to address the challenges of immersive technology use in transit contexts:

- **Critical Cues for Awareness:** Passengers, personal belongings, and journey information are essential cues that should be consistently available in the system. These foundational anchors serve as a starting point to reduce user effort, providing immediate awareness of key elements in transit environments. A concrete implementation of this approach was used in Study VI (Chapter 5), where participants were asked to compare portals they designed themselves with pre-designed portals that specifically highlighted other passengers, personal belongings, and journey progression. Feedback from this study showed that some participants appreciated having a useful starting point provided by the pre-set portals. They noted that manually setting up portals took time and required a certain level of skill. Customisation options can then allow users to adapt the system further to their specific needs and preferences.

- **Grounding Users in Virtual Environments:** To ensure a seamless connection between the real and virtual, anchors should consistently link users to their real-world locations. Furniture anchors, for example, can orient users by showing where passengers are seated, helping to ground users. However, a balance is needed to ensure the visual field is not overwhelmed. An example of users being grounded while using a furniture anchor can be seen in Study V (Chapter 5), where only the outlines of the furniture were displayed. The depth of these furniture anchors was adjusted to ensure they did not obstruct the cinema screen, supporting immersion. This approach helped minimise visual distraction while allowing users to locate themselves and other passengers within the shared space. While the study did not explore alternative visual styles, the outline-based approach shows potential as a lightweight solution for grounding users in shared physical spaces. Future designs should explore ways to simplify these visuals and reduce unnecessary screen clutter.

- **Contrasting Real and Virtual**: Visual separation of real and virtual elements is crucial to avoid confusion between realities. Anchors should incorporate contrasting features, such as highlighting or outlining, to ensure that real-world cues are easily distinguishable from the virtual environment. Avoiding confusion between realities is necessary for users to maintain immersion. In Studies III and IV, a transparent anchor approach was used, applying a semi-transparent yellow-green overlay to distinguish passengers and other key anchors from the rest of the virtual scene, which was rendered in full colour, dimension, and saturation. In Study V, a simplified white outline was used instead to further reduce visual clutter. While this helped minimise distraction, some participants noted that it was harder to tell what the other person was doing, such as whether they were wearing a headset. This suggests that while low-detail representations can serve as a useful starting point, a mid-level visual approach may better balance contrast with the need to convey more information about the anchor.

- **Passive Environmental Monitoring:** Dynamic environmental changes, such as passenger movements or route progression, need to be tracked automatically by the system. The focus here is on significant changes in direction or position, such as passengers getting closer or changing locations, rather than small movements. Passive monitoring helps users maintain awareness without requiring constant manual adjustments, reducing cognitive load and avoiding 'information wormholes', where critical real-world events might be missed. Reality Anchors can support continuous passive monitoring, helping reduce the effort required from users to stay aware of their surroundings. This was contrasted in Study VI, where manually tracking real-time changes in transit environments led to cognitive overload and reduced awareness. While this thesis did not explore how significant environmental changes could be further highlighted to immersive headset users, future designs could explore this as a way to extend the current approach.

- **Customisation to User Needs**: Reality Anchors should provide users with control over what cues are displayed and how they are prioritised. This includes adapting the system to different journey types, such as focusing on route progression during self-managed trips or emphasising personal belongings in crowded environments. An example of this was implemented in Study III, where users were able to select and adjust anchors throughout their journey. Anchor choices were influenced by journey needs and context, and participants were also given the option to adjust the visibility radius to view anchors at a closer or further distance. While the ability to choose anchors was very well received, the visibility radius option was used less frequently. Some participants found the expanded radius distracting due to the amount of visual space it occupied, though it remained useful for those particularly concerned about other passengers. These findings suggest that giving users control over anchor selection is essential, while radius adjustments may not be needed by all users. A default radius of 2.5 metres, which was used in Study III and reflects the upper range of the social zone in proxemics theory [63], can serve as an effective starting point.

- **Need to Evolve for Complex Social Interactions:** As immersive headsets become more widely adopted, new social norms and behaviours surrounding their use are likely to emerge, as previously seen with mobile phones. While Reality Anchors address key safety, awareness, and social concerns, they lack the non-verbal cues necessary for nuanced social interactions, such as gaze direction and body language. Study V included representations of real-tracked passengers as skeletal figures, with simplified facial markers such as eyes and a nose to indicate head orientation. While this was not designed specifically to study social cues, some participants found it difficult to determine gaze direction or whether someone was attempting to initiate an interaction. This highlights the complexity of integrating social cues into reality-awareness systems. While simplified representations may support basic awareness, they often fall short in supporting more complex social interactions. On the other hand, high-fidelity representations, such as simulated eyes, can lead to discomfort or rejection, with some users describing them as 'creepy' [271]. Addressing this 'gaze gap' could help facilitate more meaningful interactions in transit settings. However, as behaviours around headsets evolve, anchors may also need to adapt to unforeseen challenges and emergent social dynamics, forming a critical area for future research.

This contribution is significant because it provides baseline guidelines for the design of similar systems in the future, ensuring that reality-awareness systems can effectively support the integration of immersive technologies into shared transit environments.

6.7 Limitations

Reflecting on the choices made in this research, several key decisions shaped the studies and should be acknowledged. Firstly, speculative methods were intentionally chosen as the most suitable approach to explore Reality Anchors. By using VR simulations and enactments, the research recreated transit scenarios in a controlled and safe environment, which proved particularly effective for investigating emergent technologies that are not yet widely available. However, while these methods offered valuable insights, they do not fully replicate the complexities of real-world transit settings. Although one study was conducted in the wild, it did not include testing the anchor solution itself. The speculative nature of this work is grounded in the expectation that advancements in sensor and camera technologies will soon address technical limitations, enabling the development of Reality Anchor-like solutions in real-world contexts. Future work can build on this foundation by evaluating these solutions in live transit environments to better understand their effectiveness in dynamic and unpredictable scenarios.

Secondly, the designs of Reality Anchors explored in this thesis utilised transparent avatars and skeleton-based visualisations, chosen for their ability to effectively represent human presence while maintaining a clear contrast with virtual environments. This approach aligns with prior research indicating that increased fidelity is not always necessary to convey presence [117]. Further work can investigate how these designs might be refined to fit more naturally within virtual scenes while preserving their distinction from real-world elements. Additionally, future studies could investigate minimising distraction while effectively conveying essential movements and gestures.

Finally, the research used a static task, where participants watched documentaries on a cinema screen, to prevent introducing confounding variables into the studies. This controlled approach ensured a focused examination of Reality Anchors. However, the use of different types of tasks, such as interactive games or collaborative assignments, should be further explored to understand how task dynamics influence the effectiveness of Reality Anchors. By examining the impact of more dynamic and interactive tasks, future work can expand the applicability of Reality Anchors across a wider range of scenarios.

6.8 Open Challenges for Future Immersive Technology in Transit

6.8.1 Moving Beyond Immersive Technologies for Entertainment

The surveys in Chapter 3 revealed a strong preference for using immersive technologies for entertainment, with participants highlighting limited awareness of their potential for other activities, such as productivity or communication. This preference informed the choice of entertainment-focused tasks in the studies conducted for this thesis. Moreover, the scenarios focused on entertainment tasks that required minimal movement or interaction with the headset and controls, as gesture-based interaction in confined spaces was beyond the scope of this thesis and has been explored elsewhere [78, 98, 173, 196, 220]. However, expanding beyond passive, entertainment-focused applications could significantly enhance the acceptance and utility of immersive technologies in transit environments.

While immersive devices are not yet seen as superior to mobile phones or laptops for productivity or communication, the development of new applications co-designed with end-users could address this perception. Research, such as Li et al.'s investigation into productivity in cars [103], demonstrates that immersive technologies are viewed favourably in certain contexts. Together with findings from research on gesture use in constrained environments, future efforts could develop transit-specific applications alongside reality-awareness solutions, such as Reality Anchors, to ensure users remain connected to their surroundings while engaging in various tasks.

6.8.2 The Changing Self-Image of Headset Users in Public Spaces

Participants in this thesis studies often reflected on how they might be perceived by others, expressing concerns about being judged for appearing disconnected from their surroundings. The appearance of the device plays a critical role in shaping these perceptions. Previous research has shown that devices perceived as ‘bulky’ or highly noticeable are less acceptable unless they serve a clear, socially validated purpose, such as aiding individuals with disabilities [155]. As headsets become smaller and more mobile, it is likely that public attitudes toward their use in transit will evolve, leading to greater acceptance in shared spaces. However, it is not only the designs of the devices that might change but also our social reactions and norms surrounding their use. For instance, headset users may develop strategies to signal their openness to interaction, while non-users may adjust how they navigate shared spaces or initiate interactions with those immersed in virtual environments. Over time, these behaviours could stabilise into familiar norms and expectations, much like how passengers have adapted to the use of headphones, smartphones, and laptops in public spaces.

Looking further into the future, immersive devices are likely to become more homogenous in terms of capabilities and affordances, creating standardised norms for interaction and streamlining the passenger experience. However, individual behaviours and preferences will remain diverse. While some passengers may seek social engagement, others may prefer to shield themselves from their surroundings. To support this spectrum of preferences, future immersive devices will need to balance connection and privacy, enabling users to either engage or disengage within public transit environments. At the same time, developments in object segmentation technology may soon enable immersive systems to automatically identify and track surrounding objects and people as anchors [274]. However, despite these technical possibilities, passengers may remain reluctant to be tracked in public spaces, particularly in situations where consent is unclear or not obtained [2]. Consequently, these capabilities may continue to challenge current assumptions about privacy and consent in public environments.

This work highlights a future open challenge to explore how immersive technologies can support the evolving social dynamics and behavioural norms of transit contexts. Ensuring that these technologies enhance both individual experiences and broader social acceptability will be a critical area for further research.

6.9 Conclusions

Immersive technologies are not yet widely adopted in transit contexts due to social, safety, and awareness concerns that affect their social acceptability. This thesis investigated the awareness needs specific to transit contexts and proposed the concept of Reality Anchors. By integrating cues from reality into virtual environments, Reality Anchors aim to reduce concerns associated with immersive technology use in transit, thereby improving their social acceptance. The research highlights that awareness of other passengers and personal belongings are key cues users in transit prioritise. The findings also emphasise that effective Reality Anchors must be consistent, contrast with the real world, provide continuous monitoring, and remain under user control. Additionally, the thesis introduces self-managed and externally managed journey types as a framework for describing and understanding the diverse experiences and requirements of different transit contexts. Overall, the research contributes to (1) identifying core awareness needs for transit users, (2) exploring the dynamics of journey types and their implications for Reality Anchors, (3) analysing real-world challenges and practical implications for awareness systems, and (4) designing the Reality Anchors concept to address barriers to immersive technology adoption in transit.

Appendices

Appendix A: Survey Used in Study I (Chapter 3)

A PDF of the survey used to conduct Study I in Chapter 3 is included on the pages that follow.

Virtual Reality use in aeroplanes (survey)

Page 1: Information Sheet

Thank you for your interest in participating in this survey about Virtual Reality (VR) use in aeroplanes. If you have questions about this research, please contact:

Laura Bajorunaite

PhD Student

University of Glasgow,

l.bajorunaite.1@research.gla.ac.uk

What is the purpose of this study?

The purpose of this survey is to understand your attitudes towards VR use during flights. The survey will ask a set of questions about your flying habits and familiarity with VR and present you with several image-led scenarios of potential VR usage in the aviation industry.

No previous experience with VR is required to participate – the only requirement for the study is to have taken at least **one flight in the last year**, which was a minimum of **1 hour long**.

What is expected of me if I take part?

You will be tasked with answering a survey with four main sections. The questions presented will be a mix of multiple choice and open-ended questions that will ask you to write a short sentence or two to answer them.

There will be a total of 18 questions in this survey and it should take around 20 minutes to complete.

If you wish to take part in the draw for the £25 Amazon voucher, you will be asked to enter your email at the end of the study.

What are the possible benefits of participating?

Your answers will help us understand your needs for in-flight VR, which could make your journeys more entertaining and productive in the future. This survey will help us design better VR applications as well as shape further research in the area.

What happens at the end of this study?

The results will be held and owned by the researcher and the University of Glasgow. The results can be outlined to the participants whenever they become available.

The results of this study may be published in a journal or presented at a conference.

Results will always be presented in such a way that data from individual participants cannot be identified. The data will be anonymous.

Can I withdraw from the study?

Your participation in this research project is voluntary, and you may withdraw from the research at any time and for any reason, without explanation.

Can I ask questions about the research project?

You may ask more questions about the study at any time - before, during and after the study. Use the contact information provided above if you have any questions.

Who has reviewed the study?

The project has been reviewed by the College Ethics Committee.

This research is funded by ERC Horizon 2020 project ViAjeRo #835197

Consent Form

Please confirm your participation in this study by completing this consent form:

- I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask questions.
- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.
- I understand that the data collected may be used in publications or presentations.
- I am at least 18 years old.
- I have taken at least one flight in the last year with a minimum duration of 1 hour.

Please select "I AGREE TO ALL OF THE ABOVE" to continue ✱ *Required*

○ I AGREE TO ALL OF THE ABOVE

Page 2: Demographics

1. How old are you?

- 18-20
- 21-29
- 30-39
- 40-49
- 50-59
- 60 or older

2. What is your gender?

- Female
- Male
- Non-Binary
- Other
- Prefer not to say

If you have selected 'Other' please explain:

3. What is your country of residence?

Page 3: Flying habits

4. How often do you fly?

- Once a year
- Infrequently (2-5 trips a year)
- Frequently (6-11 trips a year)
- Regularly (12+)

5. Which class do you travel in usually?

- Economy
- Premium Economy
- Business
- First
- Chartered/Private

6. What proportion of your travel is for leisure (not business)?

Please enter a percentage out of 100%.

7. What proportion of your travel is spent travelling alone?

Please enter a percentage out of 100%.

8. How do you usually spend your time when flying?

Please don't select more than 1 answer(s) per row.

	None of my time	A little of my time	Some of my time	A lot of my time
Entertainment (videos, games, reading etc.)	☐	☐	☐	☐
Socialising	☐	☐	☐	☐
Productivity (work related activities, writing etc.)	☐	☐	☐	☐
Sleeping	☐	☐	☐	☐
Eating/drinking	☐	☐	☐	☐
Looking out the window	☐	☐	☐	☐
Other	☐	☐	☐	☐

If you have selected 'Other' please explain:

Is there anything you would like to be able to do in flight that you feel you cannot right now?

9. In a sentence or two, please describe how you feel about flying?

(Examples – I love to fly, and do so at every opportunity, I hate to fly and only do if required by my work etc.)

Page 4: Familiarity with VR

This is the Oculus Quest VR headset.

VR Headsets like this are worn on your head, and block out your view of reality, replacing it with a private virtual world of your choosing, such as a virtual cinema, an office, or an immersive game.

10. Have you ever used a Virtual Reality (VR) headset?

- ○ Yes
- ○ No (please move to question 14)

11. If yes, which headset(s) have you used?

- ☐ Oculus Quest
- ☐ Gear VR
- ☐ Oculus Rift
- ☐ HTC Vive
- ☐ Sony PlayStation VR

- [ ] Google Cardboard
- [ ] Other

If you have selected 'Other' please explain:

12. If yes, have you ever used it when travelling by air?

- ○ Yes
- ○ No

13. If you have used it when travelling by air, please describe your experiences with the headset, and the activities you engaged in:

14. a) Please rank your interest in using a Virtual Reality headset on your future flights:

- ○ Not at all interested
- ○ Not very interested
- ○ Neutral
- ○ Somewhat interested
- ○ Very interested

b) Please have a look at the following images. Image 1 represents an economy class airline seat, whilst image 2 represents a business class seat.

IMAGE 1

IMAGE 2

Would you feel any more likely to use VR in either class?

- Economy class (image 1)
- Business class (image 2)
- No difference

Please explain your answer:

Page 5: VR use scenarios

15. Please rank your interest in using a VR headset on flights for the below activities:

Please don't select more than 1 answer(s) per row.

	Not at all interested	Not very interested	Neutral	Somewhat interested	Very interested
Entertainment (watching videos, playing games etc.)	☐	☐	☐	☐	☐
Communication (using the device to video chat, catch up with social media etc.)	☐	☐	☐	☐	☐
Work (completing your work tasks in a virtual environment, participating in meetings etc.)	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

Please explain your answer:

16. Please rank your interest in using a VR headset on flight for the below journey lengths:

Please don't select more than 1 answer(s) per row.

	Not at all interested	Not very interested	Neutral	Somewhat interested	Very interested
Domestic (up to 1 hour)	☐	☐	☐	☐	☐
Short haul (up to 3 hours)	☐	☐	☐	☐	☐
Medium haul (3-6 hours)	☐	☐	☐	☐	☐
Long haul (more than 6 hours)	☐	☐	☐	☐	☐

Please explain your answer:

17. Would you be more likely to use the airline provided headset or your own when...

YOUR OWN HEADSET

AIRLINE PROVIDED HEADSET

Bottom picture credit: REUTERS/Fabrizio Bensch

Please don't select more than 1 answer(s) per row.

	More likely my own	Neutral	More likely airline
Travelling alone	☐	☐	☐
Travelling with friends or family	☐	☐	☐
Travelling with work colleagues	☐	☐	☐

Why?

18. a) Would you bring your own headset on the plane?

- Very unlikely
- Moderately unlikely
- Neither likely nor unlikely
- Moderately likely
- Very likely

b) Would you use a headset on the plane if provided for free?

- Very unlikely
- Moderately unlikely
- Neither likely nor unlikely
- Moderately likely
- Very likely

c) Would you pay to use a headset on a plane as an upgrade to your seat?

- Very unlikely
- Moderately unlikely
- Neither likely nor unlikely
- Moderately likely
- Very likely

Page 6: Prize draw

If you would like to take part in the prize draw for the £25 Amazon voucher, please enter your email address below: *Optional*

Would you like to be added to the mailing list for future studies? *Optional*

- Yes
- No

Appendix B: Survey Used in Study II (Chapter 3)

A PDF of the survey used to conduct Study II in Chapter 3 is included on the pages that follow.

Info and Consent

Information Sheet

Hello!
Thank you for your interest in participating in this survey about Virtual Reality (VR) use on public transport.
If you have questions about this research, please contact:
Laura Bajorunaite
PhD Student
University of Glasgow,
l.bajorunaite.1@research.gla.ac.uk

1. What is the purpose of this study?
The purpose of this survey is to understand attitudes towards VR use on public transport.
The survey will ask a set of questions about your travel habits and familiarity with VR and present you with several image-led scenarios of potential VR usage in travel.
No previous experience with VR is required to participate – the only requirement for the study is to have used at least one of the following modes of transport at least once in the last year:

- **Bus**
- **Train**
- **Taxi**

2. What is expected of me if I take part?
You will be tasked with answering a survey with four main sections. The questions presented will be a mix of multiple choice and open-ended questions that will ask you to write a short sentence or two to answer them.
There will be a total of 22 questions in this survey and it should take around 15 minutes to complete.
If you wish to take part in the draw for the £25 Amazon voucher, you will be asked to enter your email at the end of the study.
3. What are the possible benefits of participating?
Your answers will help us understand your needs for VR use when travelling, which could make your journeys more entertaining and productive in the future. This survey will help us design better VR applications as well as shape further research in the area.
4. What happens at the end of this study?

The results will be held and owned by the researcher and the University of Glasgow. The results can be outlined to the participants whenever they become available.
The results of this study may be published in a journal or presented at a conference.
Results will always be presented in such a way that data from individual participants cannot be identified. The data will be anonymous.
Upon publication, anonymous research data will be deposited in a suitable data repository, making the data available to other researchers.

5. Can I withdraw from the study?

Your participation in this research project is voluntary, and you may withdraw from the research at any time and for any reason, without explanation.

6. Can I ask questions about the research project?

You may ask more questions about the study at any time - before, during and after the study. Use the contact information provided above if you have any questions.

7. Who has reviewed the study?

The project has been approved by the College Ethics Committee.

This research is funded by ERC Horizon 2020 project ViAjeRo #835197

Consent Form

Please confirm your participation in this study by completing this consent form:

- I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask questions.
- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.
- I understand that the data collected may be used in publications or presentations.
- I am at least 18 years old.
- I have used a bus, train, or taxi at least once in the last year.

Please select "I AGREE TO ALL OF THE ABOVE" to continue

○ I AGREE TO ALL OF THE ABOVE

Demographics

Demographics

How old are you?

○ 18-24
○ 25-34
○ 35-44
○ 45-54
○ 55-64
○ 65-74
○ 75-84
○ 85+

What is your gender?

- Female
- Male
- Non-Binary
- Other (please specify):
- Prefer not to say

In which country do you currently reside?

Travelling habits

Travelling habits

For the following questions, if you have not used the mentioned mode of transport in the last year, please skip to the next question.

How often do you travel by bus [local travel]?

- Infrequently (1-11 trips a year)
- Frequently (at least once a month)
- Regularly (at least once a week)

When you use a bus, what is the most common purpose of your travel?

- Work
- Leisure/Other

How often do you travel by coach [long distance bus travel]?

- Infrequently (1-11 trips a year)
- Frequently (at least once a month)
- Regularly (at least once a week)

When you use a coach, what is the most common purpose of your travel?

- Work
- Leisure/Other

How often do you travel by local train/subway?

- Infrequently (1-11 trips a year)
- Frequently (at least once a month)
- Regularly (at least once a week)

When you use a local train/subway, what is the most common purpose of your travel?

- Work
- Leisure/Other

How often do you travel by long distance train?

- Infrequently (1-11 trips a year)
- Frequently (at least once a month)
- Regularly (at least once a week)

When you use a long distance train, what is the most common purpose of your travel?

- Work
- Leisure/Other

How often do you travel by taxi?

- Infrequently (1-11 trips a year)
- Frequently (at least once a month)
- Regularly (at least once a week)

When you use a taxi what is the most common purpose of your travel?

- Work
- Leisure/Other

How do you usually spend your time when travelling for leisure?
Please select N/A if you do not travel for leisure

	None of my time	A little of my time	Some of my time	A lot of my time	N/A
Entertainment (videos, games, reading etc.)	O	O	O	O	O
Socialising	O	O	O	O	O

	None of my time	A little of my time	Some of my time	A lot of my time	N/A
Productivity (work related activities, writing etc.)	○	○	○	○	○
Sleeping/resting	○	○	○	○	○
Eating/drinking	○	○	○	○	○
Looking out the window	○	○	○	○	○
Other (please specify):	○	○	○	○	○

How do you usually spend your time when travelling for work?
Please select N/A if you do not travel for work

	None of my time	A little of my time	Some of my time	A lot of my time	N/A
Entertainment (videos, games, reading etc.)	○	○	○	○	○
Socialising	○	○	○	○	○
Productivity (work related activities, writing etc.)	○	○	○	○	○
Sleeping/resting	○	○	○	○	○
Eating/drinking	○	○	○	○	○
Looking out the window	○	○	○	○	○
Other (please specify):	○	○	○	○	○

Familiarity with VR

Familiarity with VR

This is the Oculus Quest VR headset.

Image: Oculus

VR Headsets like this are worn on your head, and block out your view of reality, replacing it with a private virtual world of your choosing, such as a virtual cinema, an office, or an immersive game.

Have you ever used a Virtual Reality (VR) headset?

- ○ Yes
- ○ No

If yes, which headset(s) have you used?

- ☐ Oculus Quest
- ☐ Gear VR
- ☐ Oculus Rift
- ☐ HTC Vive
- ☐ Sony PlayStation VR
- ☐ Google Cardboard
- ☐ [ ] Other (please specify):

If yes, have you ever used it when travelling for work or leisure?

- ☐ Used it when travelling for work
- ☐ Used in when travelling for leisure

If you have used it when travelling for work or leisure, please describe your experiences with the headset, and the activities you engaged in:

Please rate your interest in using a Virtual Reality headset on your future journeys when travelling for work:

- Not at all interested
- Not very interested
- Neutral
- Somewhat interested
- Very interested

When travelling for work, would you be more likely to use the headset on a short journey (up to 1h) or a longer journey (1h+)?

- More likely on a short journey (up to 1h)
- More likely on a longer journey (1h+)
- Neutral

Please rate your interest in using a Virtual Reality headset on your future journeys when travelling for leisure:

- Not at all interested
- Not very interested
- Neutral
- Somewhat interested
- Very interested

When travelling for leisure, would you be more likely to use the headset on a short journey (up to 1h) or a longer journey (1h+)?

- More likely on a short journey (up to 1h)
- More likely on a longer journey (1h+)
- Neutral

VR use scenarios

VR use scenarios

For the following question, if you have not used the mentioned mode of transport in the last year, please answer only the applicable parts of the question.

Would you use a VR headset in the different modes of public transport?

	Very unlikely	Moderately unlikely	Neutral	Moderately likely	Very likely
Bus [local travel]	O	O	O	O	O
Coach [long distance bus travel]	O	O	O	O	O
Local train/subway	O	O	O	O	O
Long distance train	O	O	O	O	O
Taxi	O	O	O	O	O

Please explain your answer:

Please rate your interest in using a VR headset on your journey for the below activities:

	Not at all interested	Not very interested	Neutral	Somewhat interested	Very interested
Entertainment (watching videos, playing games etc.)	O	O	O	O	O
Communication (using the device to video chat, catch up with social media etc.)	O	O	O	O	O
Work (completing your work tasks in a virtual environment, participating in meetings etc.)	O	O	O	O	O
Other (please specify):	O	O	O	O	O

Please explain your answer:

Please rate your interest in using a VR headset when travelling for the below journey lengths:

	Not at all interested	Not very interested	Neutral	Somewhat interested	Very interested
Up to 1 hour	O	O	O	O	O
Up to 3 hours	O	O	O	O	O
3-6 hours	O	O	O	O	O
More than 6 hours	O	O	O	O	O

Please explain your answer:

When are you most likely to use a VR headset?

- ☐ When travelling alone
- ☐ When travelling with friends or family
- ☐ When travelling with work colleagues
- ☐ Neutral

Image scenarios

Please look at the following image. It shows a commute scenario. Please imagine you enter and take a seat in this situation.

How comfortable would you be using the headset in this situation?

- ○ Very uncomfortable
- ○ Uncomfortable
- ○ Neutral
- ○ Comfortable
- ○ Very comfortable

Please explain your answer:

Image scenarios

Please look at the following image. It shows a commute scenario. Please imagine you enter and take a seat in this situation.

How comfortable would you be using the headset in this situation?

- Very uncomfortable
- Uncomfortable
- Neutral
- Comfortable
- Very comfortable

Please explain your answer:

Prize draw

Prize Draw

If you would like to take part in the prize draw for the £25 Amazon voucher, please enter your email address below:

Would you like to be added to the mailing list for future studies?

- Yes
- No

Powered by Qualtrics

Appendix C: Interview Guide for Study III (Chapter 4)

No.	Question & Probes
1	Have a look at the printouts of the first scenario you saw today [repeat this for the other environment]. Can you describe what felt safe or unsafe about it? Probes: Why? Why not? [Did they see the other passengers, furniture?]
2	Did you feel that the mix of bus and virtual objects in this scenario was socially acceptable? Probes: Why? Why not?
3	Did you feel it was useful to have this mix of bus and virtual content in this scenario? Probes: What made you feel that way?
4	Was this mix of bus and virtual content distracting? Probes: Why? Why not? What distracted you the most?
5	In this scenario, did you feel like you have escaped the bus environment completely? Probes: Why? Why not?
6	In this scenario, did you feel like you were fully immersed in the documentary? Probes: Why? Why not?
7	Was there anything else that you liked or disliked in this scenario? Probes: Why?

Appendix D: Interview Guide for Study IV (Chapter 4)

No.	Question & Probes
Warm-up.	
1	*Warm-up question.* What are your initial reactions to the two journeys you have experienced?
Experiencing the Anchors.	
2	Why have you turned on/off “Anchor name” during your first journey? Probes: Did you think the anchors were distracting or easy to ignore? Why? Which anchors were more/less distracting? How did it compare to the second journey you experienced?
3	How did you experience watching the documentary in this way? Probes: How immersed in the documentary did you feel? What made you feel that way? Which anchors strengthen/weaken the immersion? How did it compare to the second journey you experienced?
4	How did you choose which anchors to have in view? Probes: How useful or not useful were the anchors? What made the anchors useful/not useful? Which anchors were most/least useful?
5	How did you prioritise the awareness between virtual versus real-world content? Probes: Did you want to keep the awareness of the subway or forget about it? How did it compare to the second journey you experienced?
Audio.	
6	What role did the audio play in your choice of visible anchors?
7	What sounds would you want to bring in or exclude if you could choose? Why? Probes: For example, announcements, doors opening/closing, people chattering etc. What about the second journey you experienced?
Social Acceptability.	

8	How socially acceptable or unacceptable was this experience? Probes: What does the term “social acceptability” mean to you? [allow answers based on own description] In our research, we describe technology as being socially acceptable when it can be used/worn around others without feeling uncomfortable, out of place or judged and where other people around the user also do not feel uncomfortable. Now that you have heard this definition, how socially acceptable or not acceptable do you think was this experience? [NOTE: start by discussing VR on public transport, then talk about the anchors].
Wrapping up.	
9	How would you feel if this journey was familiar to you, for example, your daily commute? Probes: Would you want to use the anchors?
10	How would you feel if this journey took place on a different mode of transport, such as a bus or a plane? Probes: Would you want to use the anchors? Would that affect your choice of anchors?

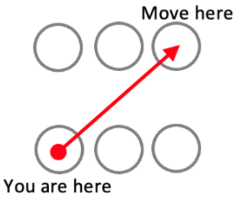
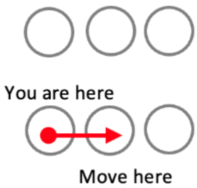
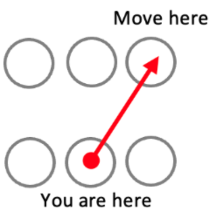
Appendix E: Interview Guide for Study V (Chapter 5)

No.	Question & Probes
Introductions.	
1	Welcome to the focus group! Before we begin, can each of you introduce yourself, mentioning which persona you portrayed during the experiment? (Allow participants to introduce themselves, ask to always mention their persona when speaking, then move on to the next question)
2	[For all] What were your initial reactions to the scenario you just experienced in the experiment? ("Can you tell us more about that?" or "What specifically stood out to you?")
Perception of Interaction.	
3	[For all] How did you feel about the interaction you were required to complete during the experiment?
4	[For mobile] When you were performing (moving/dropping pens/asking a question), how did you feel? Did you have any concerns?
5	[For VR user] When you were performing (asking a question/moving), how did you feel? Did you have any concerns?
6	[For VR+ RA user] When you were asking the questions, how did you feel? Did you have any concerns?
7	[For VR + RA & Mobile users] When you were observing (change based on persona) how did you feel? Did you have any concerns?
8	[For VR user] Did you notice anything happening around you? What stood out to you? Did you have any concerns?
9	[For all] Were there any surprises or unexpected moments? ("What did you think of the other participants' interactions?" or "When you were observing that, what did you think?")
Social Acceptability.	
10	What does the term "social acceptability" mean to you? In our research, we describe technology as being socially acceptable when it can be used/worn around others without feeling uncomfortable, out of place or judged and where other people around the user also do not feel uncomfortable.

11	Now that you have heard this definition, how socially acceptable or not acceptable do you think was this experience? Let's discuss in more detail.
12	[For mobile user] When you had to move to a different seat, stretch and drop the pens did, you think it was socially acceptable or unacceptable? How would you feel about the interaction if your role was VR user/ Reality Anchors user?
13	When you were asked a question by the VR user/VR + Reality Anchors user/ saw a VR user moving, did you think their actions were socially acceptable or unacceptable?
14	[For VR user] When you had to ask a question and move seats, did you think it was socially acceptable or unacceptable? How would you feel about the interaction if your role was a mobile user/ Reality Anchors user?
15	When you were asked a question by the Reality Anchors user, did you think their action was socially acceptable or unacceptable?
16	Did you notice any other actions happening around you? Did you think they were socially acceptable or unacceptable?
17	[For Reality Anchors User] You had to ask a couple of questions. Did you think it was socially acceptable or unacceptable? How would you feel about the interaction if your role was a mobile user/ VR user?
18	Did you notice any other actions happening around you? Did you think they were socially acceptable or unacceptable? ("When you saw other passengers moving around/asking questions, did you think their actions were socially acceptable or unacceptable?") ("What makes you say that?" or "Can you explain more?")
Using Reality Anchors.	
19	[For all] How did you feel about the VR headset with cues from reality?
20	[For observers] Does knowing that the VR + Reality Anchors user could see you change how you feel about the interaction you completed? Did you realise you were being seen? ("What did you think of the Reality Anchors?" or, for observers, "Would you have acted differently if you were using a headset with the Reality Anchors?")
21	[For all] How would you feel about using a headset with the cues enabled in a real travelling context? For example, a daily commute, or a long-haul trip?
22	[For all] Would the mode of transport influence your feelings about using the headset with Reality Anchors? ("Why is that?" or "Can you tell us more about your thoughts on that?")

23	[For all] Is there anything else that you would like to mention before we wrap up?
24	[For all] Any final questions or comments? (Allow each participant to answer, then conclude the focus group).

List of prompts used in Study V.

User	Time	Prompt
Mobile	2.5 min	1. Please stand up; 2. Do some stretches; 3. Move over here: 
	7 min	1. Please move over here:  2. Please drop your bag with pens.
VR	4.5 min	1. Please ask a person to your left a question: “Could you tell me what is the final destination for this train?” 2. Please remove your headset and move over here: 
	9 min	Please take off the headset and leave the chair area.
XR	6 min	Please ask the person in front of you, "So, what are your plans in Edinburgh?"
	9 min	Please turn to the person on your left and ask them: “Could you tell me what time it is?”

Appendix F: Interview Guide for Study VI (Chapter 5)

No.	Question & Probes
During the break between train rides.	
1	Could you share your first impressions of what you have just experienced?
2	How did you decide where to sit?
Reflections.	
3	In retrospect, how did you feel about using a virtual reality headset on the train?
4	How did the experience of using a virtual reality headset on a train compare with your expectations? Were there any surprises?
Mixing real and virtual.	
5	Did you feel more present in the train, the virtual environment, or the mix? Please explain.
6	How comfortable or uncomfortable did the mix of real and virtual content make you feel during the experience? Why?
Concerns.	
7	Did you have any concerns during the journey? If yes, how did you deal with these concerns?
8	How comfortable or uncomfortable did you feel about using the VR headset?
9	Considering the social context during the journey, what did you think other people were thinking about you? Was this on your mind?
Perceptions of portals.	
10	Did the virtual reality experience impact your sense of social connection with other passengers? If yes, how?
11	What are your overall thoughts on the portals?
12	Reflecting on the portals you drew; what influenced your choice to draw a portal?
13	On the journey back, there were three pre-set portals. How did that compare to your setup on the way out?

Appendix G: Visual Mapping of the Progression of Studies in This Thesis

Studies I & II

Purpose: Identify barriers to the acceptance of immersive technologies in public transport

Method: Surveys

Key Findings: Journey length and mode affect acceptance (e.g., shorter journeys, such as bus trips, perceived as less acceptable).
Transit-specific awareness needs include maintaining awareness of other passengers, personal belongings, surroundings, and journey progression.

Action: Informed the design of Reality Anchors (RA).

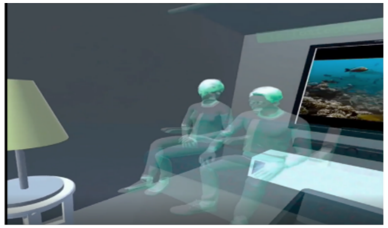
Study III

Purpose: Test initial user reactions to Reality Anchors: passengers, belongings, and furniture, and examine their effect on acceptance of headset use in transit.

Method: VR Simulations

Key Findings: People and personal belongings were the most effective anchors.
Journeys could be categorised as self- or externally managed, helping shape Study IV. The study also highlighted the value of user control and the potential of radius-based anchors.

Action: Informed the next study by introducing self- and externally managed journeys and confirming the need for a journey information anchor and anchor control.



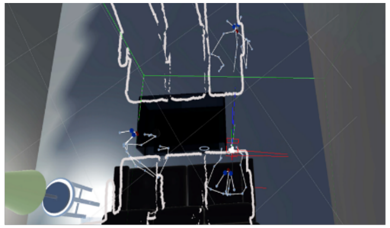
Study IV

Purpose: Explore anchor usage on self-managed and externally managed journeys.

Method: VR Simulations

Key Findings: Self-managed journeys heightened the use of anchors like signage and passengers, while externally managed journeys required fewer, enabling greater focus on immersive content; as journeys progressed, anchor use shifted in response to changing awareness needs.

Action: Highlighted the need to understand how unpredictable real-world conditions, such as passenger interactions and immersive device use in live transit, shape reality-awareness needs.



Study V

Purpose: Examined how passengers using different devices handle unexpected co-located interactions and how these influence Reality Anchors and acceptance of immersive technologies.

Method: Enactments

Key Findings: RA reduced safety concerns by maintaining awareness of nearby passengers. However, verbal interactions remained difficult without non-verbal cues like gaze or expression. These findings suggest that anchors may need to evolve to better support complex social interactions.

Action: Revealed social interaction challenges in real-world use, prompting the next study to explore how changing environments affect awareness needs during live train journeys.

Study VI

Purpose: To examine the effect of dynamic real-world transit environments on reality awareness systems, focusing on their role in supporting passenger safety, awareness, and social concerns.

Method: In-the-Wild Study

Key Findings: Portals, a simplified form of Reality Anchors, help address safety, awareness, and social concerns but make managing real and virtual environments challenging. Users preferred passive monitoring, pointing to Reality Anchors' potential to reduce cognitive effort in transit.

Action: Highlighted Reality Anchors as an effective first step toward improving acceptance of immersive technologies in transit by addressing safety, awareness, and social concerns.

Bibliography

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

[2] Melvin Abraham, Pejman Saeghe, Mark Mcgill, and Mohamed Khamis. 2022. Implications of XR on Privacy, Security and Behaviour: Insights from Experts. In *Nordic Human-Computer Interaction Conference*, October 08, 2022. ACM, New York, NY, USA, 1–12. https://doi.org/10.1145/3546155.3546691

[3] Anne Adams and Anna L Cox. 2008. Questionnaires, in-depth interviews and focus groups. In *Research Methods for Human-Computer Interaction*, Paul Cairns and Anna L Cox (eds.). Cambridge University Press, Cambridge, 17–34. https://doi.org/DOI: 10.1017/CBO9780511814570.003

[4] David Ahlström, Khalad Hasan, and Pourang Irani. 2014. Are you comfortable doing that? In *Proceedings of the 16th international conference on Human-computer interaction with mobile devices & services*, September 23, 2014. ACM, New York, NY, USA, 193–202. https://doi.org/10.1145/2628363.2628381

[5] N. Ahmadpour, M. Kühne, J. M. Robert, and P. Vink. 2016. Attitudes towards personal and shared space during the flight. *Work* 54, 4 (September 2016), 981–987. https://doi.org/10.3233/WOR-162346

[6] Naseem Ahmadpour, Gitte Lindgaard, Jean Marc Robert, and Bernard Pownall. 2014. The thematic structure of passenger comfort experience and its relationship to the context features in the aircraft cabin. *Ergonomics* 57, 6 (2014), 801–815. https://doi.org/10.1080/00140139.2014.899632

[7] Takuto Akiyoshi, Masashi Abe, Yuki Shimizu, Yusaku Takahama, Koki Nagata, Yosuke Okami, and Taishi Sawabe. 2022. Hype Dlive: XR Live Performance System for Improving Passenger Comfort in Autonomous Driving. In *HAI 2022 - Proceedings of the 10th Conference on Human-Agent Interaction*, December 05, 2022. Association for Computing Machinery, Inc, 296–298. https://doi.org/10.1145/3527188.3563916

[8] Ghassem Alaee, Amit Deasi, Lourdes Peña-Castillo, Edward Brown, and Oscar Meruvia-Pastor. 2018. A User Study on Augmented Virtuality Using Depth Sensing Cameras for Near-Range Awareness in Immersive VR. In *IEEE VR's 4th Workshop on Everyday Virtual Reality (WEVR 2018)*, March 2018. Reutlingen, Germany.

[9] Fouad Alallah, Khalad Hasan, Ali Neshati, Edward Lank, Pourang Irani, Yumiko Sakamoto, and Andrea Bunt. 2018. Performer vs. observer: Whose comfort level should we consider when examining the social acceptability of input modalities for head-worn display? In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST*, November 28, 2018. Association for Computing Machinery. https://doi.org/10.1145/3281505.3281541

[10] Lui Albæk Thomsen, Niels Christian Nilsson, Rolf Nordahl, and Boris Lohmann. 2019. Asymmetric collaboration in virtual reality. *Tidsskriftet Læring og Medier (LOM)* 12, 20 (March 2019). https://doi.org/10.7146/lom.v12i20.109391

[11] Álvaro Aranda Muñoz, Nina Bozic Yams, and Lisa Carlgren. 2023. CO-DESIGNING TECHNOLOGICAL EXPLORATIONS IN DEVELOPING FUTURES LITERACY THROUGH SPECULATIVE DESIGN AND AN ARTISTIC INTERVENTION.

Proceedings of the Design Society 3, (July 2023), 957–966. https://doi.org/10.1017/pds.2023.96

[12] Eric P.S. Baumer, Mark Blythe, and Theresa Jean Tanenbaum. 2020. Evaluating design fiction: The right tool for the job. In *DIS 2020 - Proceedings of the 2020 ACM Designing Interactive Systems Conference*, July 03, 2020. Association for Computing Machinery, Inc, 1901–1913. https://doi.org/10.1145/3357236.3395464

[13] Subhasis Bhaumik, Subrata Chattopadhyay, Tanushyam Chattopadhyay, and Srijan Bhattacharya. 2022. *Proceedings of International Conference on Industrial Instrumentation and Control*. Springer Nature Singapore, Singapore. https://doi.org/10.1007/978-981-16-7011-4

[14] Verena Biener, Snehanjali Kalamkar, John J. Dudley, Jinghui Hu, Per Ola Kristensson, Jörg Müller, and Jens Grubert. 2024. Working with XR in Public: Effects on Users and Bystanders. In *2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, March 16, 2024. IEEE, 779–780. https://doi.org/10.1109/VRW62533.2024.00186

[15] Laurens Boer and Jared Donovan. 2012. Provotypes for participatory innovation. In *Proceedings of the Designing Interactive Systems Conference*, June 11, 2012. ACM, New York, NY, USA, 388–397. https://doi.org/10.1145/2317956.2318014

[16] Evren Bozgeyikli and Victor Gomes. 2022. Googly Eyes: Displaying User's Eyes on a Head-Mounted Display for Improved Nonverbal Communication. In *CHI PLAY 2022 - Extended Abstracts of the 2022 Annual Symposium on Computer-Human Interaction in Play*, November 02, 2022. Association for Computing Machinery, Inc, 253–260. https://doi.org/10.1145/3505270.3558348

[17] Nina Bozic Yams and Álvaro Aranda Muñoz. 2021. Poetics of Future Work: Blending Speculative Design with Artistic Methodology. In *Conference on Human Factors in Computing Systems - Proceedings*, May 08, 2021. Association for Computing Machinery. https://doi.org/10.1145/3411763.3443451

[18] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qual Res Psychol* 3, 2 (2006), 77–101. https://doi.org/10.1191/1478088706qp063oa

[19] Virginia Braun and Victoria (Associate Professor in Sexuality Studies) Clarke. 2013. *Successful qualitative research: a practical guide for beginners*. SAGE, London. Retrieved from https://go.exlibris.link/GT5nYJGv

[20] Marion Buchenau and Jane Fulton Suri. 2000. Experience prototyping. In *Proceedings of the conference on Designing interactive systems processes, practices, methods, and techniques - DIS '00*, 2000. ACM Press, New York, New York, USA, 424–433. https://doi.org/10.1145/347642.347802

[21] Stuart Candy and Kelly Kornet. 2019. Turning foresight inside out: An introduction to ethnographic experiential futures. *Journal of Futures Studies* 23, 3 (March 2019), 3-22. https://doi.org/10.6531/JFS.201903_23(3).0002

[22] Alan Chamberlain and Andy Crabtree. 2020. Research 'In the Wild.' . 1-6. https://doi.org/10.1007/978-3-030-18020-1_1

[23] Liwei Chan and Kouta Minamizawa. 2017. FrontFace: Facilitating communication between HMD users and outsiders using front-facing-screen HMDs. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services, MobileHCI 2017*, September 04, 2017. Association for Computing Machinery, Inc. https://doi.org/10.1145/3098279.3098548

[24] Ji Won Chung, Xiyu Jenny Fu, Zachary Deocadiz-Smith, Malte F Jung, and Jeff Huang. 2023. Negotiating Dyadic Interactions through the Lens of Augmented Reality Glasses. July 10, 2023. Association for Computing Machinery (ACM), 493–508. https://doi.org/10.1145/3563657.3595967

[25] Gabriel Cirio, Peter Vangorp, Emmanuelle Chapoulie, Maud Marchal, Anatole L ´ Ecuyer, and George Drettakis. 2012. *Walking in a Cube: Novel Metaphors for Safely Navigating Large Virtual Environments in Restricted Real Workspaces*.

[26] Juliet Corbin and Anselm Strauss. 2012. Basics of Qualitative Research (3rd ed.): Techniques and Procedures for Developing Grounded Theory. *Basics of Qualitative Research (3rd ed.): Techniques and Procedures for Developing Grounded Theory* (2012), 2021–2022. https://doi.org/10.4135/9781452230153

[27] Andy Crabtree, Alan Chamberlain, Rebecca E. Grinter, Matt Jones, Tom Rodden, and Yvonne Rogers. 2013. Introduction to the special issue of "The turn to the wild. *ACM Transactions on Computer-Human Interaction 20*. https://doi.org/10.1145/2491500.2491501

[28] 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. https://doi.org/10.1080/15213269.2015.1015740

[29] F D Davis. 1985. A technology acceptance model for empirically testing new end-user information systems: Theory and results. *Management* Ph.D., May (1985), 291. https://doi.org/oclc/56932490

[30] Tamara Denning, Zakariya Dehlawi, and Tadayoshi Kohno. 2014. In situ with bystanders of augmented reality glasses: Perspectives on recording and privacy-mediating technologies. In *Conference on Human Factors in Computing Systems - Proceedings*, 2014. Association for Computing Machinery, 2377–2386. https://doi.org/10.1145/2556288.2557352

[31] Audrey Desjardins, Cayla Key, Heidi R. Biggs, and Kelsey Aschenbeck. 2019. Bespoke booklets: A method for situated co-speculation. In *DIS 2019 - Proceedings of the 2019 ACM Designing Interactive Systems Conference*, June 18, 2019. Association for Computing Machinery, Inc, 697–709. https://doi.org/10.1145/3322276.3322311

[32] Bob Doyle. 2016. 5 Reasons Why Google Glass was a Miserable Failure - Business 2 Community. Retrieved June 4, 2020 from https://www.business2community.com/tech-gadgets/5-reasons-google-glass-miserable-failure-01462398

[33] Anthony Dunne and Fiona Raby. 2013. *Speculative Everything: Design, Fiction, and Social Dreaming*. The MIT Press.

[34] Pouya Eghbali, Kaisa Väänänen, and Tero Jokela. 2019. Social acceptability of virtual reality in public spaces: Experiential factors and design recommendations. *PervasiveHealth: Pervasive Computing Technologies for Healthcare* (2019). https://doi.org/10.1145/3365610.3365647

[35] Chris Elsden, David Chatting, Abigail C. Durrant, Andrew Garbett, Bettina Nissen, John Vines, and David S. Kirk. 2017. On speculative enactments. In *Conference on Human Factors in Computing Systems - Proceedings*, 2017. Association for Computing Machinery, 5386–5399. https://doi.org/10.1145/3025453.3025503

[36] Ahmed Elsharkawy, Aya Ataya, Dohyeon Yeo, Minwoo Seong, Seokhyun Hwang, Joseph DelPreto, Wojciech Matusik, Daniela Rus, and SeungJun Kim. 2024. Adaptive In-Vehicle Virtual Reality for Reducing Motion Sickness: Manipulating Passenger Posture During Driving Events. In *Companion of the*

2024 on ACM International Joint Conference on Pervasive and Ubiquitous Computing, October 05, 2024. ACM, New York, NY, USA, 832–836. https://doi.org/10.1145/3675094.3678381

[37] Isamu Endo, Kazuki Takashima, Maakito Inoue, Kazuyuki Fujita, Kiyoshi Kiyokawa, and Yoshifumi Kitamura. 2021. ModularHMD: A Reconfigurable Mobile Head-Mounted Display Enabling Ad-hoc Peripheral Interactions with the Real World. In *UIST 2021 - Proceedings of the 34th Annual ACM Symposium on User Interface Software and Technology*, October 10, 2021. Association for Computing Machinery, Inc, 100–117. https://doi.org/10.1145/3472749.3474738

[38] Barrett Ens, Joel Lanir, Anthony Tang, Scott Bateman, Gun Lee, Thammathip Piumsomboon, and Mark Billinghurst. 2019. Revisiting collaboration through mixed reality: The evolution of groupware. *International Journal of Human Computer Studies* 131, (November 2019), 81–98. https://doi.org/10.1016/j.ijhcs.2019.05.011

[39] Gary W. Evans and Richard E. Wener. 2007. Crowding and personal space invasion on the train: Please don't make me sit in the middle. *J Environ Psychol* 27, 1 (March 2007), 90–94. https://doi.org/10.1016/j.jenvp.2006.10.002

[40] Facebook Technologies, LLC. Oculus Quest: All-in-One VR Headset | Oculus. Retrieved June 4, 2020 from https://www.oculus.com/quest/

[41] Pedro Gil Farias, Roy Bendor, and Bregje F. Van Eekelen. 2022. Social dreaming together: A critical exploration of participatory speculative design. In *ACM International Conference Proceeding Series*, August 19, 2022. Association for Computing Machinery, 147–154. https://doi.org/10.1145/3537797.3537826

[42] Andreas Rene Fender and Christian Holz. 2022. Causality-preserving Asynchronous Reality. In *Conference on Human Factors in Computing Systems - Proceedings*, April 29, 2022. Association for Computing Machinery. https://doi.org/10.1145/3491102.3501836

[43] Carlos Bermejo Fernandez and Pan Hui. 2022. Life, the Metaverse and Everything: An Overview of Privacy, Ethics, and Governance in Metaverse. In *Proceedings - 2022 IEEE 42nd International Conference on Distributed Computing Systems Workshops, ICDCSW 2022*, 2022. Institute of Electrical and Electronics Engineers Inc., 272–277. https://doi.org/10.1109/ICDCSW56584.2022.00058

[44] Laura E. Forlano and Megan K. Halpern. 2023. Speculative Histories, Just Futures: From Counterfactual Artifacts to Counterfactual Actions. *ACM Transactions on Computer-Human Interaction* 30, 2 (April 2023), 1–37. https://doi.org/10.1145/3577212

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

[46] Charlotte Frei, Hani S. Mahmassani, and Andreas Frei. 2015. Making time count: Traveler activity engagement on urban transit. *Transp Res Part A Policy Pract* 76, (June 2015), 58–70. https://doi.org/10.1016/j.tra.2014.12.007

[47] Ceenu George, Philipp Janssen, David Heuss, and Florian Alt. 2019. Should I interrupt or not? Understanding interruptions in head-mounted display settings. *DIS 2019 - Proceedings of the 2019 ACM Designing Interactive Systems Conference* (2019), 497–510. https://doi.org/10.1145/3322276.3322363

[48] Ceenu George, Patrick Tamunjoh, and Heinrich Hussmann. 2020. Invisible Boundaries for VR: Auditory and Haptic Signals as Indicators for Real World Boundaries. *IEEE Trans Vis Comput Graph* 26, 12 (December 2020), 3414–3422. https://doi.org/10.1109/TVCG.2020.3023607

[49] Ceenu George, An Ngo Tien, and Heinrich Hussmann. 2020. Seamless, Bi-directional Transitions along the Reality-Virtuality Continuum: A Conceptualization and Prototype Exploration. *Proceedings - 2020 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2020* (2020), 412–424. https://doi.org/10.1109/ISMAR50242.2020.00067

[50] Sarthak Ghosh, Lauren Winston, Nishant Panchal, Philippe Kimura-Thollander, Jeff Hotnog, Douglas Cheong, Gabriel Reyes, and Gregory D. Abowd. 2018. NotifiVR: Exploring Interruptions and Notifications in Virtual Reality. *IEEE Trans Vis Comput Graph* 24, 4 (April 2018), 1447–1456. https://doi.org/10.1109/TVCG.2018.2793698

[51] Mar Gonzalez-Franco and Andrea Colaco. 2024. Guidelines for Productivity in Virtual Reality. *Interactions* 31, 3 (May 2024), 46–53. https://doi.org/10.1145/3658407

[52] Google. Glass – Glass. Retrieved June 4, 2020 from https://www.google.com/glass/start/

[53] Matt Gottsacker, Nahal Norouzi, Kangsoo Kim, Gerd Bruder, and Greg Welch. 2021. Diegetic representations for seamless cross-reality interruptions. In *Proceedings - 2021 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2021*, 2021. Institute of Electrical and Electronics Engineers Inc., 310–319. https://doi.org/10.1109/ISMAR52148.2021.00047

[54] Jeronimo Gustavo Grandi, Henrique Galvan Debarba, and Anderson Maciel. 2019. Characterizing Asymmetric Collaborative Interactions in Virtual and Augmented Realities. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, March 2019. IEEE, 127–135. https://doi.org/10.1109/VR.2019.8798080

[55] 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. https://doi.org/10.1007/s11116-012-9396-7

[56] Stephen Groening. 2013. Aerial screens. *Hist Technol* 29, 3 (2013), 284–303. https://doi.org/10.1080/07341512.2013.858523

[57] Jens Grubert, Eyal Ofek, Michel Pahud, and Per Ola Kristensson. 2018. The Office of the Future: Virtual, Portable, and Global. *IEEE Comput Graph Appl* 38, 6 (November 2018), 125–133. https://doi.org/10.1109/MCG.2018.2875609

[58] Jan Gugenheimer, Christian Mai, Mark McGill, Julie Williamson, Frank Steinicke, and Ken Perlin. 2019. Challenges Using Head-Mounted Displays in Shared and Social Spaces. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, May 02, 2019. ACM, New York, NY, USA, 1–8. https://doi.org/10.1145/3290607.3299028

[59] 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*, May 02, 2017. Association for Computing Machinery, 4021–4033. https://doi.org/10.1145/3025453.3025683

[60] Jan Gugenheimer, Evgeny Stemasov, Harpreet Sareen, and Enrico Rukzio. 2017. FaceDisplay: Enabling multi-user interaction for mobile virtual reality. In *Conference on Human Factors in Computing Systems - Proceedings*, May 06, 2017. Association for Computing Machinery, 369–372. https://doi.org/10.1145/3027063.3052962

[61] Jan Gugenheimer, Wen Jie Tseng, Abraham Hani Mhaidli, Jan Ole Rixen, Mark McGill, Michael Nebeling, Mohamed Khamis, Florian Schaub, and Sanchari Das. 2022. Novel Challenges of Safety, Security and Privacy in Extended Reality. In *Conference on Human Factors in Computing Systems - Proceedings*, April 27, 2022. Association for Computing Machinery. https://doi.org/10.1145/3491101.3503741

[62] Jaybie A.De Guzman, Kanchana Thilakarathna, and Aruna Seneviratne. 2023. Privacy and Security Issues and Solutions for Mixed Reality Applications. In *Springer Handbooks*. Springer Science and Business Media Deutschland GmbH, 157–183. https://doi.org/10.1007/978-3-030-67822-7_7

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

[64] Daniel Harley and Cayley MacArthur. 2023. Sharing Play Spaces: Design Lessons from Reddit Posts Showing Virtual Reality in the Home. July 10, 2023. Association for Computing Machinery (ACM), 509–522. https://doi.org/10.1145/3563657.3596005

[65] Jeremy Hartmann, Christian Holz, Eyal Ofek, and Andrew D. Wilson. 2019. RealityCheck: Blending virtual environments with situated physical reality. *Conference on Human Factors in Computing Systems - Proceedings* (2019), 1–12. https://doi.org/10.1145/3290605.3300577

[66] Michael Heim. 1994. *The Metaphysics of Virtual Reality*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195092585.001.0001

[67] Ingi Helgason and Michael Smyth. 2020. Ethnographic fictions: Research for speculative design. In *DIS 2020 Companion - Companion Publication of the 2020 ACM Designing Interactive Systems Conference*, July 06, 2020. Association for Computing Machinery, Inc, 203–207. https://doi.org/10.1145/3393914.3395872

[68] Richard J. Holden and Ben Tzion Karsh. 2010. The Technology Acceptance Model: Its past and its future in health care. *J Biomed Inform* 43, 1 (2010), 159–172. https://doi.org/10.1016/j.jbi.2009.07.002

[69] Kenneth Holstein, Erik Harpstead, Rebecca Gulotta, and Jodi Forlizzi. 2020. Replay enactments: Exploring possible futures through historical data. In *DIS 2020 - Proceedings of the 2020 ACM Designing Interactive Systems Conference*, July 03, 2020. Association for Computing Machinery, Inc, 1607–1618. https://doi.org/10.1145/3357236.3395427

[70] Eva Hornecker and Emma Nicol. 2012. What do lab-based user studies tell us about in-the-wild behavior? In *Proceedings of the Designing Interactive Systems Conference*, June 11, 2012. ACM, New York, NY, USA, 358–367. https://doi.org/10.1145/2317956.2318010

[71] Robin P. Horton, Tamsin Buck, Patrick E. Waterson, and Chris W. Clegg. 2001. Explaining intranet use with the technology acceptance model. *Journal of Information Technology* 16, 4 (2001), 237–248. https://doi.org/10.1080/02683960110102407

[72] Yi Ta Hsieh, Antti Jylhä, Valeria Orso, Luciano Gamberini, and Giulio Jacucci. 2016. Designing a willing-to-use-in-public hand gestural interaction technique for smart glasses. In *Conference on Human Factors in Computing Systems - Proceedings*, May 07, 2016. Association for Computing Machinery, 4203–4215. https://doi.org/10.1145/2858036.2858436

[73] HTC Corporation. 2020. VIVE™ | Discover Virtual Reality Beyond Imagination. Retrieved June 4, 2020 from https://www.vive.com

[74] Hikaru Ibayashi, Yuta Sugiura, Daisuke Sakamoto, Natsuki Miyata, Mitsunori Tada, Takashi Okuma, Takeshi Kurata, Masaaki Mochimaru, and Takeo Igarashi. 2015. Dollhouse VR: A multi-view, multi-user collaborative design workspace with VR technology. In *SIGGRAPH Asia 2015 Emerging*

Technologies, SA 2015, November 02, 2015. Association for Computing Machinery, Inc. https://doi.org/10.1145/2818466.2818480

[75] Bret Jackson, Linda Lor, and Brianna C. Heggeseth. 2024. Workspace Guardian: Investigating Awareness of Personal Workspace Between Co-Located Augmented Reality Users. *IEEE Trans Vis Comput Graph* 30, 5 (May 2024), 2724–2733. https://doi.org/10.1109/TVCG.2024.3372073

[76] Pascal Jansen, Fabian Fischbach, Jan Gugenheimer, Evgeny Stemasov, Julian Frommel, and Enrico Rukzio. 2020. ShARe: Enabling co-located asymmetric multi-user interaction for augmented reality head-mounted displays. In *UIST 2020 - Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*, October 20, 2020. Association for Computing Machinery, Inc, 459–471. https://doi.org/10.1145/3379337.3415843

[77] Kisung Jeong, Jinmo Kim, Mingyu Kim, Jiwon Lee, and Chanhun Kim. 2020. Asymmetric interface: User interface of asymmetric virtual reality for new presence and experience. *Symmetry (Basel)* 12, 1 (January 2020). https://doi.org/10.3390/SYM12010053

[78] Mohamed Kari and Christian Holz. 2023. HandyCast: Phone-based Bimanual Input for Virtual Reality in Mobile and Space-Constrained Settings via Pose-and-Touch Transfer. In *Conference on Human Factors in Computing Systems - Proceedings*, April 19, 2023. Association for Computing Machinery. https://doi.org/10.1145/3544548.3580677

[79] Jasmine Kaur, Rishabh Devgon, Smera Goel, Arunesh Singh, Kyzyl Monteiro, and Advika Singh. 2022. Future of Intimate Artefacts: A Speculative Design Investigation. In *ACM International Conference Proceeding Series*, November 09, 2022. Association for Computing Machinery, 57–66. https://doi.org/10.1145/3570211.3570216

[80] Norene Kelly. 2017. All the world's a stage. *Interactions* 24, 6 (October 2017), 56–60. https://doi.org/10.1145/3137093

[81] Norene Kelly. 2018. My Device, My Self: Wearables as a Specific Case of the Social Acceptability of Technology. In *CHI'18 Workshop on (Un)Acceptable!?!—Re-thinking the Social Acceptability of Emerging Technologies*, April 2018. Montreal, QC.

[82] Norene Kelly and Stephen B Gilbert. 2016. The WEAR Scale : Developing a Measure of the Social Acceptability of a Wearable Device The WEAR Scale : Developing a Measure of the Social Acceptability of a Wearable Device. (2016).

[83] Norene Kelly and Stephen B. Gilbert. 2018. The wearer, the device, and its use: Advances in understanding the social acceptability of wearables. In *Proceedings of the Human Factors and Ergonomics Society*, 2018. Human Factors and Ergonomics Society Inc., 1027–1031. https://doi.org/10.1177/1541931218621237

[84] Adam Kendon. 1967. Some functions of gaze-direction in social interaction. *Acta Psychol (Amst)* 26, (1967), 22–63. https://doi.org/10.1016/0001-6918(67)90005-4

[85] Jarrod Knibbe, Jonas Schjerlund, Mathias Petræus, and Kasper Hornbæk. 2018. The dream is collapsing: The experience of exiting VR. In *Conference on Human Factors in Computing Systems - Proceedings*, April 20, 2018. Association for Computing Machinery. https://doi.org/10.1145/3173574.3174057

[86] Pascal Knierim, Thomas Kosch, and Albrecht Schmidt. 2021. The Nomadic Office: A Location Independent Workspace through Mixed Reality. *IEEE*

Pervasive Comput 20, 4 (2021), 71–78. https://doi.org/10.1109/MPRV.2021.3119378

[87] Marion Koelle, Abdallah El Ali, Vanessa Cobus, Wilko Heuten, and Susanne C.J. Boll. 2017. All about acceptability? Identifying factors for the adoption of data glasses. In *Conference on Human Factors in Computing Systems - Proceedings*, May 02, 2017. Association for Computing Machinery, 295–300. https://doi.org/10.1145/3025453.3025749

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

[89] Marion Koelle, Susanne Boll, Halley Profita, Shaun Kane, Thomas Olsson, Julie Williamson, and Robb Mitchell. 2018. (Un)Acceptable!?! – re-thinking the social acceptability of emerging technologies. In *Conference on Human Factors in Computing Systems - Proceedings*, April 20, 2018. Association for Computing Machinery. https://doi.org/10.1145/3170427.3170620

[90] Marion Koelle, Thomas Olsson, Robb Mitchell, Julie Williamson, and Susanne Boll. 2019. What is (un)acceptable? *Interactions* 26, 3 (April 2019), 36–40. https://doi.org/10.1145/3319073

[91] Maulik C. Kotecha, Ting Ju Chen, Daniel A. McAdams, and Vinayak Krishnamurthy. 2021. Design ideation through speculative fiction: Foundational principles and exploratory study. *Journal of Mechanical Design, Transactions of the ASME* 143, 8 (August 2021). https://doi.org/10.1115/1.4049656

[92] Nadia Kovach. What is VR and how does Virtual Reality work in modern world? Retrieved June 4, 2020 from https://thinkmobiles.com/blog/what-is-vr/

[93] Richard A Krueger and Mary Anne Casey. 2000. *Focus groups : a practical guide for applied research*. SAGE Publications, Inc, Thousand Oaks, Calif. Retrieved from https://ezproxy.lib.gla.ac.uk/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=nlebk&AN=63273&site=ehost-live

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

[95] Laerd Statistics. 2015. Friedman test using SPSS Statistics. *Statistical tutorials and software guides*. Retrieved from https://statistics.laerd.com/

[96] Jonathan Lazar, Jinjuan Heidi Feng, and Harry Hochheiser. 2017. Surveys. In *Research Methods in Human Computer Interaction*. Elsevier, 105–133. https://doi.org/10.1016/B978-0-12-805390-4.00005-4

[97] Jonathan Lazar, Jinjuan Heidi Feng, and Harry Hochheiser. 2017. Interviews and focus groups. In *Research Methods in Human Computer Interaction*. Elsevier, 187–228. https://doi.org/10.1016/B978-0-12-805390-4.00008-X

[98] Do Young Lee, Youryang Lee, Yonghwan Shin, and Ian Oakley. 2018. Designing socially acceptable hand-to-face input. In *UIST 2018 - Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology*, October 11, 2018. Association for Computing Machinery, Inc, 711–723. https://doi.org/10.1145/3242587.3242642

[99] Hsinju Lee, Fang Hsin Hsu, Wei Ko Li, Jie Tsai, Ying Yu Chen, and Yung Ju Chang. 2023. Get Distracted or Missed the Stop? Investigating Public Transit Passengers' Travel-Based Multitasking Behaviors, Motives, and Challenges. In *Conference on Human Factors in Computing Systems - Proceedings*, April

19, 2023. Association for Computing Machinery. https://doi.org/10.1145/3544548.3581391

[100] Jiwon Lee, Mingyu Kim, and Jinmo Kim. 2020. RoleVR: Multi-experience in immersive virtual reality between co-located HMD and non-HMD users. *Multimed Tools Appl* 79, 1–2 (January 2020), 979–1005. https://doi.org/10.1007/s11042-019-08220-w

[101] Sueyoon Lee, Irene Viola, Silvia Rossi, Zhirui Guo, Ignacio Reimat, Kinga Lawicka, Alina Striner, and Pablo Cesar. 2024. Designing and Evaluating a VR Lobby for a Socially Enriching Remote Opera Watching Experience. *IEEE Trans Vis Comput Graph* 30, 5 (May 2024), 2055–2065. https://doi.org/10.1109/TVCG.2024.3372081

[102] Laura Lewis, Harshada Patel, Mirabelle D'Cruz, and Sue Cobb. 2017. What makes a space invader? Passenger perceptions of personal space invasion in aircraft travel. *Ergonomics* 60, 11 (November 2017), 1461–1470. https://doi.org/10.1080/00140139.2017.1313456

[103] Jingyi Li, Ceenu George, Andrea Ngao, Kai Holländer, Stefan Mayer, and Andreas Butz. 2020. An exploration of users thoughts on rear-seat productivity in virtual reality. *Adjunct Proceedings - 12th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2020* (2020), 92–95. https://doi.org/10.1145/3409251.3411732

[104] Jingyi Li, Ceenu George, Andrea Ngao, Kai Holländer, Stefan Mayer, and Andreas Butz. 2021. Rear-seat productivity in virtual reality: Investigating vr interaction in the confined space of a car. *Multimodal Technologies and Interaction* 5, 4 (April 2021). https://doi.org/10.3390/mti5040015

[105] R Likert. 1932. A technique for the measurement of attitudes. *Archives of Psychology* 22 140, (1932), 55.

[106] Cecilia Loureiro-Koechlin, Jose Rodrigo Cordoba-Pachon, Lynne Coventry, Soteris Demetriou, and Charles Weir. 2022. Vision: Design Fiction for Cybersecurity Using Science Fiction to Help Software Developers Anticipate Problems. In *ACM International Conference Proceeding Series*, September 29, 2022. Association for Computing Machinery, 79–84. https://doi.org/10.1145/3549015.3554295

[107] Glenn Lyons and John Urry. 2005. Travel time use in the information age. *Transp Res Part A Policy Pract* 39, 2–3 (February 2005), 257–276. https://doi.org/10.1016/j.tra.2004.09.004

[108] Christian Mai, Sarah Aragon Bartsch, and Lea Rieger. 2018. Evaluating shared surfaces for co-located mixed-presence collaboration. In *ACM International Conference Proceeding Series*, November 25, 2018. Association for Computing Machinery, 1-5. https://doi.org/10.1145/3282894.3282910

[109] Christian Mai, Lukas Rambold, and Mohamed Khamis. 2017. TransparentHMD: Revealing the HMD user's face to bystanders. In *ACM International Conference Proceeding Series*, November 26, 2017. Association for Computing Machinery, 515–520. https://doi.org/10.1145/3152832.3157813

[110] 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*, September 29, 2018. ACM, New York, NY, USA, 286–298. https://doi.org/10.1145/3240167.3240200

[111] Ville Mäkelä, Rivu Radiah, Saleh Alsherif, Mohamed Khamis, Chong Xiao, Lisa Borchert, Albrecht Schmidt, and Florian Alt. 2020. Virtual Field Studies: Conducting Studies on Public Displays in Virtual Reality. *Conference on*

Human Factors in Computing Systems - Proceedings (2020), 1–15. https://doi.org/10.1145/3313831.3376796
[112] Aliaksandr Malokin, Giovanni Circella, and Patricia L. Mokhtarian. 2021. Do millennials value travel time differently because of productive multitasking? A revealed-preference study of Northern California commuters. *Transportation (Amst)* 48, 5 (October 2021), 2787–2823. https://doi.org/10.1007/s11116-020-10148-2
[113] Shady Mansour, Pascal Knierim, Joseph O'Hagan, Florian Alt, and Florian Mathis. 2023. BANS: Evaluation of Bystander Awareness Notification Systems for Productivity in VR. March 11, 2023. Internet Society. https://doi.org/10.14722/usec.2023.234566
[114] Paul Marshall, Richard Morris, Yvonne Rogers, Stefan Kreitmayer, and Matt Davies. 2011. Rethinking "multi-user": an in-the-wild study of how groups approach a walk-up-and-use tabletop interface. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, May 07, 2011. ACM, New York, NY, USA, 3033–3042. https://doi.org/10.1145/1978942.1979392
[115] Florian Mathis. 2024. Everyday Life Challenges and Augmented Realities: Exploring Use Cases For, and User Perspectives on, an Augmented Everyday Life. In *ACM International Conference Proceeding Series*, April 04, 2024. Association for Computing Machinery, 52–62. https://doi.org/10.1145/3652920.3652921
[116] Florian Mathis, Kami Vaniea, and Mohamed Khamis. 2021. Replicueauth: Validating the use of a lab-based virtual reality setup for evaluating authentication systems. In *Conference on Human Factors in Computing Systems - Proceedings*, May 06, 2021. Association for Computing Machinery. https://doi.org/10.1145/3411764.3445478
[117] Florian Mathis, Kami Vaniea, and Mohamed Khamis. 2021. Observing Virtual Avatars: The Impact of Avatars' Fidelity on Identifying Interactions. In *ACM International Conference Proceeding Series*, June 01, 2021. Association for Computing Machinery, 154–164. https://doi.org/10.1145/3464327.3464329
[118] Mark Mcgill, Daniel Boland, Roderick Murray-Smith, and Stephen Brewster. 2015. A dose of reality: Overcoming usability challenges in VR head-mounted displays. *Conference on Human Factors in Computing Systems - Proceedings* 2015-April, (2015), 2143–2152. https://doi.org/10.1145/2702123.2702382
[119] 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*, September 21, 2019. Association for Computing Machinery, Inc, 434–441. https://doi.org/10.1145/3349263.3351330
[120] Mark McGill, Gang Li, Alex Ng, Laura Bajorunaite, Julie Williamson, Frank Pollick, and Stephen Brewster. 2022. Augmented, Virtual and Mixed Reality Passenger Experiences. In *Studies in Computational Intelligence*. Springer Science and Business Media Deutschland GmbH, 445–475. https://doi.org/10.1007/978-3-030-77726-5_17
[121] Mark McGill, Alexander Ng, and Stephen Brewster. 2017. I am the passenger: How visual motion cues can influence sickness for in-car VR. *Conference on Human Factors in Computing Systems - Proceedings* 2017-May, May (2017), 5655–5668. https://doi.org/10.1145/3025453.3026046
[122] Mark McGill, John H. Williamson, and Stephen Brewster. 2016. Examining the role of smart TVs and VR HMDs in synchronous at-a-distance media consumption. *ACM Transactions on Computer-Human Interaction* 23, 5 (November 2016). https://doi.org/10.1145/2983530

[123] 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. https://doi.org/10.1007/s10055-019-00420-x

[124] Mark McGill, Graham Wilson, Daniel Medeiros, and Stephen Anthony Brewster. 2022. PassengXR: A Low Cost Platform for Any-Car, Multi-User, Motion-Based Passenger XR Experiences. In *UIST 2022 - Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology*, October 29, 2022. Association for Computing Machinery, Inc. https://doi.org/10.1145/3526113.3545657

[125] Joshua McVeigh-Schultz, Max Kreminski, Keshav Prasad, Perry Hoberman, and Scott S. Fisher. 2018. Immersive design fiction: Using VR to prototype speculative interfaces and interaction rituals within a virtual storyworld. In *DIS 2018 - Proceedings of the 2018 Designing Interactive Systems Conference*, June 08, 2018. Association for Computing Machinery, Inc, 817–830. https://doi.org/10.1145/3196709.3196793

[126] 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. *Proceedings - 2021 IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2021* (2021), 21–30. https://doi.org/10.1109/VR50410.2021.00022

[127] 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. *Proceedings - 2021 IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2021* (2021), 21–30. https://doi.org/10.1109/VR50410.2021.00022

[128] Daniel Medeiros, Romane Dubus, Julie Williamson, Graham Wilson, Katharina Pöhlmann, and Mark McGill. 2023. Surveying the Social Comfort of Body, Device, and Environment-Based Augmented Reality Interactions in Confined Passenger Spaces Using Mixed Reality Composite Videos. *Proc ACM Interact Mob Wearable Ubiquitous Technol* 7, 3 (September 2023), 1–25. https://doi.org/10.1145/3610923

[129] Daniel Medeiros, Mark McGill, Alexander Ng, Robert McDermid, Nadia Pantidi, Julie Williamson, and Stephen Brewster. 2022. From Shielding to Avoidance: Passenger Augmented Reality and the Layout of Virtual Displays for Productivity in Shared Transit. *IEEE Trans Vis Comput Graph* 28, 11 (November 2022), 3640–3650. https://doi.org/10.1109/TVCG.2022.3203002

[130] Rachel Metz. 2014. Google Glass Is Dead; Long Live Smart Glasses | MIT Technology Review. Retrieved October 19, 2020 from https://www.technologyreview.com/2014/11/26/169918/google-glass-is-dead-long-live-smart-glasses/

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

[132] Paul Milgram and Herman Colquhoun. 1999. A Taxonomy of Real and Virtual World Display Integration. *Mixed Reality: Merging real and virtual worlds, 1*, 1–26.

[133] Mario Montagud, Jie Li, Gianluca Cernigliaro, Abdallah El Ali, Sergi Fernández, and Pablo Cesar. 2022. Towards socialVR: evaluating a novel technology for watching videos together. *Virtual Real* 26, 4 (December 2022), 1593–1613. https://doi.org/10.1007/s10055-022-00651-5

[134] Calkin S Montero, Jason Alexander, Mark T Marshall, and Sriram Subramanian. 2010. Would you do that?: understanding social acceptance of gestural interfaces. In *Proceedings of the 12th international conference on*

Human computer interaction with mobile devices and services - MobileHCI '10, 2010. ACM Press, New York, New York, USA, 275. https://doi.org/10.1145/1851600.1851647

[135] 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). https://doi.org/10.1098/rsif.2016.0414

[136] Hendrik Müller, Aaron Sedley, and Elizabeth Ferrall-Nunge. 2014. Survey Research in HCI. In *Ways of Knowing in HCI*. Springer New York, New York, NY, 229–266. https://doi.org/10.1007/978-1-4939-0378-8_10

[137] Jörg Müller, Robert Walter, Gilles Bailly, Michael Nischt, and Florian Alt. 2012. Looking glass: a field study on noticing interactivity of a shop window. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, May 05, 2012. ACM, New York, NY, USA, 297–306. https://doi.org/10.1145/2207676.2207718

[138] Lei Nelissen and Mathias Funk. 2022. Rationalizing Dark Patterns: Examining the Process of Designing Privacy UX Through Speculative Enactments. *International Journal of Design* 16, 1 (April 2022), 75–92. https://doi.org/10.57698/v16i1.05

[139] Christian Monrad Nielsen, Michael Overgaard, Michael Bach Pedersen, and Jan Stage. 2006. *It's Worth the Hassle! The Added Value of Evaluating the Usability of Mobile Systems in the Field.*

[140] Evangelos Niforatos, Adam Palma, Roman Gluszny, Athanasios Vourvopoulos, and Fotis Liarokapis. 2020. Would you do it?: Enacting Moral Dilemmas in Virtual Reality for Understanding Ethical Decision-Making. In *Conference on Human Factors in Computing Systems - Proceedings*, April 21, 2020. Association for Computing Machinery. https://doi.org/10.1145/3313831.3376788

[141] Anton Nijholt. 2021. Experiencing Social Augmented Reality in Public Spaces. *UbiComp/ISWC 2021 - Adjunct Proceedings of the 2021 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2021 ACM International Symposium on Wearable Computers* (2021), 570–574. https://doi.org/10.1145/3460418.3480157

[142] Bing Ning and Mingtao Pei. 2024. Task and Environment-Aware Virtual Scene Rearrangement for Enhanced Safety in Virtual Reality. *IEEE Trans Vis Comput Graph* (May 2024). https://doi.org/10.1109/TVCG.2024.3372115

[143] Joseph O'Hagan, Mohamed Khamis, Mark McGill, and Julie R. Williamson. 2022. Exploring Attitudes Towards Increasing User Awareness of Reality From Within Virtual Reality. In *IMX 2022 - Proceedings of the 2022 ACM International Conference on Interactive Media Experiences*, June 21, 2022. Association for Computing Machinery, Inc, 151–159. https://doi.org/10.1145/3505284.3529971

[144] Joseph O'Hagan, Pejman Saeghe, Jan Gugenheimer, Daniel Medeiros, Karola Marky, Mohamed Khamis, and Mark McGill. 2022. Privacy-Enhancing Technology and Everyday Augmented Reality. *Proc ACM Interact Mob Wearable Ubiquitous Technol* 6, 4 (December 2022), 1–35. https://doi.org/10.1145/3569501

[145] Joseph O'Hagan and Julie R Williamson. 2020. Reality aware VR headsets. In *Proceedings of the 9TH ACM International Symposium on Pervasive Displays*, June 04, 2020. ACM, New York, NY, USA, 9–17. https://doi.org/10.1145/3393712.3395334

[146] Joseph O'Hagan, Julie R. Williamson, Mark McGill, and Mohamed Khamis. 2021. Safety, power imbalances, ethics and proxy sex: Surveying in-the-wild

interactions between VR users and bystanders. In *Proceedings - 2021 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2021*, 2021. Institute of Electrical and Electronics Engineers Inc., 211–220. https://doi.org/10.1109/ISMAR52148.2021.00036

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

[148] Namkee Park, Kwan Min Lee, and Pauline Hope Cheong. 2007. University instructors' acceptance of electronic courseware: An application of the technology acceptance model. *Journal of Computer-Mediated Communication* 13, 1 (2007), 163–186. https://doi.org/10.1111/j.1083-6101.2007.00391.x

[149] Sang Min Park and Young Gab Kim. 2022. A Metaverse: Taxonomy, Components, Applications, and Open Challenges. *IEEE Access* 10, (2022), 4209–4251. https://doi.org/10.1109/ACCESS.2021.3140175

[150] Harshada Patel and Mirabelle D'Cruz. 2018. Passenger-centric factors influencing the experience of aircraft comfort. *Transp Rev* 38, 2 (2018), 252–269. https://doi.org/10.1080/01441647.2017.1307877

[151] Leonardo Pavanatto, Chris North, Doug A. Bowman, Carmen Badea, and Richard Stoakley. 2021. Do we still need physical monitors? An evaluation of the usability of AR virtual monitors for productivity work. In *Proceedings - 2021 IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2021*, March 01, 2021. Institute of Electrical and Electronics Engineers Inc., 759–767. https://doi.org/10.1109/VR50410.2021.00103

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

[153] Katharina Margareta Theresa Pöhlmann, Gang Li, Mark McGill, Reuben Markoff, and Stephen Anthony Brewster. 2023. You spin me right round, baby, right round: Examining the Impact of Multi-Sensory Self-Motion Cues on Motion Sickness During a VR Reading Task. In *Conference on Human Factors in Computing Systems - Proceedings*, April 19, 2023. Association for Computing Machinery. https://doi.org/10.1145/3544548.3580966

[154] J Preece, Y Rogers, and H Sharp. 2002. Identifying needs and establishing requirements. In *Interaction Design: Beyond Human-computer Interaction*. J. Wiley & Sons, 201–238. Retrieved from https://books.google.lt/books?id=yIC9kgEACAAJ

[155] Halley Profita, Reem Albaghli, Leah Findlater, Paul Jaeger, and Shaun K Kane. 2016. The AT Effect : How Disability Affects the Perceived Social Acceptability of Head-Mounted Display Use College of Information Studies. (2016).

[156] Halley Profita, James Clawson, Scott Gilliland, Clint Zeagler, Thad Starner, Jim Budd, and Ellen Yi-luen Do. 2013. Don ' t Mind Me Touching My Wrist : A Case Study of Interacting with On-Body Technology in Public. August 2014 (2013). https://doi.org/10.1145/2493988.2494331

[157] Zhanyan Qiu, Mark McGill, Katharina Margareta Theresa Pöhlmann, and Stephen Anthony Brewster. 2024. Augmenting Virtual Spatial UIs with Physics- and Direction-Based Visual Motion Cues to Non-Disruptively Mitigate Motion Sickness. In *ACM Symposium on Spatial User Interaction*, October 07, 2024. ACM, New York, NY, USA, 1–10. https://doi.org/10.1145/3677386.3682079

[158] Md Mahmudur Rahman, Mary F. Lesch, William J. Horrey, and Lesley Strawderman. 2017. Assessing the utility of TAM, TPB, and UTAUT for advanced driver assistance systems. *Accid Anal Prev* 108, September (2017), 361–373. https://doi.org/10.1016/j.aap.2017.09.011

[159] Amon Rapp. 2019. Design fictions for behaviour change: exploring the long-term impacts of technology through the creation of fictional future prototypes. *Behaviour and Information Technology* 38, 3 (March 2019), 244–272. https://doi.org/10.1080/0144929X.2018.1526970

[160] James Reason and Joseph J Brand. 1975. *Motion sickness*. Academic Press, London.

[161] Julie Rico and Stephen Brewster. 2010. Usable gestures for mobile interfaces. In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, 2010. ACM Press, New York, New York, USA, 887. https://doi.org/10.1145/1753326.1753458

[162] Ronda Ringfort-Felner, Robin Neuhaus, Judith Dörrenbächer, Sabrina Großkopp, Dimitra Theofanou-Fülbier, and Marc Hassenzahl. 2023. Design Fiction in a Corporate Setting – a Case Study. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*, July 10, 2023. ACM, New York, NY, USA, 2093–2108. https://doi.org/10.1145/3563657.3596126

[163] Franziska Roesner, Taday Oshi Kohno, and David Molnar. 2014. Security and privacy for augmented reality systems. *Commun ACM* 57, 4 (2014), 88–96. https://doi.org/10.1145/2580723.2580730

[164] Yvonne Rogers. 2011. Interaction design gone wild. *Interactions* 18, 4 (July 2011), 58–62. https://doi.org/10.1145/1978822.1978834

[165] Yvonne Rogers, Kay Connelly, Lenore Tedesco, William Hazlewood, Andrew Kurtz, Robert E Hall, Josh Hursey, and Tammy Toscos. 2007. Why it's worth the hassle: The value of in-situ studies when designing ubicomp. In *In: Krumm, J.; Abowd, G. D.; Seneviratne, A. and Strang, T. eds. UbiComp 2007: Ubiquitous Computing*, John Krumm, Gregory D. Abowd, Aruna Seneviratne and Thomas Strang (eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 336–353. https://doi.org/10.1007/978-3-540-74853-3

[166] Yvonne Rogers and Paul Marshall. 2017. *Research in the Wild*. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-031-02220-3

[167] Francisco Javier Rondan-Cataluña, Jorge Arenas-Gaitán, and Patricio Esteban Ramírez-Correa. 2015. A comparison of the different versions of popular technology acceptance models a non-linear perspective. *Kybernetes* 44, 5 (2015), 788–805. https://doi.org/10.1108/K-09-2014-0184

[168] Daniel M Russell and Ed H Chi. 2014. Looking Back: Retrospective Study Methods for HCI. In *Ways of Knowing in HCI*, Judith S Olson and Wendy A Kellogg (eds.). Springer New York, New York, NY, 373–393. https://doi.org/10.1007/978-1-4939-0378-8_15

[169] Marie Russell, Rachel Price, Louise Signal, James Stanley, Zachery Gerring, and Jacqueline Cumming. 2011. What do passengers do during travel time? Structured observations on buses and trains. *J Public Trans* 14, 3 (2011), 123–146. https://doi.org/10.5038/2375-0901.14.3.7

[170] Antti Salovaara, Antti Oulasvirta, and Giulio Jacucci. 2017. Evaluation of prototypes and the problem of possible futures. In *Conference on Human Factors in Computing Systems - Proceedings*, May 02, 2017. Association for Computing Machinery, 2064–2077. https://doi.org/10.1145/3025453.3025658

[171] Steve Sato and Tony Salvador. 1999. Methods & tools: Playacting and focus troupes:: theater techniques for creating quick, intense, immersive, and

engaging focus group sessions. *Interactions* 6, 5 (September 1999), 35–41. https://doi.org/10.1145/312683.312715

[172] Gian Luca Savino, Niklas Emanuel, Steven Kowalzik, Felix A. Kroll, Marvin C. Lange, Matthis Laudan, Rieke Leder, Zhanhua Liang, Dayana Markhabayeva, Martin Schmeißer, Nicolai Schütz, Carolin Stellmacher, Zihe Xu, Kerstin Bub, Thorsten Kluss, Jaime Maldonado, Ernst Kruijff, and Johannes Schöning. 2019. Comparing pedestrian navigation methods in virtual reality and real life. In *ICMI 2019 - Proceedings of the 2019 International Conference on Multimodal Interaction*, October 14, 2019. Association for Computing Machinery, Inc, 16–25. https://doi.org/10.1145/3340555.3353741

[173] Thereza Schmelter and Kristian Hildebrand. 2020. Analysis of Interaction Spaces for VR in Public Transport Systems. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, March 2020. IEEE, Atlanta, GA, 279–280. https://doi.org/10.1109/VRW50115.2020.00058

[174] Benjamin Lukas Schnitzer, Polona Caserman, and Oliver Korn. 2024. Shaken, not stirred: Effects of Minimal Rotational Motion Cues on Cybersickness in a VR Flying Experience. In *Proceedings of Mensch und Computer 2024*, September 2024. ACM, New York, NY, USA, 605–610. https://doi.org/10.1145/3670653.3677517

[175] 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.

[176] 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. *MobileHCI 2018 - Beyond Mobile: The Next 20 Years - 20th International Conference on Human-Computer Interaction with Mobile Devices and Services, Conference Proceedings Adjunct* September (2018), 111–118. https://doi.org/10.1145/3236112.3236127

[177] Takashi Shibata. 2002. Head mounted display. *Displays* 23, 1–2 (2002), 57–64. https://doi.org/10.1016/S0141-9382(02)00010-0

[178] Adalberto L. Simeone, Robbe Cools, Stan Depuydt, João Maria Gomes, Piet Goris, Joseph Grocott, Augusto Esteves, and Kathrin Gerling. 2022. Immersive Speculative Enactments: Bringing Future Scenarios and Technology to Life Using Virtual Reality. In *Conference on Human Factors in Computing Systems - Proceedings*, April 29, 2022. Association for Computing Machinery. https://doi.org/10.1145/3491102.3517492

[179] Mel Slater. 2009. Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, 1535 (December 2009), 3549–3557. https://doi.org/10.1098/rstb.2009.0138

[180] Mel Slater, Anthony Steed, John Mccarthy, and Francesco Marinelli. 2002. The Virtual Ante-Room: Assessing Presence through Expectation and Surprise. (2002). Retrieved October 23, 2024 from https://www.researchgate.net/publication/2499466

[181] Mel Slater, Mary C Whitton, Anthony Steed, Sharif Razzaque, and David Swapp. 2002. Redirected walking in place. In *Eight Eurographics Workshop on Virtual Environments*, 2002. The Eurographics Association. Retrieved from https://www.researchgate.net/publication/228595419

[182] Maximilian Speicher, Brian D. Hall, and Michael Nebeling. 2019. What is Mixed Reality? In *Proceedings of the 2019 CHI Conference on Human Factors*

in Computing Systems, May 02, 2019. ACM, New York, NY, USA, 1–15. https://doi.org/10.1145/3290605.3300767

[183] Aaron Stafford, Wayne Piekarski, and Bruce Thomas. 2006. Implementation of god-like interaction techniques for supporting collaboration between outdoor AR and indoor tabletop users. In *2006 IEEE/ACM International Symposium on Mixed and Augmented Reality*, October 2006. IEEE, 165–172. https://doi.org/10.1109/ISMAR.2006.297809

[184] statstutor community project. Friedman test in SPSS (Non-parametric equivalent to repeated measures ANOVA). Retrieved November 4, 2020 from https://www.sheffield.ac.uk/polopoly_fs/1.714575!/file/stcp-marshall-FriedmanS.pdf

[185] F. Steinicke, G. Bruder, J. Jerald, H. Frenz, and M. Lappe. 2010. Estimation of Detection Thresholds for Redirected Walking Techniques. *IEEE Trans Vis Comput Graph* 16, 1 (January 2010), 17–27. https://doi.org/10.1109/TVCG.2009.62

[186] Ayoung Suh and Jane Prophet. 2018. The state of immersive technology research: A literature analysis. *Comput Human Behav* 86, (September 2018), 77–90. https://doi.org/10.1016/j.chb.2018.04.019

[187] Ivan E. Sutherland. 1968. A head-mounted three dimensional display. In *Proceedings of the December 9-11, 1968, fall joint computer conference, part I on - AFIPS '68 (Fall, part I)*, September 20, 1968. ACM Press, New York, New York, USA, 757. https://doi.org/10.1145/1476589.1476686

[188] Philipp Sykownik, Sukran Karaosmanoglu, Katharina Emmerich, Frank Steinicke, and Maic Masuch. 2023. VR Almost There: Simulating Co-located Multiplayer Experiences in Social Virtual Reality. In *Conference on Human Factors in Computing Systems - Proceedings*, April 19, 2023. Association for Computing Machinery. https://doi.org/10.1145/3544548.3581230

[189] Yujie Tao and Pedro Lopes. 2022. Integrating Real-World Distractions into Virtual Reality. In *UIST 2022 - Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology*, October 29, 2022. Association for Computing Machinery, Inc. https://doi.org/10.1145/3526113.3545682

[190] Omer Tene and Jules Polonetsky. 2014. A Theory of Creepy : Technology , Privacy , and Shifting Social Norms. 16, 1 (2014). Retrieved October 23, 2024 from https://www.researchgate.net/publication/259891883_A_Theory_of_Creepy_Technology_Privacy_and_Shifting_Social_Norms

[191] Jared Austin Peter Kay Thomas. 2009. The Social Environment of Public Transport. Open Access Victoria University of Wellington | Te Herenga Waka. https://doi.org/10.26686/wgtn.16967875.v1

[192] Harry Timmermans and Peter Van der Waerden. 2008. Synchronicity of Activity Engagement and Travel in Time and Space. *Transportation Research Record: Journal of the Transportation Research Board* 2054, 1 (January 2008), 1–9. https://doi.org/10.3141/2054-01

[193] Maciej Tomczak and Ewa Tomczak. 2014. The need to report effect size estimates revisited. An overview of some recommended measures of effect size. *Trends Sport Sci* 1, 21 (2014), 19–25. Retrieved from http://www.wbc.poznan.pl/Content/325867/5_Trends_Vol21_2014_no1_20.pdf

[194] Tram Thi Minh Tran, Callum Parker, Marius Hoggenmüller, Luke Hespanhol, and Martin Tomitsch. 2023. Simulating Wearable Urban Augmented Reality Experiences in VR: Lessons Learnt from Designing Two Future Urban

Interfaces. *Multimodal Technologies and Interaction* 7, 2 (February 2023). https://doi.org/10.3390/mti7020021

[195] Wen Jie Tseng, Elise Bonnail, Mark McGill, Mohamed Khamis, Eric Lecolinet, Samuel Huron, and Jan Gugenheimer. 2022. The Dark Side of Perceptual Manipulations in Virtual Reality. In *Conference on Human Factors in Computing Systems - Proceedings*, April 29, 2022. Association for Computing Machinery. https://doi.org/10.1145/3491102.3517728

[196] Wen Jie Tseng, Samuel Huron, Eric Lecolinet, and Jan Gugenheimer. 2023. FingerMapper: Mapping Finger Motions onto Virtual Arms to Enable Safe Virtual Reality Interaction in Confined Spaces. In *Conference on Human Factors in Computing Systems - Proceedings*, April 19, 2023. Association for Computing Machinery. https://doi.org/10.1145/3544548.3580736

[197] Alarith Uhde and Marc Hassenzahl. 2021. Towards a Better Understanding of Social Acceptability. In *Conference on Human Factors in Computing Systems - Proceedings*, May 08, 2021. Association for Computing Machinery. https://doi.org/10.1145/3411763.3451649

[198] Alarith Uhde, Tim Zum Hoff, and Marc Hassenzahl. 2022. Obtrusive Subtleness and Why We Should Focus on Meaning, not Form, in Social Acceptability Studies. In *ACM International Conference Proceeding Series*, November 27, 2022. Association for Computing Machinery, 89–99. https://doi.org/10.1145/3568444.3568457

[199] Viswanath Venkatesh and Hillol Bala. 2008. Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences* 39, 2 (2008), 273–315. https://doi.org/10.1111/j.1540-5915.2008.00192.x

[200] Viswanath Venkatesh and Fred D. Davis. 2000. Theoretical extension of the Technology Acceptance Model: Four longitudinal field studies. *Manage Sci* 46, 2 (2000), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

[201] Viswanath Venkatesh, M.G. Morris, G.B. Davis, and F.D. Davis. 2003. User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly* 27, 3 (2003), 425. https://doi.org/10.2307/30036540

[202] Viswanath Venkatesh and Michael G. Morris. 2000. Why don't men ever stop to ask for directions? Gender, social influence, and their role in technology acceptance and usage behavior. *MIS Q* 24, 1 (2000), 115–136. https://doi.org/10.2307/3250981

[203] Viswanath Venkatesh, J.Y.L Thong, and X. Xu. 2012. Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology. *MIS Quarterly* 36, 1 (2012), 157. https://doi.org/10.2307/41410412

[204] Maurizio Vergari, Tanja Kojic, Francesco Vona, Franca Garzotto, Sebastian Moller, and Jan Niklas Voigt-Antons. 2021. Influence of interactivity and social environments on user experience and social acceptability in virtual reality. In *Proceedings - 2021 IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2021*, March 01, 2021. Institute of Electrical and Electronics Engineers Inc., 695–704. https://doi.org/10.1109/VR50410.2021.00096

[205] Veronica. 2020. An Evaluation of the Employee Self-Service Feature of SAP System with Technology Acceptance Model (TAM): A Case Study. *Proceedings of 2020 International Conference on Information Management and Technology, ICIMTech 2020* August (2020), 761–766. https://doi.org/10.1109/ICIMTech50083.2020.9211291

[206] Leo R. Vijayasarathy. 2004. Predicting consumer intentions to use on-line shopping: The case for an augmented technology acceptance model. *Information and Management* 41, 6 (2004), 747–762. https://doi.org/10.1016/j.im.2003.08.011

[207] Virtual Reality Society. 2017. What is Virtual Reality? - Virtual Reality Society. Retrieved June 4, 2020 from https://www.vrs.org.uk/virtual-reality/what-is-virtual-reality.html

[208] 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

[209] Chiu-Hsuan Wang, Bing-Yu Chen, and Liwei Chan. 2022. RealityLens: A User Interface for Blending Customized Physical World View into Virtual Reality. In *The 35th Annual ACM Symposium on User Interface Software and Technology*, October 29, 2022. ACM, New York, NY, USA, 1–11. https://doi.org/10.1145/3526113.3545686

[210] Yu Wang, Raphael Johannes Schimmerl, Martin Kocur, and Philipp Wintersberger. 2023. Ubiquity of VR: Towards Investigating Ways of Interrupting VR Users to Obtain Their Attention in Public Spaces. In *Virtual Reality and Mixed Reality*, Gabriel Zachmann, Krzysztof Walczak, Omar A Niamut, Kyle Johnsen, Wolfgang Stuerzlinger, Mariano Alcañiz-Raya, Greg Welch and Patrick Bourdot (eds.). Springer Nature Switzerland, Cham, 40–52. https://doi.org/10.1007/978-3-031-48495-7_3

[211] Mark Wardman and Glenn Lyons. 2016. The digital revolution and worthwhile use of travel time: implications for appraisal and forecasting. *Transportation (Amst)* 43, 3 (May 2016), 507–530. https://doi.org/10.1007/s11116-015-9587-0

[212] Chris Warin and Delphine Reinhardt. 2022. Vision: Usable Privacy for XR in the Era of the Metaverse. In *ACM International Conference Proceeding Series*, September 29, 2022. Association for Computing Machinery, 111–116. https://doi.org/10.1145/3549015.3554212

[213] Laura Watts and John Urry. 2008. Moving methods, travelling times. *Environ Plan D* 26, 5 (2008), 860–874. https://doi.org/10.1068/d6707

[214] Carolin Wienrich and Kristina Schindler. 2019. Challenges and requirements of immersive media in autonomous car: Exploring the feasibility of virtual entertainment applications. *i-com* (2019). https://doi.org/10.1515/icom-2018-0030

[215] Julie R. Wiliamson, Andrew Crossan, and Stephen Brewster. 2011. Multimodal mobile interactions: Usability studies in real world settings. *ICMI'11 - Proceedings of the 2011 ACM International Conference on Multimodal Interaction* (2011), 361–368. https://doi.org/10.1145/2070481.2070551

[216] Julie R. Williamson, Stephen Brewster, and Rama Vennelakanti. 2013. Mo!Games: Evaluating mobile gestures in the wild. In *ICMI 2013 - Proceedings of the 2013 ACM International Conference on Multimodal Interaction*, 2013. 173–180. https://doi.org/10.1145/2522848.2522874

[217] 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*, May 02, 2019. Association for Computing Machinery. https://doi.org/10.1145/3290605.3300310

[218] Julie R. Williamson, Joseph O'Hagan, John Alexis Guerra-Gomez, John H. Williamson, Pablo Cesar, and David A. Shamma. 2022. Digital Proxemics: Designing Social and Collaborative Interaction in Virtual Environments. In *Conference on Human Factors in Computing Systems - Proceedings*, April 29, 2022. Association for Computing Machinery. https://doi.org/10.1145/3491102.3517594

[219] 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. In *DIS 2019 - Proceedings of the 2019 ACM Designing Interactive Systems Conference*, June 18, 2019. Association for Computing Machinery, Inc, 487–496. https://doi.org/10.1145/3322276.3322334

[220] Graham Wilson, Mark McGill, Daniel Medeiros, and Stephen Brewster. 2023. A Lack of Restraint: Comparing Virtual Reality Interaction Techniques for Constrained Transport Seating. *IEEE Trans Vis Comput Graph* 29, 5 (May 2023), 2390–2400. https://doi.org/10.1109/TVCG.2023.3247084

[221] 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*, May 07, 2011. ACM, New York, NY, USA, 143–146. https://doi.org/10.1145/1978942.1978963

[222] Shihui Xu, Bo Yang, Boyang Liu, Kelvin Cheng, Soh Masuko, and Jiro Tanaka. 2019. Sharing Augmented Reality Experience Between HMD and Non-HMD User. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2019. Springer Verlag, 187–202. https://doi.org/10.1007/978-3-030-22649-7_16

[223] Amal Yassien, Mohamed Ahmed Soliman, and Slim Abdennadher. 2022. QuarantivityVR: Supporting Self-Embodiment for Non-HMD Users in Asymmetric Social VR Games. *i-com* 21, 1 (April 2022), 55–70. https://doi.org/10.1515/icom-2022-0005

[224] Jaeheung Yoo, Saesol Choi, Yujong Hwang, and Mun Y. Yi. 2021. The Role of User Resistance and Social Influences on the Adoption of Smartphone. *Journal of Organizational and End User Computing* 33, 2 (March 2021), 36–58. https://doi.org/10.4018/JOEUC.20210301.oa3

[225] Boram Yoon, Hyung-il Kim, Gun A. Lee, Mark Billinghurst, and Woontack Woo. 2019. The Effect of Avatar Appearance on Social Presence in an Augmented Reality Remote Collaboration. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, March 2019. IEEE, 547–556. https://doi.org/10.1109/VR.2019.8797719

[226] André Zenner, Marco Speicher, Sören Klingner, Donald Degraen, Florian Daiber, and Antonio Krüger. 2018. Immersive notification framework: Adaptive & plausible notifications in virtual reality. *Conference on Human Factors in Computing Systems - Proceedings* 2018-April, (2018), 1-6. https://doi.org/10.1145/3170427.3188505

[227] Li-Li Zhang, Jun-Qin Wang, Rui-Rui Qi, Lei-Lei Pan, Min Li, and Yi-Ling Cai. 2016. Motion Sickness: Current Knowledge and Recent Advance. *CNS Neurosci Ther* 22, 1 (January 2016), 15–24. https://doi.org/10.1111/cns.12468

[228] Louis A. Zurcher. 1979. The airplane passenger: Protection of self in an encapsulated group. *Qual Sociol* 1, 3 (January 1979), 77–99. https://doi.org/10.1007/BF02429895

[229] 2013. Why Google Glass Is Creepy - Scientific American. Retrieved October 20, 2020 from https://www.scientificamerican.com/article/why-google-glass-is-creepy/

[230] 2013. *Mastering the Semi-Structured Interview and Beyond : From Research Design to Analysis and Publication*. New York University Press, New York, UNITED STATES. Retrieved from http://ebookcentral.proquest.com/lib/gla/detail.action?docID=1187368

[231] 2014. Google tries (and fails) to convince us that Glass isn't scary - ExtremeTech. Retrieved October 20, 2020 from https://www.extremetech.com/extreme/179040-google-tries-and-fails-to-convince-us-that-glass-isnt-scary
[232] 2014. The revolt against Google 'Glassholes.' Retrieved October 20, 2020 from https://nypost.com/2014/07/14/is-google-glass-cool-or-just-plain-creepy/
[233] 2015. Google Glass is the creepy innovation we didn't want - Chicago Tribune. Retrieved October 20, 2020 from https://www.chicagotribune.com/opinion/editorials/ct-glass-google-0121-20150120-story.html
[234] 2019. British workers spend 492 days of their lives travelling into work - Lloyds Banking Group plc. Retrieved October 20, 2020 from https://www.lloydsbankinggroup.com/Media/Press-Releases/2019-press-releases/lloyds-bank/british-workers-spend-492-days-of-their-lives-travelling-into-work/
[235] Transport Statistics Great Britain: 2022 Summary - GOV.UK. Retrieved December 8, 2024 from https://www.gov.uk/government/statistics/transport-statistics-great-britain-2023/transport-statistics-great-britain-2022-summary
[236] Apple Vision Pro - Apple. Retrieved September 17, 2024 from https://www.apple.com/apple-vision-pro/
[237] In-flight VR: Using the Oculus Quest on a Plane | by Vittorio | Medium. Retrieved September 5, 2023 from https://medium.com/@vibronet/in-flight-vr-using-the-oculus-quest-on-a-plane-38c9808c32b2
[238] I'm the creepy guy wearing a VR headset on your plane (and it's great) - Polygon. Retrieved September 5, 2023 from https://www.polygon.com/2015/3/27/8302453/im-the-creepy-guy-wearing-a-vr-headset-on-your-plane-and-its-great
[239] "I will never use VR". Part 3: Perception | by Raymond Meester | Medium. Retrieved September 24, 2024 from https://raymondmeester.medium.com/i-will-never-use-vr-3f18b612cf57
[240] Why Are VR Headsets So Bulky? Retrieved September 24, 2024 from https://gizmodo.com/why-are-vr-headsets-so-bulky-1845109876
[241] Buy VIVE Hardware | VIVE European Union. Retrieved December 27, 2024 from https://www.vive.com/eu/product/vive/
[242] Meta Quest 2 | Advanced All-In-One VR Headset | Meta Quest | Meta Store. Retrieved September 15, 2022 from https://store.facebook.com/gb/quest/products/quest-2/
[243] Meta Quest Pro: Our Most Advanced New VR Headset | Meta Store | Meta Store. Retrieved September 5, 2023 from https://www.meta.com/quest/quest-pro/
[244] Meta Quest 3: New Mixed Reality VR Headset - Shop Now | Meta Store | Meta Store. Retrieved September 17, 2024 from https://www.meta.com/quest/quest-3/
[245] 2 Days Left on VFX1 Headgear Virtual Reality System eBay Auction – Dynamic Subspace. Retrieved January 11, 2025 from https://dynamicsubspace.net/2009/08/03/2-days-left-on-vfx1-headgear-virtual-reality-system/
[246] Apple Vision Pro: The iPhone moment for spatial learning – Chief Learning Officer. Retrieved January 11, 2025 from https://www.chieflearningofficer.com/2023/06/14/apple-vision-pro-the-iphone-moment-for-spatial-learning/

[247] (154) Infinite Office - YouTube. Retrieved May 11, 2025 from https://www.youtube.com/watch?v=5_bVkbG1ZCo
[248] Londoners are the most embarassed by talking to strangers | YouGov. Retrieved September 30, 2024 from https://yougov.co.uk/politics/articles/16621-londoners-are-least-pleased-prospect-talking-stran
[249] Japanese people least likely to talk to strangers or offer help on airplanes, survey finds - Japan Today. Retrieved September 30, 2024 from https://japantoday.com/category/features/lifestyle/japanese-people-least-likely-to-talk-to-strangers-or-offer-help-on-airplanes-survey-finds
[250] Use Apple Vision Pro on an airplane or train with Travel Mode - Apple Support. Retrieved October 1, 2024 from https://support.apple.com/en-us/118510
[251] Travel mode on Meta Quest | Meta Store. Retrieved October 1, 2024 from https://www.meta.com/help/quest/articles/in-vr-experiences/oculus-features/travel-mode/
[252] Adding thrill to every ride | holoride. Retrieved September 5, 2023 from https://www.holoride.com/en
[253] Build new augmented reality experiences that seamlessly blend the digital and physical worlds | ARCore | Google Developers. Retrieved May 6, 2023 from https://developers.google.com/ar
[254] ARKit 6 - Augmented Reality - Apple Developer. Retrieved May 6, 2023 from https://developer.apple.com/augmented-reality/arkit/
[255] Lens Studio. Retrieved May 6, 2023 from https://ar.snap.com/lens-studio
[256] Smart Bus Seat Occupancy Detection System | HIOTRON. Retrieved January 28, 2023 from https://www.hiotron.com/smart-bus-seat-occupancy-detection-system/
[257] Control passenger occupancy in real time. Retrieved January 28, 2023 from https://www.initse.com/ende/news-resources/knowledge-database/articles/2020/control-passenger-occupancy-in-real-time/
[258] CCTV & surveillance cameras - Transport for London. Retrieved January 28, 2023 from https://tfl.gov.uk/corporate/privacy-and-cookies/cctv
[259] Inside Facebook Reality Labs: Research updates and the future of social connection - Tech at Meta. Retrieved January 28, 2023 from https://tech.facebook.com/reality-labs/2019/9/inside-facebook-reality-labs-research-updates-and-the-future-of-social-connection/
[260] AirTag popularity growing, Apple expected to ship 35 million units by the end of 2022 | The Apple Post. Retrieved January 28, 2023 from https://www.theapplepost.com/2022/06/19/airtag-popularity-growing-apple-expected-to-ship-35-million-units-by-the-end-of-2022/
[261] London Bus | 3D Characters | Unity Asset Store. Retrieved March 17, 2022 from https://assetstore.unity.com/packages/3d/characters/london-bus-62744
[262] Unity Real-Time Development Platform | 3D, 2D VR & AR Engine. Retrieved September 15, 2022 from https://unity.com/
[263] Mixamo. Retrieved March 10, 2022 from https://www.mixamo.com/#/
[264] 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
[265] lamp lamp free 3D model | CGTrader. Retrieved March 17, 2022 from https://www.cgtrader.com/free-3d-models/furniture/lamp/lamp-lamp--13

[266] (1220) Our Planet | One Planet | FULL EPISODE | Netflix - YouTube. Retrieved September 15, 2022 from https://www.youtube.com/watch?v=GfO-3Oir-qM&t=1s
[267] 10 Theatre Games Perfect For Drama Class - Theatre Nerds. Retrieved September 14, 2023 from https://theatrenerds.com/10-theatre-games-perfect-drama-class/
[268] Immersed. Retrieved May 6, 2024 from https://immersed.com/
[269] What Is EyeSight on Apple's Vision Pro Headset? How Does It Work? Retrieved August 22, 2023 from https://www.makeuseof.com/vision-pro-eyesight-feature-explained/
[270] Apple's EyeSight Feature on Vision Pro Is Creepier Than It Needs to Be - CNET. Retrieved August 22, 2023 from https://www.cnet.com/tech/computing/apples-eyesight-feature-on-vision-pro-is-creepier-than-it-needs-to-be/
[271] Apple Vision Pro: The Good, the Bad and the Creepy | Audioholics. Retrieved August 22, 2023 from https://www.audioholics.com/gadget-reviews/apple-vision-pro-the-good-the-bad-and-the-creepy
[272] How to Use VR Pass-through? | Meta for Work. Retrieved May 18, 2025 from https://forwork.meta.com/gb/blog/what-is-vr-passthrough/
[273] How to use Passthrough on Meta Quest | Quest help | Meta Store. Retrieved May 18, 2025 from https://www.meta.com/en-gb/help/quest/617966963105359/?srsltid=AfmBOoq18vba40DWb9EuHaZXX5AsDh46WV6o_w6jPeH3DSzirdRnsUSK
[274] Our New AI Model Can Segment Anything – Even Video. Retrieved May 18, 2025 from https://about.fb.com/news/2024/07/our-new-ai-model-can-segment-video/